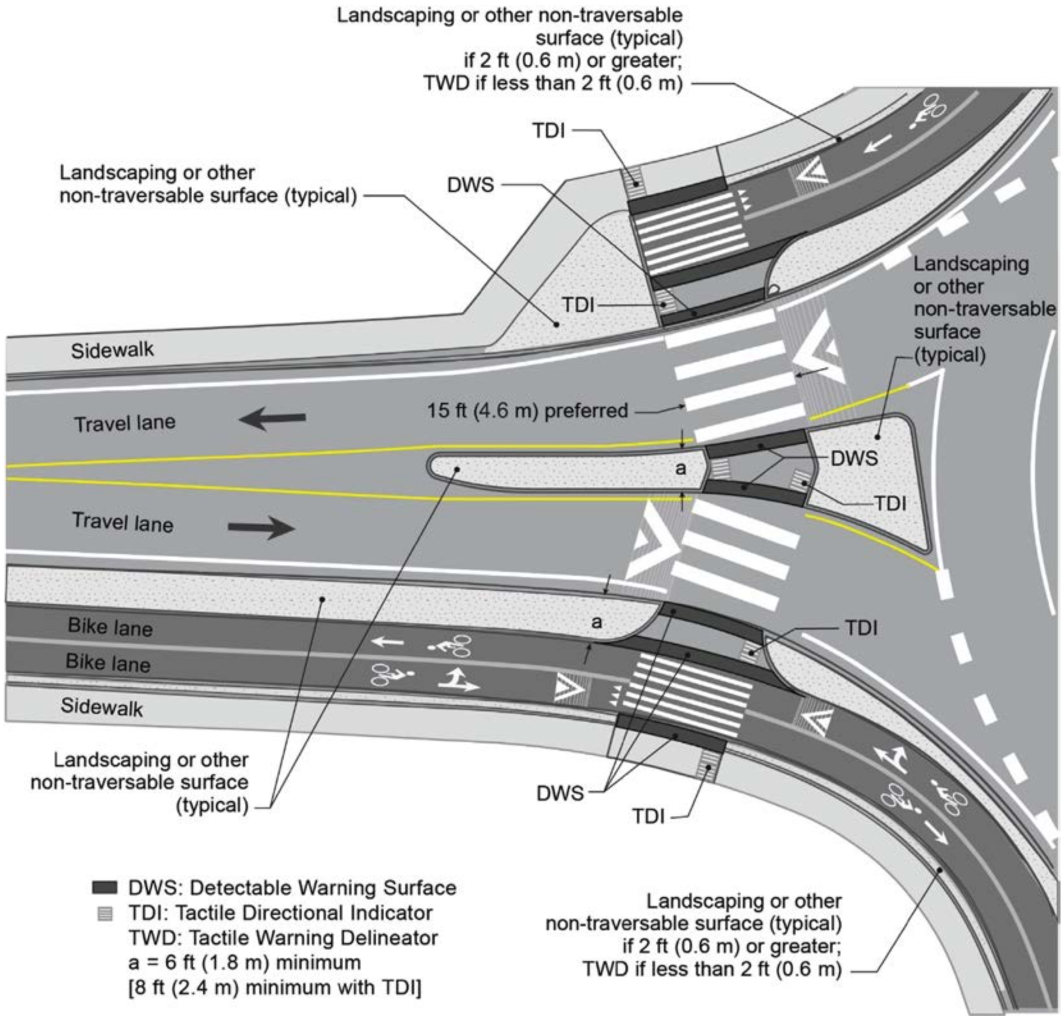
Exhibit 10.34. Widened, shared, and raised shared-use crossing with two-way cycle track.



horizontal, vertical, and cross-section design needs. Attaining target performance often means iteratively considering and testing three-dimensional design elements. Horizontal design cannot be assessed in isolation.

For any roundabout configuration, practitioners must determine the design vehicle and how it will travel through the roundabout between curbs, with some movements possibly using a truck apron for trailer off-tracking. In addition, the larger, but less frequent, control (or check) vehicle must be selected. A variety of techniques can accommodate this vehicle, including hardened surfaces or aprons beyond the curb, passageways through splitter islands or the central island, removable signs, or other treatments. For some vehicle movements, the truck driver may have to drive their cab onto the truck apron.

For trucks with trailers, the roundabout needs to be designed for the cab of the truck to stay within the traveled way and not mount curbs, with only the trailer using the truck apron. This has been common practice throughout the United States and meets the expectations of most truck drivers. For roundabouts with traversable central islands, the cab and trailer can be assumed to use the traversable island. Vehicles assumed to use the truck apron or traversable central islands include trucks and emergency vehicles.

