MONTANA DEPARTMENT OF TRANSPORTATION

ROAD DESIGN MANUAL

Chapter 6

Intersections and Interchanges

January 2026

Contents

Chapter 6

Intersections and Interchanges

Intersections and interchanges are an important part of the transportation system. Intersections create access and provide mobility on a facility; however they are a location of inherent conflict. The operational efficiency, capacity, safety, and cost of the transportation system depend largely upon the design of intersections and interchanges, especially in urban areas.

The primary design objectives of intersections and interchanges are:

- Minimize the potential for and the severity of conflicts among motor vehicles, bicycles, and pedestrians.
- Provide for the convenience, ease, and comfort of all users.
- Provide adequate capacity.
- Examine potential system-wide impacts, especially for new construction.

Chapter 6 discusses the geometric design of at-grade intersections including intersection traffic control, intersection alignment, intersection profile, and turning radii. It provides an overview of lanes at intersections, approaches, multimodal design considerations, speed reduction treatments, as well as alternative forms of intersections, including roundabouts, and interchanges.

Major intersections are intersections involving public roads, often in urban areas. Minor intersections are intersections involving private roads.

The design team should coordinate with the Traffic and Safety Bureau for all work related to major intersections and interchanges.

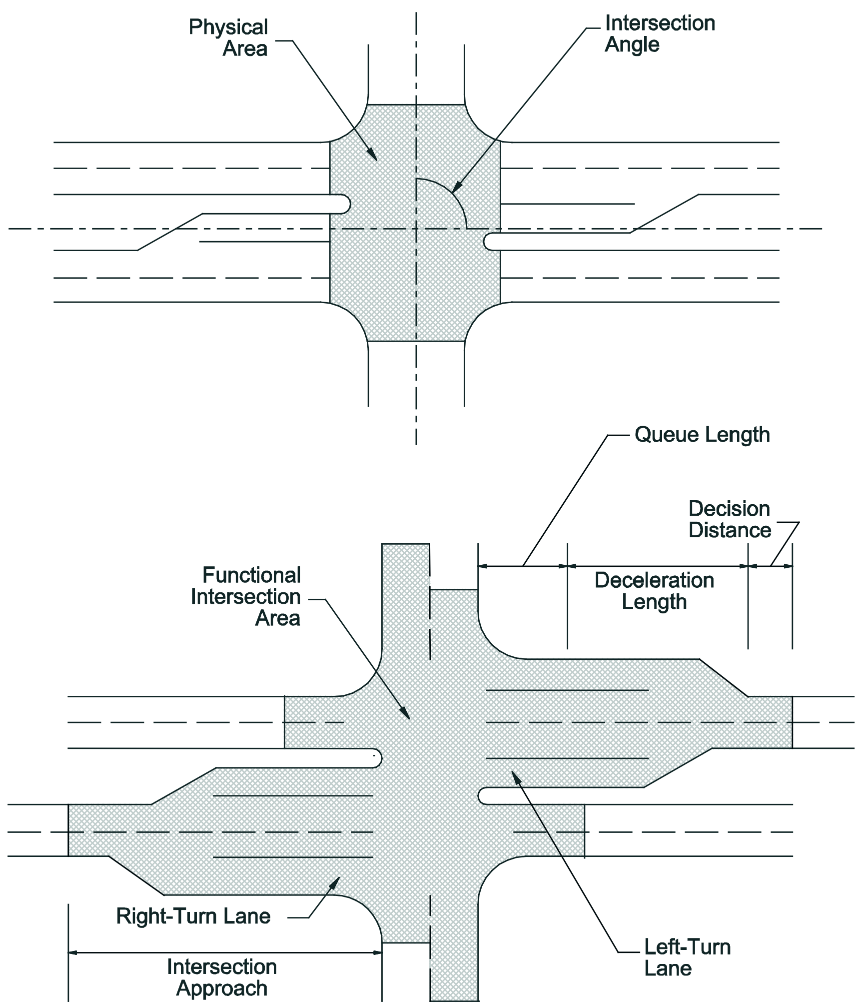
6.1 INTERSECTION DESIGN PRINCIPLES AND APPROACH

Intersections are defined as the general area where two or more roadways join or cross. Exhibit 6-1 illustrates the physical area and the functional area in the intersection. The physical area is the area that facilitates traffic movements, including motor vehicles, bicycles and pedestrians. The functional area extends both upstream and downstream from the intersection to accommodate decision distance, deceleration, queuing, and acceleration.

It should be noted that most of the principles and design guidance provided in this chapter apply to minor rural unsignalized intersections such as public approaches or private and farm field approaches, as well as private driveways in urban settings.

Interchanges include a grade separation of the two crossing roadways, but the same intersection-related principles are also applied to the ramp terminal intersections. Interchange design includes the determination of the appropriate interchange type based on the anticipated travel demand, the placement of ramps, as well as the assessment of ramp-spacing along the freeway corridor to provide a consistent message and expectation to the driver. Additional interchange design considerations are discussed in Section 6.8.

Exhibit 6-1
Physical and Functional Intersection Area



Source: Transportation Research Board (TRB) *(1)*

Intersections are a key feature of the roadway in four respects:

1. **Focus of activity.** Intersections are located in areas with a concentration of travel destinations.

2. **Conflicting movements.** Due to the various directions of travel for each of the various modes (e.g., motor vehicles, pedestrians, and bicycles), conflicting movements arise at intersections.
3. **Traffic control.** Movements at intersections are regulated through traffic control devices, such as yield signs, stop signs, roundabouts, and traffic signals. While aiming to improve safety, the traffic control also creates delay for certain movements.
4. **Capacity.** The capacity of the intersection, as defined by the *Highway Capacity Manual*, is the "maximum sustainable hourly flow rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given period under prevailing roadway, environmental, traffic, and control conditions" *(1)*.

Given the complexity of the concurrent activity at an intersection, additional consideration is needed at intersections in roadway design. The following basic elements should be considered in intersection design:

1. **Human factors.** These can include driving, walking, and cycling habits; the ability of users to make decisions; user expectancy; decision and reaction time; and conformance to natural paths of movement.
2. **Traffic considerations.** These can include classification of each intersecting roadway, design and actual capacities, design-hour turning movements, size and operating characteristics of vehicles, variety of movements (diverging, merging, weaving and crossing), vehicle speeds, transit involvement, crash experience, bicycle movements, and pedestrian movements.
3. **Physical elements.** These can include character and use of abutting property, vertical alignments at the intersection, sight distance, angle of the intersection, conflict area, geometric design features, traffic control devices, lighting equipment, roadside design features, environmental factors, crosswalks, driveways, and access management treatments.
4. **Economic factors.** These can include cost of improvements, effects of controlling or limiting rights-of-way on abutting residential or commercial properties where channelization restricts or prohibits vehicular movements, and energy consumption.

The following subsections will cover the general controls for intersections, including intersection traffic control, intersection alignment, intersection profile, and turning radii.

6.1.1 Intersection Traffic Control

At an intersection, the roadway with the higher roadway classification is considered the major roadway. The roadway with the lower roadway classification is considered the minor roadway.

The intersection traffic control type is a decision made by the Traffic and Safety Bureau. This considers the operational tradeoffs and safety of various users of the intersection. The design team should collaborate with the Traffic and Safety Bureau to identify the intersection traffic control type.

The type of intersection traffic control impacts the capacity of the intersection and the operations of each of the movements. Several types of intersection control are the following:

1. **Yield-controlled intersection.** A yield-controlled intersection is an intersection where one or more legs are controlled by a yield sign and are permitted to enter the intersection without stopping if there are no potentially conflicting vehicles on the major roadway.
2. **Roundabout.** A roundabout is a form of yield-controlled intersection with a generally circular shape, characterized by yield on entry and circulation around a central island.
3. **Stop-controlled intersection.** A stop-controlled intersection is an intersection where one or more legs are controlled by a stop sign.
4. **Signalized intersection.** A signalized intersection is controlled by a traffic signal. The operations of a signalized intersection are impacted by the signal timing of the intersection.

6.1.2 Intersection Alignment

This section provides a general discussion about intersection alignment as a general control for intersection design, as well as guidance on horizontal alignment and intersection angles. Refer to Chapter 3 for additional information on horizontal alignment.

6.1.2.1 Horizontal Curves

An intersection should preferably be located on tangent sections of the intersecting roadways. When a minor road intersects a major road where the major road is on a horizontal curve, the geometric design of the intersection becomes more complicated, particularly for sight distance, turning movements, channelization, and superelevation.

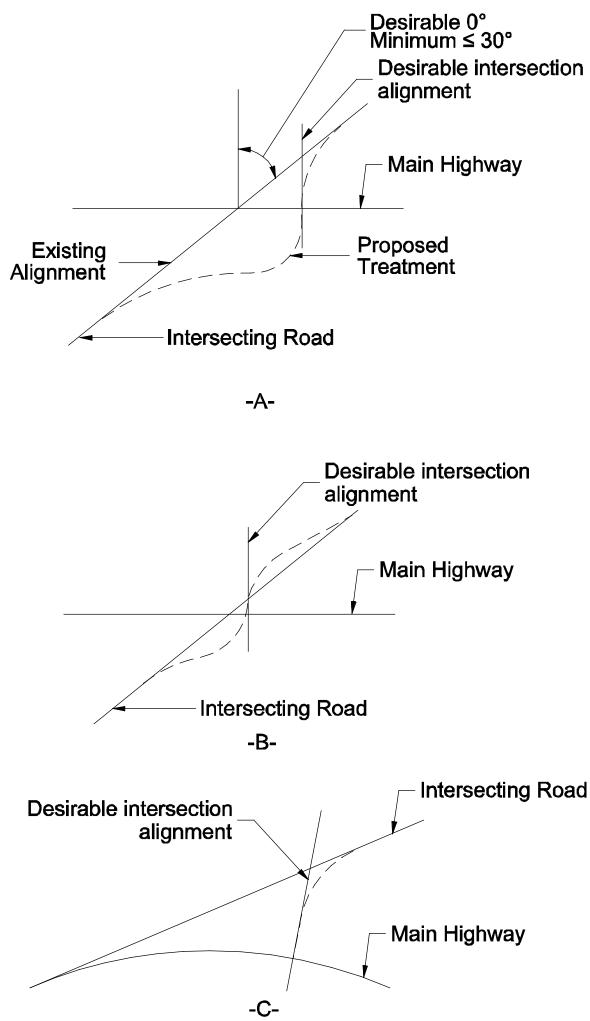
6.1.2.2 Angle of Intersection

It is desirable for roadways to intersect at, or as close to, 90 degrees as practical. Skewed intersections are undesirable for several reasons:

- Vehicular turning movements become more restricted for the acute angle and too fast for the larger angle,
- The accommodation of large trucks for turning may require additional pavement and channelization,
- The exposure time for vehicles and pedestrians crossing the main traffic flow is increased, and
- The driver's line of sight for one of the sight triangles becomes restricted.