10.5.1 General Considerations

The design vehicle is a significant controlling factor for many single-lane roundabout dimensions. In particular, the choice of design vehicle and what larger vehicles need to be accommodated affect the ICD, entry width, entry radius, and circulatory roadway width. For example, in areas with high truck volumes (e.g., a freeway ramp terminal intersection, industrial areas, warehousing, or intermodal ports), a larger diameter better serves large vehicles and minimizes the widths for the entries, exits, and circulatory roadway. However, smaller-diameter roundabouts with appropriate entry and exit configurations may adequately serve high truck volumes. In general, a fundamental design objective may be to provide the smallest roundabout possible (commensurate with the project context). This includes the project characteristics, project type, and project influences.

Design vehicle volumes and patterns can greatly influence roundabout planning and design decisions. Large vehicles traveling as *through* vehicles can readily be served by roundabouts in the lower ICD range. Truck routes and designated routes for permitted vehicles can support design choices. Minor intersection approaches may be designed differently than the major roadway. For reconstruction projects with constrained right-of-way, it might be reasonable to configure the intersection so that single-unit trucks and buses can easily make all movements. For example, a minor approach serving a residential area may serve the occasional moving truck. The right turns to and from the minor leg might be designed to accommodate the rare larger truck. However, if other access to the area is available, these accommodations may be less critical.

A fundamental consideration of single-lane roundabout design is whether a central island is to include a non-traversable portion (i.e., a landscaped or hardscaped area) or if design vehicles may traverse the entire central island. As ICD becomes smaller, it becomes more likely that a roundabout will require a fully traversable central island along with potential partially or fully traversable splitter islands. In this situation, landscape areas, signs, or street furniture may have to be positioned out of the expected truck path to accommodate larger vehicles.

Practitioners may configure the roundabout to serve specific design vehicles. Passenger buses need to be accommodated within the circulatory roadway without tracking over the truck apron, which could jostle bus occupants. Buses and motor coach dimensions can vary significantly between type and configuration. Recreational routes are often frequented by motor homes and other recreational vehicles. Agricultural areas are frequented by tractors, combines, and other farm machinery. Manufacturing areas may see oversize trucks. Each of these special design vehicles needs to be incorporated into the design process early, as they can affect fundamental design decisions about size, position, and approach alignment.

At single-lane roundabouts, the right-turn movement is often the controlling intersection movement. This is especially true for locations with skewed approach alignments (less than a 90-degree angle between adjacent approach centerlines). To adequately accommodate the design vehicle, the corner radius may sometimes be increased to serve the vehicle swept path. This may result in a wide portion of entry and portion of the circulatory roadway. This wide area may be marked with striping (which may create geometric speed control challenges) or addressed via an external truck apron. Pedestrian waiting areas must be established outside the truck swept path.

Exhibit 10.35 depicts a single-lane roundabout in a rural location on a state highway. The right side of the splitter island at the entry was pulled away from the edge of the traveled way to accommodate a design vehicle larger than a WB-67. While this splitter island design serves large vehicles, it could also diminish the beneficial channelization effect that guides users onto the circulatory roadway as drivers tend to follow curb lines. While it does provide additional space, there may be other options available to serve large vehicles.

Mini-roundabouts and compact roundabouts require unique considerations compared with roundabouts with non-traversable central islands. The location and size of mini-roundabouts and compact roundabout central islands (and the corresponding width of the circulatory roadway)

Exhibit 10.35. Example of treatments to serve large vehicle.

LOCATION: OR 126/SW Tom McCall Road, Prineville, Oregon.
SOURCE: Kittelson & Associates, Inc.

are dictated primarily by passenger car swept path requirements. Passenger cars should be able to navigate through the intersection without traversing the central island.

Compact roundabouts may have fully traversable central islands (to serve design vehicles) with ICD dimensions that commonly allow for raised or mountable splitter islands. Mini-roundabout ICD dimensions are sometimes small enough to require the entire splitter island or the portion of splitter island between the circulatory roadway and the pedestrian crossings to be flush or fully mountable. For mini-roundabouts and some compact roundabouts, a small ICD often results in buses having to travel over the central island. For compact roundabouts with larger ICDs, it may be possible to accommodate the swept path of a bus vehicle within the circulatory roadway.

10.5.2 Truck Aprons

This section discusses truck aprons as they relate to horizontal alignments and features. Chapter 11: Vertical Alignment and Cross-Section Design discusses vertical considerations for truck aprons and other vertical design elements. Truck aprons may be constructed in a variety of ways and with varying materials. Chapter 13: Curb and Pavement Details discusses this in more detail.

A traversable truck apron on the central island is typical for most single-lane roundabouts to accommodate large vehicles while minimizing other roundabout dimensions. The width of the truck apron is based on the swept path of the design vehicle, with the remainder being the non-traversable portion of the central island. External truck aprons may be used on the external curb areas, preferably away from pedestrian crossings, to support truck swept paths while constraining the fastest path for smaller vehicles. Some agencies use truck aprons that are wider than the swept path of the design vehicle, such as to facilitate snowplow operations (the snowplow operator drives on the truck apron) or to allow for parking of a maintenance vehicle.

Truck aprons need to be traversable to trucks but elevated to discourage passenger vehicle drivers from using them. CAD-based vehicle turning path simulation software can determine truck apron width. Truck aprons commonly have the following characteristics:

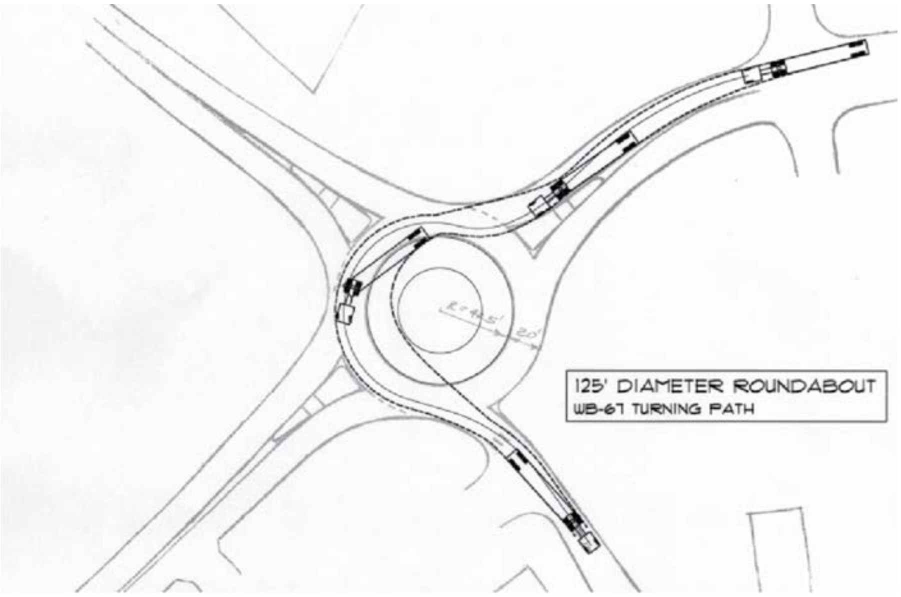
- Truck aprons may range in width from 3 ft to 15 ft (1.0 m to 4.6 m) and be configured as needed to serve the design vehicle. Some agencies use minimum truck apron widths of 10 ft to 12 ft (3.0 m to 3.6 m) to allow for maintenance vehicles and snowplows to access the roundabout. If truck aprons beyond 15 ft (4.6 m) in width are needed, this may be an opportunity to evaluate the benefit of a larger ICD or a smaller ICD with a fully traversable central island.

- The truck apron may benefit from being constructed from a different material than the circulatory roadway pavement to differentiate it from the roadway and the sidewalk. The apron may be colored to further differentiate it from roadways and sidewalks. However, a well-defined pedestrian circulation pattern with an appropriate buffer to the circulating roadway and clear crossing points may minimize the need for this distinction. Well-defined pedestrian circulation patterns and design features benefit all pedestrians, including people who are blind or have low vision.

Exhibit 10.36 and Exhibit 10.37 show sketches of the same roundabout with two different ICDs: 125 ft (38 m) and 140 ft (43 m), respectively. As illustrated in the exhibits, a wider truck apron is often required to accommodate a left-turning vehicle at a roundabout with a smaller ICD. This limits the amount of central island landscaping possible, which may then limit the visibility of the central island on the approach. Wider entries and larger entry radii are also typically required for a small-diameter roundabout to accommodate the design vehicle.