The intersection angle should not exceed 30 degrees from perpendicular. Intersections with a skew greater than 30 degrees from perpendicular should be reviewed to identify ways to potentially address the line of sight challenges. It is not always possible to correct intersection angles; the design team should apply the principles of performance-based design by considering the project’s intended outcomes, and documenting the decision process accordingly. For existing intersections, the design team is encouraged to consider realigning the intersection so that its skew is within 30 degrees of perpendicular. Where skew angles greater than 30 degrees are present, the intersection may require geometric improvements, such as realignment, auxiliary lanes, and greater corner sight distance. Exhibit 6-2 illustrates various angles of intersection and potential improvements that can be made to the alignment.

Exhibit 6-2
Treatments for Skewed Intersections



Source: AASHTO *(2)*

6.1.3 Intersection Profile

Reducing an approach grade to meet guidelines may result in a cut section for the approach, which could introduce a snow drifting condition that did not exist previously.

This section outlines design guidance for intersection approach gradient, cross slope transitions, vertical alignment, and intersection sight distance. Refer to Chapter 4 for additional vertical profile information and to Chapter 2 for intersection sight distance guidance.

To allow for the best overall intersection profile design, the mainline horizontal and vertical alignments, as well as its cross section, control the optimum intersection center point and elevations. The design team should aim

Designing minor approaches to meet the approach guidelines may negatively affect right-of-way and access in ways that may not have been intended or considered.

for this desired control point to develop the intersection design (e.g., flatter approach grades, better sight lines, less right-of-way needs, and shorter approach connections). The project context and existing conditions should be considered at the start of a project to ensure that the design will meet the function of an existing approach, without undue adverse effects. Special considerations are needed for all approaches that extend beyond the existing right-of-way to ensure that the approaches do not adversely impact land use, or encroach onto neighboring properties. If approaches have structures close to the highway and/or other physical constraints, and meeting guidelines may not be feasible, this should be documented in the appropriate report.

6.1.3.1 Gradient

Landing areas with a pedestrian crossing should be designed to meet ADA guidance.

The gradient of roadways approaching an intersection should be designed to provide the appropriate drainage, as well as driver expectancy and comfort depending on if the roadway is stop controlled or is free flowing through the intersection. The gradient of a major roadway that is free flowing through the intersection may be designed with a straight grade though the intersection. Typically, drainage from a lower classification of roadway (e.g., collector) should not flow onto a higher classification of roadway (e.g., arterial).

Use of steeper approach slopes does not require a design exception, but should be documented in the appropriate report.

The approach of a roadway leading into an unsignalized rural intersection (e.g., public approaches, private and farm field approaches) is known as a "landing area". The "landing area" is typically created to store stopped vehicles and position the motorist to obtain appropriate sight distance. The intersection should desirably be slightly higher than the approaching roadway, such that the landing area will slope upward toward the intersection on a gradient not to exceed 3 percent. Because of topographical constraints, the landing area may slope downward toward the intersection on a gradient not to exceed 3 percent; however this should be avoided, if practical, due to drainage considerations and to reduce the possibility of a vehicle sliding into the intersection when icy conditions exist.

If a minor road intersects at a superelevated area of the major road, the landing should be designed to avoid a large grade break where the landing meets the intersection. This can be accomplished by providing a vertical curve at the end of the intersection approach, or by introducing small angle breaks within the landing. For landing areas with a pedestrian crossing a gradient of 1.5 percent is preferred for design purposes through the pedestrian crossing.

At a minimum, the length of the landing area toward the intersection should be at least 75 feet for public roads and at least 25 feet for other facilities. When using vertical curves on approaches for public roads, the vertical curve should not encroach onto the landing.

Farm Field Approaches are revocable access points to the highway from agricultural land.

The gradient of the approach beyond the landing area should not exceed 6 percent for public or private approaches unless site constraints require a steeper grade. The gradient of farm field approaches should not exceed 10 percent.

6.1.3.2 Cross Slope Transitions

One or both of the roadways approaching the intersection may need to be transitioned (or warped) to match, or coordinate the cross slope and grade at the intersection. The design team should consider the following:

Refer to NCHRP Report 659 for additional guidance for the design of driveways.

1. **Stop-Controlled and Yield-Controlled Intersections.** When the minor road is stop-controlled or yield-controlled, the profile grade line and cross slope of the major road will normally be maintained through an intersection, and the cross slope of the stop-controlled or yield-controlled leg will be transitioned to match the major road profile grade. The design team may need to consider alignments through the intersection, if there is potential for a future signal at the intersection.
2. **Signalized Intersection.** At signalized intersections, or potential future signalized intersections, the cross slope of the minor road will typically be transitioned to meet the longitudinal grade (profile) of the major road. If both intersecting roads have approximately equal importance, the design team may want to consider transitioning both roadways to form a plane section through the intersection. Where compromises are necessary between the two major roadways, the smoother riding characteristics should be provided for the roadway with the higher design speeds and/or traffic volumes.
3. **Transition Distance**. The transition from the normal crown of the minor roadway to match the longitudinal grade of the major roadway should be accomplished in a transition distance of 50 feet or more in rural areas. The 50-foot transition distance is also desirable for urban areas but, at a minimum, the transition may be accomplished within the radius of the intersection corner (curb return). See Exhibit 6-3.

The comfort criteria are based on the comfort effect of change in vertical direction in a sag vertical curve because of the combined gravitational and inertial forces.

6.1.3.3 Vertical Profile

Where the profile of the minor road is adjusted to meet the major road, this will result in angular breaks for traffic on the minor road if no vertical curve is inserted. The following options are presented in order from the most desirable to the least desirable; see Exhibit 6-4:

1. **Vertical Curves.** Vertical curves that meet the criteria for stopping sight distance (SSD) as described in Chapter 2, Section 2.8, should be used on the minor road approaches to an intersection. For the approaching legs of an intersection, the vertical curve prior to the approach landing should be designed based on the roadway condition and project context. The grades of the tangents for the vertical curve are the grade of the landing area (G_1) and the profile grade of the minor roadway (G_2); see Exhibit 6-4. The Point of Vertical Tangency (PVT) will be located at the end of the landing (75 feet) from the paved shoulder of the mainline. The PVT can be shifted onto the landing area if the gradient of the landing does not exceed 3 percent.
2. **Sag Vertical Curves.** If constraints do not allow room for sag vertical curves meeting SSD, the next most desirable option is to design the sag for comfort. The length of vertical curve can be determined as follows:

Equation 6.1-1

$$L = \frac{AV^2}{46.5}$$

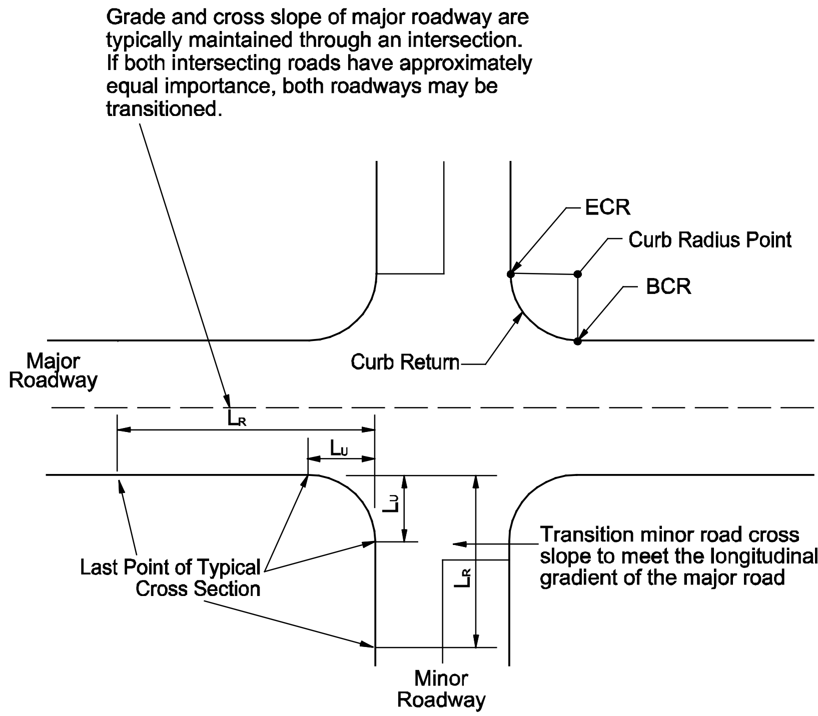
where:

L = length of sag vertical curve, feet

A = algebraic difference between grades, percent

V = design speed, mph

**Exhibit 6-3
Pavement Cross Slope Transitions Through Intersections**



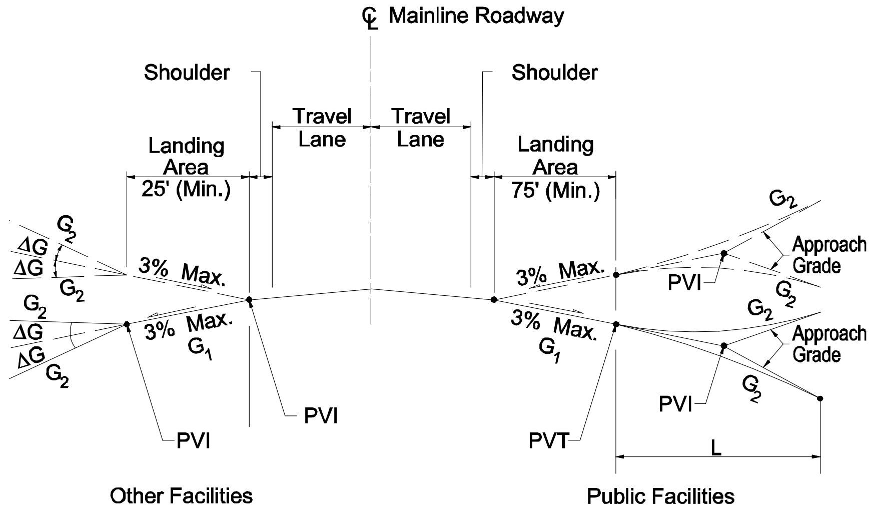
L_R =Transition Length For Rural and Urban Roadways ≥50 ft

L_U =Minimum Allowable Transition Length for Urban Roadways

ECR = End of Curb Return

BCR = Beginning of Curb Return

Exhibit 6-4
Vertical Profiles for Approaches



PVI = Point of Vertical Intersection
PVT = Point of Vertical Tangency

3. **Angular Breaks.** Angular breaks between the landing area and the approach gradient are typically used on minor approaches; see Exhibit 6-4. For major approaches, it may be impractical to provide vertical curves on the approaches under some restricted conditions where angular breaks are necessary approaching the intersection. Exhibit 6-5 provides the maximum allowable angular breaks for various design speeds. Where angular breaks are used, the minimum distance between successive angle points should be at least 15 feet. The angular break (ΔG), defined as the absolute value of G_2 minus G_1, occurs between the landing area and approach roadway; see Exhibit 6-4. These principles also apply to the tie-in locations for approaches (where G_2 intersects with the existing approach grade), and vertical curves should be considered when grade breaks exceed the values provided in Exhibit 6-5.

Exhibit 6-5 Maximum Change in Grades without a Vertical Curve

Design Speed (mph)	Crest Angular Breaks (ΔG)	Sag Angular Breaks (ΔG)
20	7.5%	4.8%
25	5.4%	2.7%
30	3.5%	1.7%
35	2.4%	1.2%
45	1.8%	0.9%
50	1.4%	0.7%
55	1.1%	0.5%
60	0.9%	0.4%

Note: Design speed applies to the roadway with the angular break. Typically, this will be the minor roadway.

6.1.3.4 Intersection Sight Distance

The design team needs to consider the effect that the intersection profile and alignment will have on intersection sight distance. Landings with steep upgrades into the intersection may put the driver's eye below or in line with roadway appurtenances (e.g., guardrail, signs). Also, large skewed intersections may require some drivers to look back over their shoulder to view conflicting traffic from the crossing street. The effect of these skews on intersection sight distance depends on the type of traffic control used at the intersection. For more information on intersection sight distance, see Chapter 2, Section 2.8.

6.1.4 Turning Radii

For intersections where trucks, pedestrians, traffic signals, turning lanes or uncommon intersection configurations are present, the Traffic and Safety Bureau should be consulted.

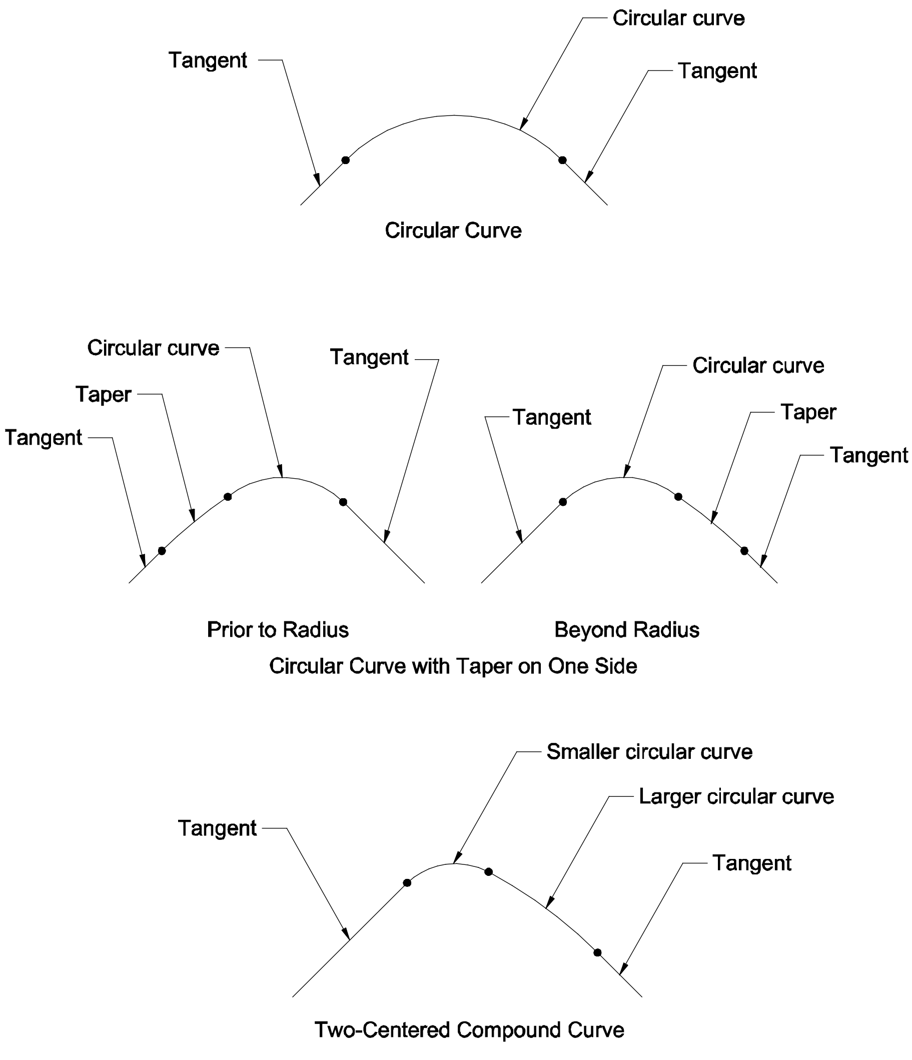
Typically, the turning radii at intersections will consist of circular curve radii. The design team should check the intersection with the design vehicle turning template to ensure the design is adequate, as well as consider the crossing distance for pedestrians and bicycles across the intersection. See Chapter 2, Section 2.2.3.4 for additional guidance regarding the design vehicle for the Interstate and Primary systems.

As illustrated in Exhibit 6-6, to accommodate right-turning vehicles at an intersection, one of the following edge of pavement or curb lines may be selected:

- Circular radius
- Compound curve (two- or three-centered)
- Circular radius with entering and/or exiting taper(s)

While the circular curve is the easiest to design and construct, and therefore is the most common, the design team should consider the benefits of the compound radii configuration or a circular radius with tapers. Circular radius curves often require greater intersection pavement area and also result in longer crossing distances for pedestrians, compared to compound curves or a radius with tapers.

Exhibit 6-6
Curb Returns



Source: AASHTO *(1)*

6.2 LANES AT INTERSECTIONS

6.2.1 Turn Lane Guidelines

When considering a right-turn lane on a through roadway, specific attention should be given to visibility on the side street. Decelerating vehicles in the turn lane can create a moving sight obstruction. The stop line for the side street should be placed so that the vehicles on the side street can see the through vehicles on the mainline without the obstruction of the right-turning vehicles along the mainline. Channelizing islands (painted or raised) can be used to control proper placement of stopped and decelerating turning vehicles.

When establishing turn lanes, the design team needs to consider access to and from private properties on the legs to the intersection. Along major roads, accesses should not be located along the length of the turn lanes. Along the minor roadway, traffic activity at access points along the minor road may induce queue spillback onto the major road. In absence of access control resolutions, it is recommended to place accesses at appropriate locations as indicated in Section 6.3.

Coordinate with the Traffic and Safety Bureau when considering the addition of a turn lane.

6.2.2 Design of Turn Lanes

For the design of turn lanes (e.g., widths, lengths, types), coordinate with the Traffic and Safety Bureau.

6.2.2.1 Widths

The following will apply to turn lane widths:

1. **Lane Widths**. Typically, the width of any turn lanes at an intersection is the same as that of the adjacent through lane, or is based on the design vehicle. In rare cases, it may be justified to provide a narrower width (e.g., restricted right-of-way).
2. **Shoulder.** For shoulders adjacent to turn lanes, the design team should consider the needs for curbed and uncurbed facilities, while maintaining the same as the normal shoulder width for the approaching roadway.
3. **Cross Slope**. The cross slope for a turn lane will typically be the same as the adjacent through lane.

6.2.2.2 Turn Lane Lengths

At high volume locations, the length of the turn lane should also include storage of turning vehicles.

For special conditions, for example railroad crossings, additional storage may be provided or a wider shoulder.

The length of a right-turn or left-turn lane at an intersection should allow for safe vehicular deceleration of turning vehicles. For urban facilities, it may be impractical to provide a turn lane length that completely accommodates the appropriate deceleration within the length of the turn lane. Therefore, the turn lane may be designed to only provide sufficient distance for storage at urban intersections. For rural facilities, the primary consideration is deceleration distance. To determine the turn lane length, the design team should consider the following:

1. **Taper.** For tapers, a straight-line taper is typically used at the entrance of the turn lane. The taper rate is determined by the design speed. Short, straight line tapers should not be used on curbed urban streets, because the natural path of vehicles may result in vehicles hitting the leading end of the taper. Where a partial tangent taper is used, the tangent section should be about two-thirds of the total length.

2. **Deceleration.** The deceleration distance is the distance a vehicle needs to decelerate from the design speed of the traveling roadway to the back of the anticipated queue (e.g., storage) at the intersection.
3. **Storage.** The storage length for turn lanes should be sufficient to store the number of vehicles likely to accumulate during the design hour.

6.2.3 Through Lanes

The number of continuous through lanes at intersections provides continuity along a corridor. For example, when a motor vehicle enters a corridor and uses it as a through route, then the lanes should be consistent throughout the corridor and vehicles should not be required to change lanes where lanes are added and removed. The lane widths should also be consistent throughout. However, it may not always be possible to provide continuous through lanes due to site constraints. If a traffic study shows that the traffic distribution supports the dropping of a lane at an intersection, overhead signage is encouraged to inform the motorists of these lane changes. More information on lane widths can be found in Chapter 5, Section 5.2.

6.3 APPROACHES

An approach is the portion of a roadway, accessing a state highway from abutting property that is within the highway right-of-way. The design team should apply the same design principles for the design of private approaches as for rural unsignalized intersections (refer to Section 6.1). In construction projects, the area in which work is needed outside of the right-of-way to adequately provide the access is also considered as part of the approach.

In absence of access control resolutions, it is recommended to locate accesses at least 100 feet, or preferably 150 feet, from the intersection for private accesses and 300 feet for public accesses.

When designating approaches, the design team should consider the following:

1. **Limited Access Control Projects.** The Right-of-Way Bureau will provide the design team with the "Limited Access Control Recommendations," which provides the designations for all approaches within Limited Access Control.
2. **Regulated Access Projects.** The Right-of-Way Bureau will not provide the design team with recommendations of designation for approaches. The design team will make this determination from "existing use" or right-of-way agreements, if applicable.

Refer to *MDT's Approach Manual for Landowners and Developers* for MDT's criteria on approaches, in addition to the information provided in this chapter for minor stop-controlled intersections *(2)*. This publication has been prepared by MDT's Traffic and Safety Bureau in conjunction with the Right-of-Way Bureau and the Maintenance Division. This document is provided at the following link on the MDT website.

[MDT Approach Manual for Landowners and Developers]

These regulations are adopted and issued according to the authority granted to MDT under current Montana Law. Unless otherwise provided or agreed to, they apply to all Federal-Aid System and other MDT jurisdiction routes. The frequency, proper placement and construction of points of access to highways are critical to the safety and capacity of those highways. These regulations are intended to provide for reasonable and safe access to highways while preserving their safety and utility to the maximum extent practical. These regulations are not intended to alter or reduce existing or future access control or access limitations, nor are they intended to alter or supersede access which has been agreed to by appropriate written contract with MDT.

More information regarding approaches can be found in Chapter 2, Section 2.7.

6.4 MULTIMODAL DESIGN CONSIDERATIONS

Intersections should be designed and operated to enable safe use and access for people of all ages and abilities using all modes of travel, including walking, cycling, driving, and riding transit. Intersections create increased exposure for all modes, and create potential conflict locations for the users. The design team should understand the context and consider trade-offs when refining the intersection geometry.

Pedestrian facilities should allow people to cross safely on foot or with an assistive device. In addition, pedestrian facilities should be designed to be accessible to all users, regardless of ability. The United States Access Board provides additional resources on accessibility and specific requirements for Accessible Public Rights of Way *(3).*

Bicycle facilities should provide safe crossings for people riding bicycles, with consideration for the potential conflict areas between bicyclists and turning motor vehicles.

Chapter 7 of this manual describes the various treatments and the integration of multimodal design in the overall design process, including at intersections. It also addresses accessibility as it relates to special consideration given to pedestrians with disabilities including accommodating pedestrians with vision or mobility impairments.

6.5 SPEED REDUCTION TREATMENTS

Downstream intersection operations (e.g. queuing, deceleration, turning vehicles) and geometry may create a condition that requires drivers to reduce their speed. At an intersection, a driver is required to perceive and comprehend a greater variety of situations than when driving on a roadway segment. Therefore, speed reduction treatments in advance of or at the intersection may be beneficial to the operations and safety of the roadway and intersection. This is particularly the case for transitional areas, where a driver may be moving from a high-speed rural environment into an urban area with lower speeds and the potential for more pedestrians and bicyclists. Speed reduction treatments can help make drivers aware of the approaching change in environment and encourage drivers to reduce their speeds as they enter the new area. Speed transitions should be considered between the roadway segment and the intersection influence area to allow drivers the opportunity to react to the change in conditions and adjust the speeds accordingly.

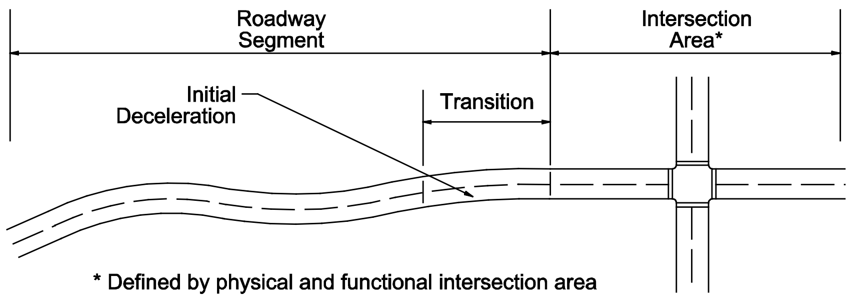
Exhibit 6-7 illustrates a schematic of the roadway segment and intersection speed relationships. The intersection influence area can be determined through geometric or operational influences.

Decisions regarding speed reduction treatment types and directions should be coordinated with the Traffic and Safety Bureau to integrate these treatments into the roadway design.

Geometric influences are where the typical section of the roadway segment is modified in advance of the intersection.

Operational influences are due to traffic operations such as queuing, lane changes, merging, or acceleration/deceleration.

Exhibit 6-7
Schematic of Roadway Segment and Intersection Speed Relationship



Source: TRB *(4)*

When considering a speed reduction treatment, the design team should evaluate the applicability, cost, implementation considerations, and potential to effectively reduce speeds and increase safety. This may include considering the following questions *(4)*:

- What is the target speed?
- Where, and by how much, should the speeds be reduced?
- What information is available about each treatment?
- Has there been any past research conducted on that particular treatment? Was the treatment effective? Were there any side effects of the treatment?

The performance-based design framework discussed in Chapter 1, Section 1.2 may provide guidance for identifying the need and purpose of a speed reduction treatment.

Examples of speed reduction treatments include the following:

- Dynamic warning signs,
- Transverse pavement markings,
- Rumble strips (note that there are noise implications with rumble strips),
- Wider longitudinal pavement markings,
- Approach curvature,
- Landscaped medians or splitter islands,
- Reduced lane width,
- Visible shoulder treatments, and
- Roadside design features.

Speed reduction treatments should be selected and designed specific for the project context and project purpose. The design team should coordinate with the

Traffic and Safety Bureau to gather speed, operations, and crash history to fully understand the needs of the facility and potential mitigation options. *NCHRP Report 613: Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections* provides additional design considerations for implementing speed reduction treatments and the potential effectiveness of various types of treatments *(4)*.

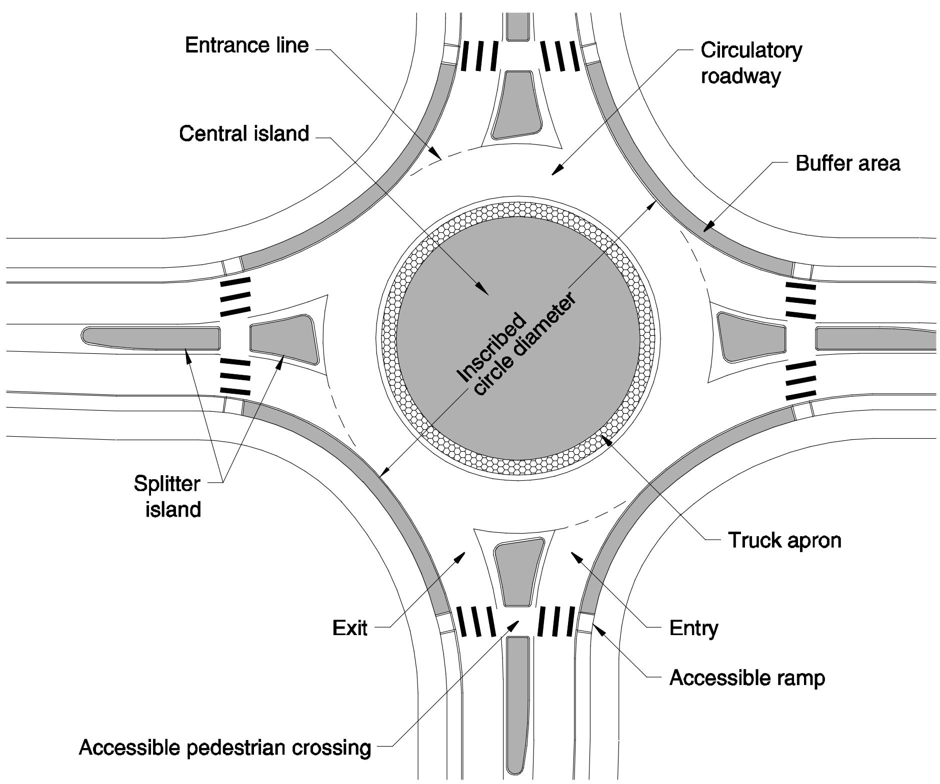
6.6 ROUNDABOUTS

This section provides an overview of roundabout design and application, which is consistent with the national guidance provided in *NCHRP Report 672: Roundabouts: An Informational Guide, Second Edition (5)*. The design team should coordinate with the Traffic and Safety Bureau regarding geometric design as well as operational and safety aspects associated with roundabouts. The design team should understand key design and operational features of a roundabout.

6.6.1 Overview and Considerations

Roundabouts are a generally circular intersection in which traffic travels counterclockwise around a central island and in which entering traffic yields to the circulating traffic. Exhibit 6-8 illustrates the key characteristics of a roundabout. The key design and operational features of a roundabout include channelized approaches, aprons to accommodate appropriate design vehicles, geometric curvature and features to induce desirable vehicular speeds, entry flares, splitter islands, pedestrian crossings on the legs, and no parking within the circulatory roadway.

Exhibit 6-8
Key Roundabout Characteristics



Source: TRB *(5)*

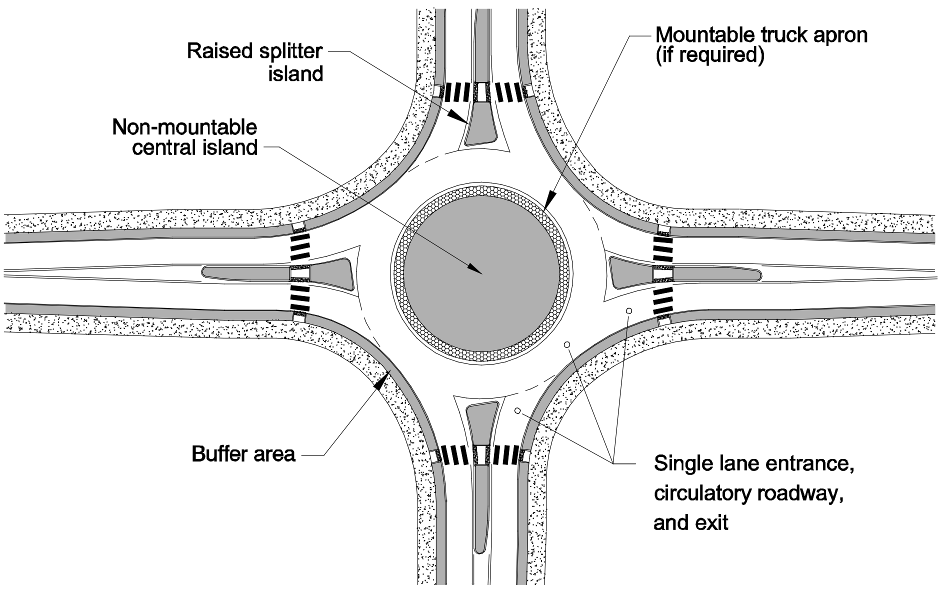
6.6.2 Types

There are various types of roundabouts in the United States. The three most common types include the single-lane roundabout, the multilane roundabout, and the mini-roundabout. Each of these types is further described below.

6.6.2.1 Single-Lane Roundabout

The single-lane roundabout is characterized as having a single-lane entry and exit at all legs and one circulatory lane. Exhibit 6-9 shows the key features of a typical single-lane roundabout, including raised splitter islands, a non-traversable central island, crosswalks, and a truck apron. They have larger inscribed circle diameters compared to mini-roundabouts, and have non-traversable central islands.

Exhibit 6-9
Example of a Single-Lane Roundabout

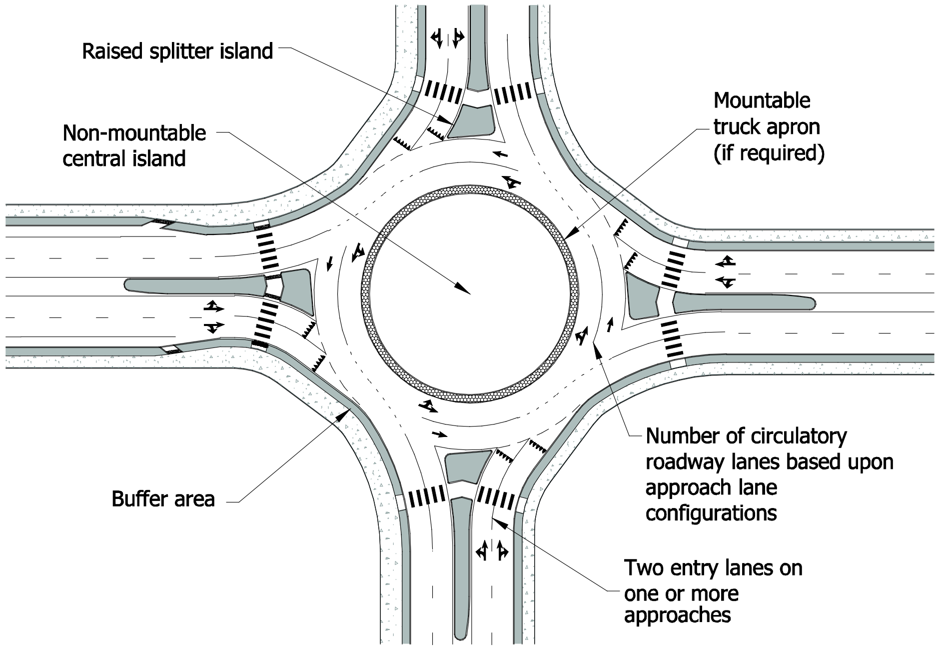


Source: TRB *(5)*

6.6.2.2 Multilane Roundabout

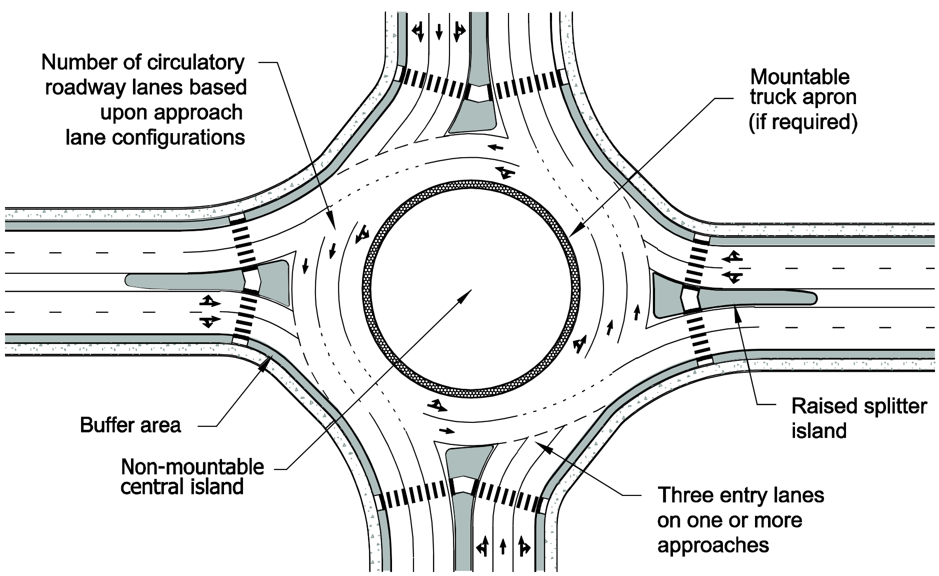
Multilane roundabouts have at least one entry and/or exit with two or more lanes, requiring wider circulatory roadways to accommodate more than one vehicle traveling side by side. Exhibit 6-10 and Exhibit 6-11 illustrate the features of a typical two-lane roundabout and a three-lane roundabout, respectively. The speeds at the entry, on the circulatory roadway, and at the exit are similar or may be slightly higher than those for the single lane roundabouts. The geometric design will include raised splitter islands, truck apron, a non-traversable central island, and appropriate entry path deflections.

Exhibit 6-10
Example of a Two-Lane Roundabout



Source: TRB *(5)*

Exhibit 6-11
Example of a Three-Lane Roundabout

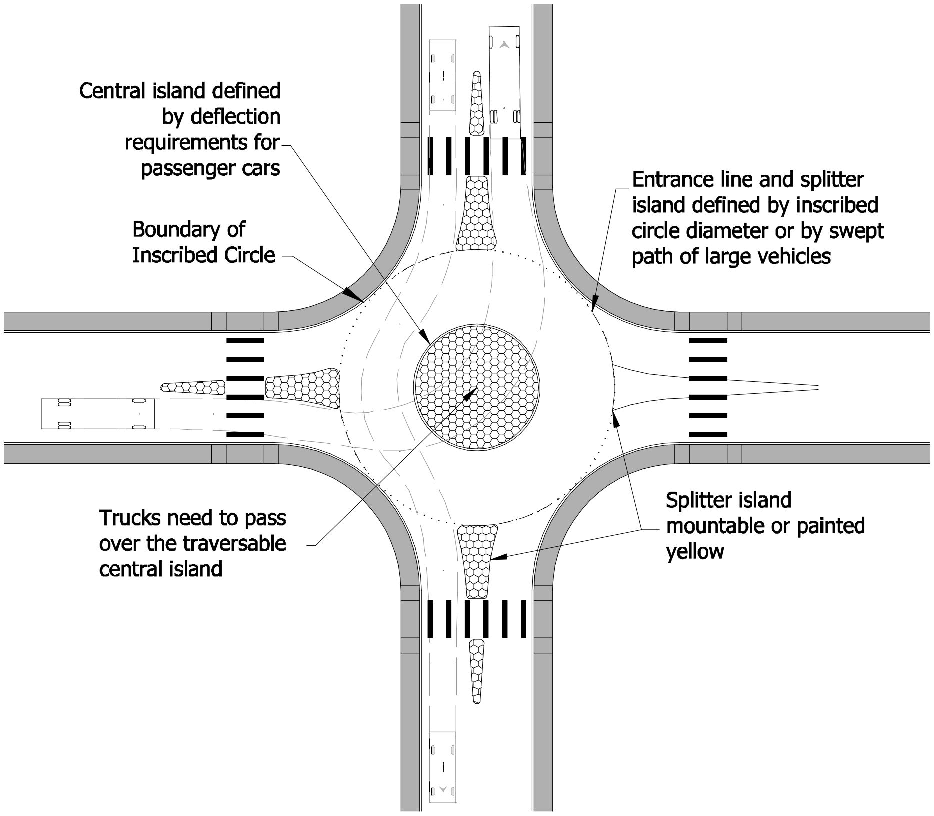


Source: TRB *(5)*

6.6.2.3 Mini-Roundabout

Mini-roundabouts are small roundabouts with a fully traversable central island. They are most commonly used in low-speed urban environments with average operating speeds of 30 miles per hour or less. Exhibit 6-12 shows the features of typical mini-roundabouts, including the fully traversable central island, the striped or traversable splitter islands, and the minimal additional pavement required. Where conventional roundabout design is infeasible due to right-of-way constraints, a mini-roundabout may be a less impactful alternative.

Exhibit 6-12
Example of a Mini-Roundabout



Source: TRB *(5)*

6.6.3 Design Principles and Objectives

A well-designed roundabout achieves the principles of speed management, lane arrangement, appropriate path alignment, appropriate design vehicle, accommodates multimodal users, and considers sight distance and visibility.

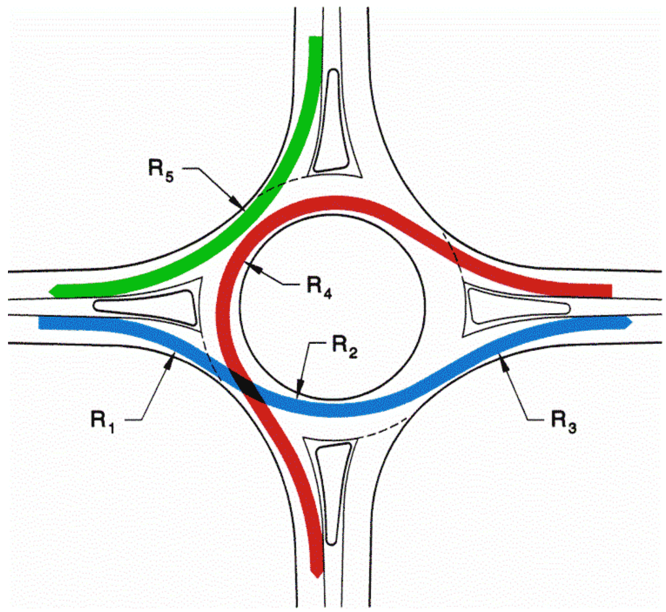
1. **Lane arrangement.** Upon identifying the number of lanes needed for the approaches and the circulatory roadway of the roundabout, the lane assignments should be determined based on operational needs for existing and design year conditions. Appropriate lane arrangement at a multilane roundabout means that a motorist chooses an approach lane based on the desired destination—the driver should not have to change lanes in the circulatory roadway. Interim designs with smaller lane configurations can be implemented in the case that design year traffic volumes are significantly greater than existing needs.
2. **Speed management.** The roundabout should reduce vehicle speeds upon entry and achieves consistency in the relative speeds between conflicting traffic streams by requiring vehicles to negotiate the roundabout along a curved path.

   The fastest path is the smoothest, flattest path possible for the single vehicle through a roundabout, in the absence of other traffic and lane markings. The

The fastest path methodology represents a theoretical attainable speed. Actual speeds may differ based on roadway characteristics and driver behavior.

fastest path for a given roundabout geometry determines the theoretical attainable entry speed through this roundabout for design purposes. The five critical path radii that should be considered include the entry path radius (R_1), the circulating path radius (R_2), the exit path radius (R_3), the left-turn path radius (R_4), and the right-turn path radius (R_5), as shown in Exhibit 6-13. Calculations for these radii and the fastest path can be found in *NCHRP Report 672 (5)*.

Exhibit 6-13
Vehicle Path Radii



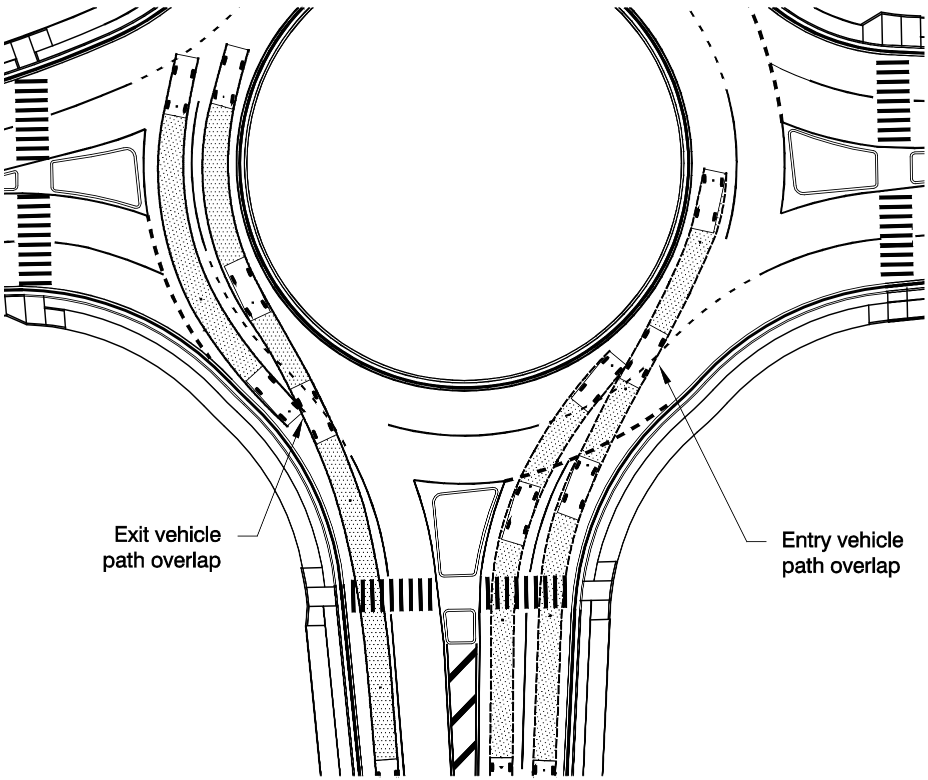
Source: TRB *(5)*

Entering design speeds based on a theoretical fastest path of 20 to 25 miles per hour are recommended at single-lane roundabouts. At multilane roundabouts, maximum entering design speeds of 25 to 30 miles per hour are recommended based on a theoretical fastest path assuming vehicles ignore all lane lines. These speeds are influenced by a variety of factors, including the geometry of the roundabout and the operating speeds of the approaching roadways. As a result, speed management is often a combination of managing speeds at the roundabout itself and managing speeds on the approaching roadways. On approaching roadways with multiple approach curves, speeds can be reduced by 10 to 15 miles per hour with each curve. Splitter islands are also implemented for speed management, and their lengths are approximately two-thirds of the deceleration distance for an approach.

3. **Appropriate path alignment.** The natural path of a vehicle is the path of how a vehicle will naturally travel through the roundabout, given the presence of traffic in all approach lanes, particularly at a multilane roundabout. The key considerations include providing appropriate alignment by arranging curve radii in conjunction with tangent sections to systematically slow vehicles approaching a roundabout. This geometry positions the motorist in the lane at the entry to align with the correct receiving circulatory lane (similar approach applies for the exits). For the safety and operation of the roundabout, the natural paths of adjacent vehicles should not overlap. In

multilane roundabouts, inadequate entry path or exit path alignment may cause path overlap. Path overlap can create safety issues and can reduce the driver's ability to navigate through the roundabout. Exhibit 6-14 shows areas of possible path overlap at a multilane roundabout with inadequate entry path or exit path alignment.

Exhibit 6-14
Path Overlap at a Multilane Roundabout with Inadequate Path Alignment



Source: TRB *(5)*

4. **Design vehicle.** The design vehicle is the largest vehicle to likely use the roundabout. The design vehicle should be determined based on the approaching roadway types and the surrounding land use characteristics, and in consultation with the local agency or MDT. The design vehicle will impact the selection of curb-to-curb widths and turning radii. Truck aprons should be designed to accommodate the pathways of larger vehicles (e.g., trailer wheels on the mountable truck apron) with no encroachment onto the central island. Depending on the roadway, consideration should be given to accommodate non-standard vehicles, such as oversized and overload vehicles. For example, the design team may make objects such as signs removable at roundabouts or provide a bypass for these vehicles. Other treatments for oversized and overload vehicles may include thickened concrete curbs, island caps, and sidewalks. Soil treatments may also be used to create a durable surface outside of the roundabout corner radii to accommodate oversized and overload vehicles. The roundabout design should be refined to accommodate the appropriate design vehicles by collaborating with the public and Motor Carrier Services.

Urban applications of roundabouts near interchanges pose new challenges with designing for multimodal users. Think of design in three dimensions rather than simply two.

Island caps are concrete caps in the medians of splitter islands.

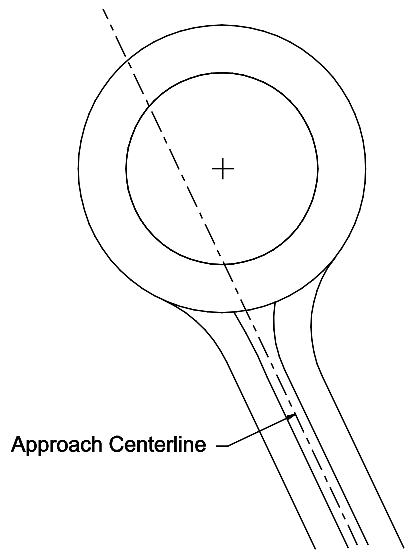
5. **Multimodal users.** The roundabout should be accessible to and usable by all users. More information on designing for multimodal users can be found in Chapter 7.
6. **Sight distance.** While the principles of sight distance at a roundabout are the same as those for a conventional intersection, there are several new considerations in assessing stopping sight distance and intersection sight distance at roundabouts. The intersection angle between consecutive entries should allow for a view of oncoming traffic from the immediate upstream entry. The design team needs to coordinate with the landscaping design to ensure appropriate sight distance needs. Convene the Roundabout Committee for questions involving fixed objects within the center island. More information regarding sight distance calculations at roundabouts can be found in Chapter 2, Section 2.8.

6.6.4 Design Considerations

The design of a roundabout involves optimizing three design decisions: (1) size, (2) position, and (3) the alignment of the approach legs. There are numerous possible combinations of each element, each with its own advantages and disadvantages. Selection of the optimum combination will often be based upon the constraints of the project site, balanced with the ability to adequately control vehicle speeds (entering, through, and exiting the roundabout), accommodate heavy vehicles, and meet the overall design objectives. The following includes design considerations based on basic principles for intersection designs, as applied to roundabout design:

1. **Size.** The selection of the inscribed circle diameter (outer curb diameter) is generally the first step in the design process. The inscribed circle diameter is determined by the number of lanes needed and the design vehicle.
2. **Position.** The position of the roundabout can be determined by creating a conceptual design of the roundabout and placing it on an intersection map. Moving the roundabout around on the map can help to identify and evaluate impacts to existing topography, facilities, and right-of-way while allowing approach alignments to achieve appropriate speed control.
3. **Approach Alignment.** The alignment of the approach legs plays an important role in the design of a roundabout. The alignment affects the amount of speed control that is achieved, the ability to accommodate the design vehicle, and the visibility angles. There are three alignment options: (1) alignment through the center of roundabout, (2) alignment to the left of center, and (3) alignment to the right of center. There are advantages and trade-offs for each alignment. MDT recommends an offset alignment to the left of the center of the inscribed circle. This design allows for increased deflection which will help to control entry speeds. A left-offset alignment also allows for better accommodation of large trucks in roundabouts with small inscribed circle diameters by allowing for a larger entry radius. A left offset alignment is shown in Exhibit 6-15.

Exhibit 6-15
Left Offset Alignment



Source: TRB *(5)*

4. **Pedestrian design considerations.** Three important components of pedestrian facilities at roundabouts include sidewalks, crosswalks, and signalized crossings. Where pedestrian circulation paths are provided and a pedestrian crossing is not intended, the pedestrian circulation path shall be separated from the curb, crosswalk to crosswalk, with landscaping or other nonprepared surface 24 inches wide minimum or a vertical edge treatment must be provided. The buffer area also provides an area for snow storage. Roundabouts in urban environments should have sidewalks, and those in rural environments should have sidewalks if there are sidewalks along the corridors leading up to the roundabout or if sidewalks are being considered in the future. Consideration should be made to accomplish the grading for future sidewalks and buffer areas with the initial roundabout construction. Crosswalks assist pedestrians in crossing the legs of the approaches of the roundabout and should balance the needs for pedestrian convenience, pedestrian safety, and roundabout operations. MDT has the following guidance regarding the design of crosswalks at roundabouts:

   - Crosswalks are placed approximately 40 to 50 feet back from the yield line. Consideration can be given to greater distances (approximately 60 to 80 feet) for the exit side to minimize the possibility of queues upstream of the crosswalk extending back into the circular roadway.

- Multilane roundabouts require signalization of the pedestrian crossings, in the form of an actuated pedestrian hybrid beacon.

In addition, similar to conventional intersections, roundabout approach grades should have a 2.1-percent maximum grade (preferably 1.5 percent to allow for construction tolerance) at the crosswalk.

5. **Bicycle design considerations.** The roundabout can be designed for bicyclists to traverse the intersection as a vehicle or as a pedestrian. For a bicyclist to use the roundabout as a vehicle, consideration should be given to the transition from an upstream bicycle lane to merging into the vehicular flow, as bicycle lanes should not be located within the circulatory roadway of roundabouts. A bicyclist may also use the shared-use path at the roundabout as a pedestrian, and bicycle ramps are typically provided to allow access to the sidewalk or shared use path at the roundabout.
6. **Parking considerations.** Parking should not be allowed in the circulatory roadway of a roundabout, as it may interfere with the efficiency and safety of roundabout operations. Parking may be accommodated in the deceleration area, unless it impedes sight lines for drivers and pedestrians.
7. **Bus stop locations.** Bus stops should not be located in the circulatory roadway. There are various design considerations for bus stop locations on the near side and the far side of the roundabout, such as entry and exit speeds, visibility of pedestrians, potential queuing behind buses during passenger loading, and merging and diverging from traffic when using a bus pull-out.
8. **Grade of circulatory roadway.** The typical roadway has a 2-percent cross slope down towards the outside of the roadway. If the entire roundabout must be tilted due to topography, grades are allowed up to 2 percent across the overall roundabout plane.
9. **Treatments for high-speed approaches.** Roundabouts located in rural areas with higher roadway speeds than urban areas need to make approaching drivers aware of the roundabout and encourage decelerating to the appropriate speeds. An alignment with successive curves may be considered for high-speed approaches. An emphasis should be placed on visibility, curbing, splitter islands, cross sectional elements, and other features to increase roundabout visibility such as landscaping and the mounding of the central island.
10. **Right-turn bypass lanes.** A right-turn bypass lane can improve the traffic operations of a single-lane roundabout without upgrading the intersection to a multilane roundabout, depending on the right-turn volumes at the intersection. A right-turn bypass lane can be designed as a full bypass with an acceleration lane in the exiting lane, or a partial bypass with a yield at the exit leg. There are tradeoffs for introducing a bypass lane, and implementation of a bypass lane may produce additional challenges for bicyclists and pedestrians due to the geometry and generally higher speeds associated with bypass lanes.
11. **Vertical considerations.** Vertical considerations, such as profiles, superelevation, and approach grades, are needed to accommodate trucks to prevent overturning at a roundabout.

12. **Materials and design details.** The materials and design details of curb types, the circulatory roadway pavement types, and the truck apron material should be selected in considering the overall design of the roundabout.
13. **Drainage.** Inlets should be placed on the outer curb line of the roundabout, as the circulatory roadway slopes away from the central island. Drainage and detention basins can use buffer areas and splitter islands (depending on the size), and discourage flow from the central island across the circulatory roadway. Consideration should be given to the locations of low points and the relative location of crosswalks.
14. **Maintenance, including snow removal and storage.** Snow is typically plowed to the outside of the roundabout, and the drainage should be facilitated as described above.

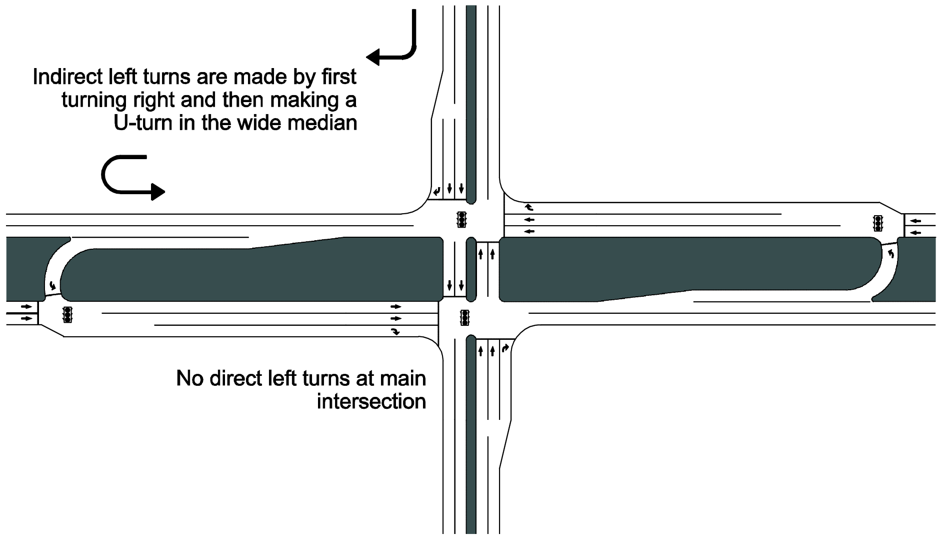
6.7 ALTERNATIVE INTERSECTIONS AND INTERCHANGES

This section includes a discussion on alternative intersections, such as Median U-turn Intersections, Restricted Crossing U-turn Intersections, Displaced Left-Turn Intersections, and Diverging Diamond Interchanges. For more information, the design team should refer to the *Federal Highway Administration (FHWA) Alternative Intersection Information Guides (6, 7, 8, 9)*.

6.7.1 Median U-Turn Intersections

The Median U-Turn (MUT) intersection is also known as the Median U-Turn Crossover, and sometimes referred to as a boulevard turnaround, a Michigan loon, or a Thru-Turn Intersection. The MUT intersection replaces direct left-turns at an intersection with indirect left-turns using a U-turn movement in a wide median, as shown in Exhibit 6-16. By eliminating left-turns on all approaches of the intersection, the MUT intersection reduces the number of traffic signal phases and conflict points at the main crossing intersection. More information can be found in the *FHWA Median U-Turn Informational Guide (6)*.

Exhibit 6-16
Key Characteristics of a MUT Intersection

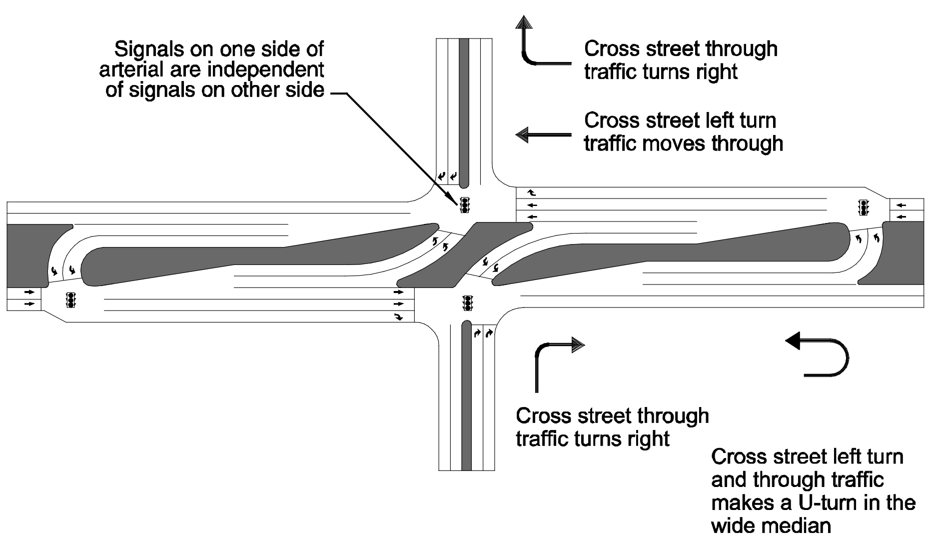


Source: FHWA *(6)*

6.7.2 Restricted Crossing U-Turn Intersections

The Restricted Crossing U-Turn (RCUT) intersection is also known as a superstreet intersection, a J-turn intersection, or a synchronized street intersection. The RCUT intersection replaces direct left-turns and through movements from cross street approaches at an intersection with indirect left-turns using a U-turn movement in a wide median. RCUT intersections can be signalized, stop-controlled, or merge- or yield-controlled. A signalized RCUT intersection is shown in Exhibit 6-17. More information can be found in the *FHWA Restricted Crossing U-Turn Informational Guide (7)*.

Exhibit 6-17
Key Characteristics of a RCUT Intersection

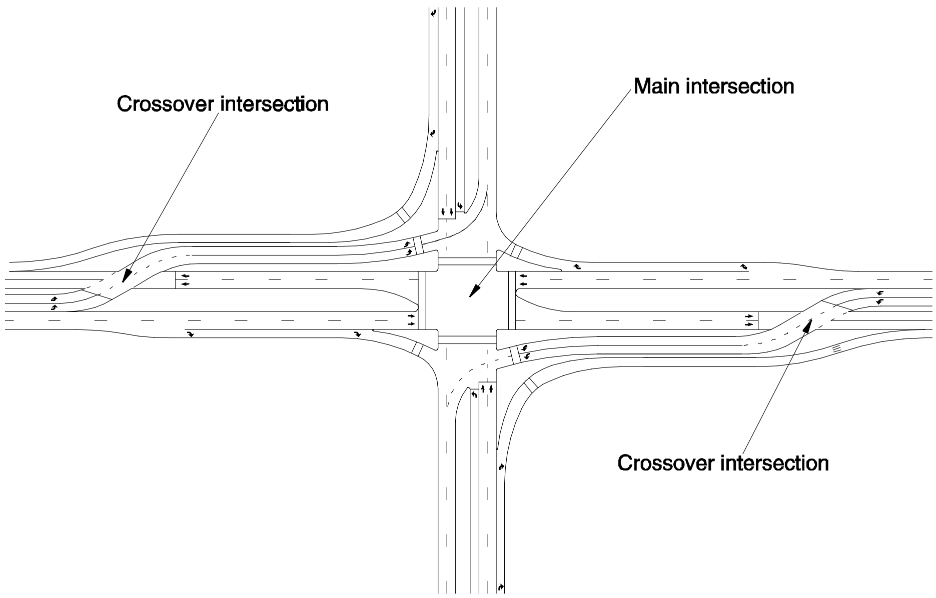


Source: FHWA *(7)*

6.7.3 Displaced Left-Turn Intersections

The Displaced Left-Turn (DLT) intersection is also known as a continuous flow intersection (CFI) and a crossover displaced left-turn intersection. The DLT intersection displaces left-turn movements of an approach to the other side of the opposing traffic flow, as shown in Exhibit 6-18. More information can be found in the *FHWA Displaced Left Turn Informational Guide (8)*.

Exhibit 6-18
Key Characteristics of a DLT Intersection

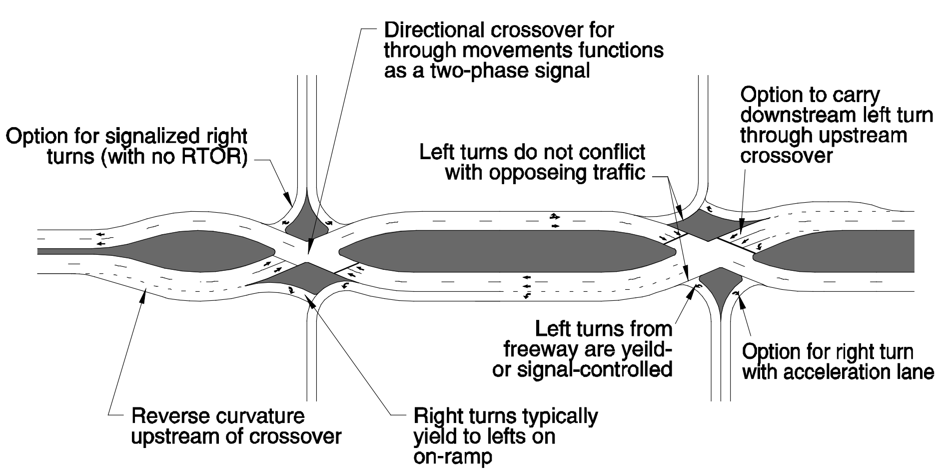


Source: FHWA *(8)*

6.7.4 Diverging Diamond Interchange

The Diverging Diamond Interchange (DDI) is also known as the double crossover diamond and is an alternative to the conventional diamond interchange. The DDI includes directional crossovers on either side of the interchange that eliminates the need for left-turning vehicles to cross the path of approaching through vehicles, as shown in Exhibit 6-19. More information can be found in the *FHWA Diverging Diamond Interchange Informational Guide (9)*.

Exhibit 6-19
Key Characteristics of a DDI



Source: FHWA *(9)*.

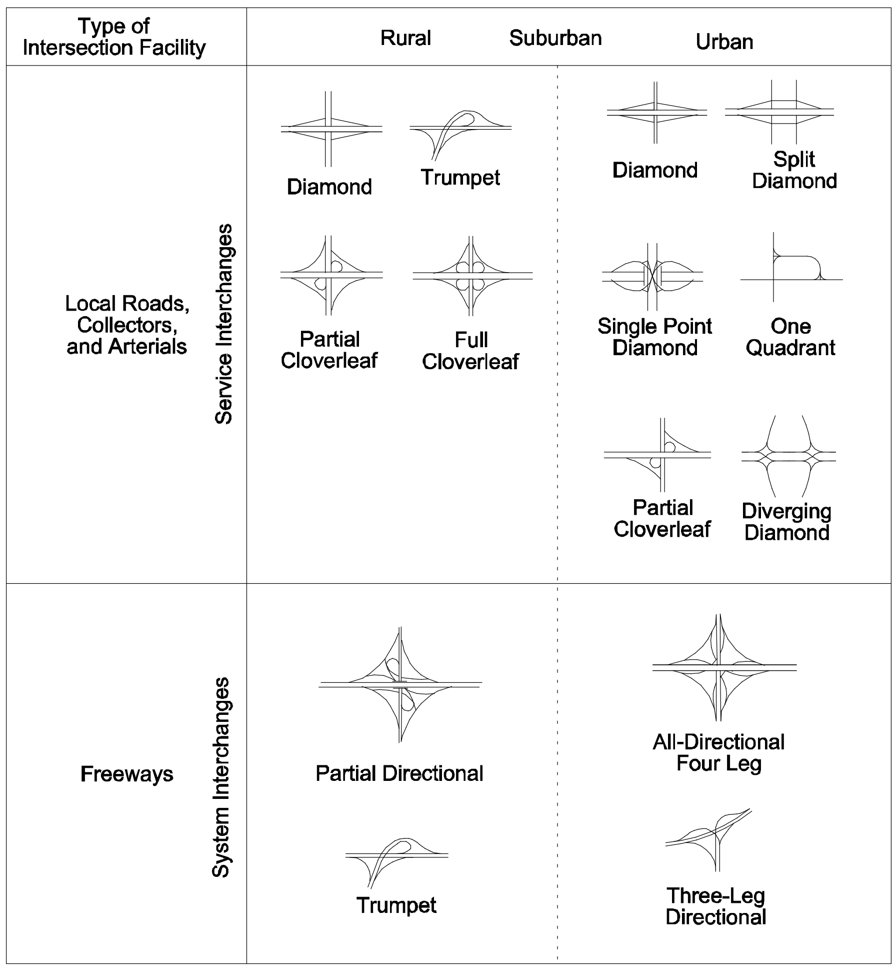
6.8 INTERCHANGES

An interchange is a system of ramps in conjunction with one or more grade separations that provides for the movement of traffic between two or more roadways on different elevation levels. The operational efficiency, capacity, safety and cost of the highway facility are largely dependent upon its design. Coordinate with the Traffic and Safety Bureau for guidance in the design of interchanges including access guidelines, selection, operations, spacing, freeway/ramp terminals, ramps, and ramp/crossroad terminals.

6.8.1 Types

There are a wide variety of interchange configurations, and Figure 6-20 shows several basic configurations of interchanges. These interchange configurations may be modified based on operational and safety needs for the specific project location.

Exhibit 6-20
Interchange Configurations



Source: AASHTO *(1)*

There are two categories of interchanges: service interchanges and system interchanges. Service interchanges are interchanges that connect a freeway to lesser facilities (e.g., local, collector, or arterial street), and system interchanges are interchanges that connect two or more freeways. Interchange configurations can be adapted to meet the needs of each category, land use, and project context. Exhibit 6-20 depicts interchanges that are adaptable on freeways as related to classifications of intersecting facilities in rural and urban environments.

In selecting the type of interchange, there are several considerations:

- Compatibility with the surrounding highway system and the functional classification of the intersecting highway,
- Route continuity and uniformity with adjacent interchanges,
- Operational characteristics,
- Road-user impacts,
- Driver expectancy,
- Topography,
- Geometric design,
- Construction and maintenance costs,
- Potential for stage construction,
- Right-of-way impacts and availability,
- Environmental impacts, and
- Potential growth of surrounding area.

6.8.2 Design Principles

Interchanges are grade-separated facilities that promote the objective of efficiency, safety, and capacity by grade separating the intersecting traveled ways (e.g., high movement volumes). The design of an interchange is influenced by a variety of factors, including highway classification, character and composition of traffic, design speed, and degree of access control. The signing needs, economics, terrain, and right-of-way should also be considered to accommodate the anticipated traffic demands.

The basic components of an interchange include the freeway, the roadway facility that it crosses, the median, ramps, and auxiliary lanes. Traffic operations and safety should guide the interchange design, with consideration for topography, local context, and cost.

Ramp spacing is a unique consideration for interchanges, and should be selected based on safety and operational impacts. Additional information regarding ramp and interchange spacing can be found in *NCHRP Report 687: Guidelines for Ramp and Interchange Spacing (10)*.

The Traffic and Safety Bureau provides additional guidance on interchange design principles.

6.9 REFERENCES

1. Transportation Research Board. *Highway Capacity Manual 2010.* Transportation Research Board of the National Academies, Washington, D.C., 2010.
2. Montana Department of Transportation (MDT). *Approach Manual for Landowners and Developers.* MDT, Helena, MT, 2013.
3. United States Access Board. *Public Right-of-Way Accessibility Guidelines (PROWAG).* Website: https://www.access-board.gov/prowag/
4. Ray, B., I. Potts, F. Hanscom, and J. McGill. *NCHRP Report 613: Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections.* Transportation Research Board of the National Academies, Washington, D.C., 2008.
5. Rodegerdts, L., J. Bansen, C. Tiesler, J. Knudsen, E. Myers, M. Johnson, M. Moule, B. Persaud, C. Lyon, S. Hallmark, H. Isebrands, R. B. Crown, B. Guichet, and A. O'Brien. *NCHRP Report 672: Roundabouts: An Informational Guide, 2nd ed.* Transportation Research Board of the National Academies, Washington, D.C., 2010.
6. Reid, J., L. Sutherland, B. Ray., and A. Daleiden. *Median U-Turn Informational Guide*. FHWA, Washington, D.C., 2014.
7. Hummer, J., B. Ray, A. Daleiden, and P. Jenior. *Restricted Crossing U-Turn Informational Guide*. FHWA, Washington, D.C., 2014.
8. Steyn, H., Z. Bugg, B. Ray, and A. Daleiden. *Displaced Left-Turn Informational Guide*. FHWA, Washington, D.C., 2014.
9. Schroeder, B., C. Cunningham, B. Ray, and A. Daleiden. *Diverging Diamond Interchange Informational Guide*. FHWA, Washington, D.C., 2014.
10. Ray, B., R. Porter, J. Leisch, and J. Mason. *NCHRP Report 687: Guidelines for Ramp and Interchange Spacing*. Transportation Research Board of the National Academies, Washington, D.C., 2011.