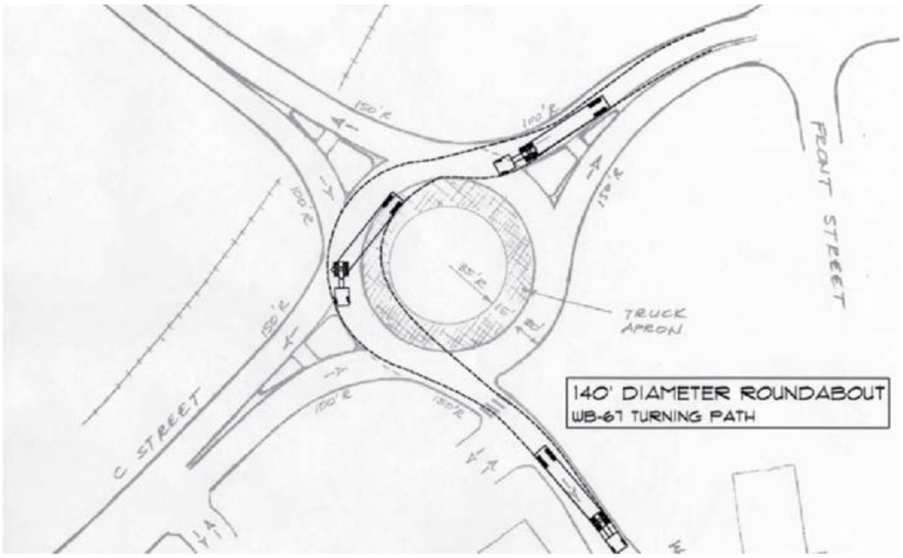
Truck aprons may also be used for maintenance vehicle parking or customized to serve swept paths for large trucks. Exhibit 10.38 shows a single-lane roundabout with a truck apron customized to meet the design vehicle through movement swept path. This configuration also depicts pavement behind a mountable curb that serves as an external truck apron. In this example, the external truck apron passes through the pedestrian crossing at each entry. This is to be avoided wherever possible; however, if unavoidable, the apron can be lowered to crosswalk level through the pedestrian crossing and then returned to its standard elevation after the crosswalk. This minimizes confusion for pedestrians with vision disabilities, who could otherwise mistake the truck apron for an appropriate place to wait. It is necessary to serve pedestrians with mobility disabilities by maintaining appropriate grades and cross slopes through the crossing.

Exhibit 10.36. Swept paths for WB-67 design vehicle at smaller-diameter roundabout.



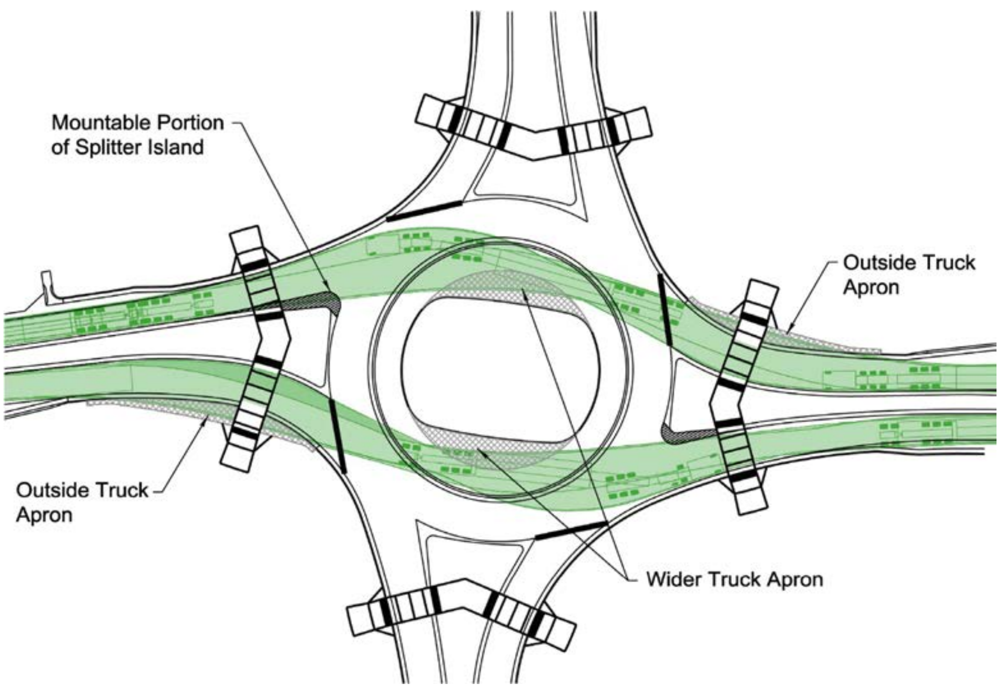
NOTE: Inscribed circle diameter of 125 ft (38 m).
SOURCE: *NCHRP Report 672* (*2*).

Exhibit 10.37. Swept path for WB-67 design vehicle at larger-diameter roundabout.



NOTE: Inscribed circle diameter of 140 ft (43 m).
SOURCE: *NCHRP Report 672* (*2*).

Exhibit 10.38. Truck apron customized for design vehicle and pedestrian crossings.



SOURCE: Adapted from Georgia Department of Transportation (*3*).

10.5.3 Design Vehicles in Multilane Roundabouts

Multilane roundabouts commonly have wider entries, circulating roadways, and exits compared with single-lane roundabouts. Multilane roundabout design vehicle considerations must consider the swept paths on entry, on exit, and within the circulatory roadway.

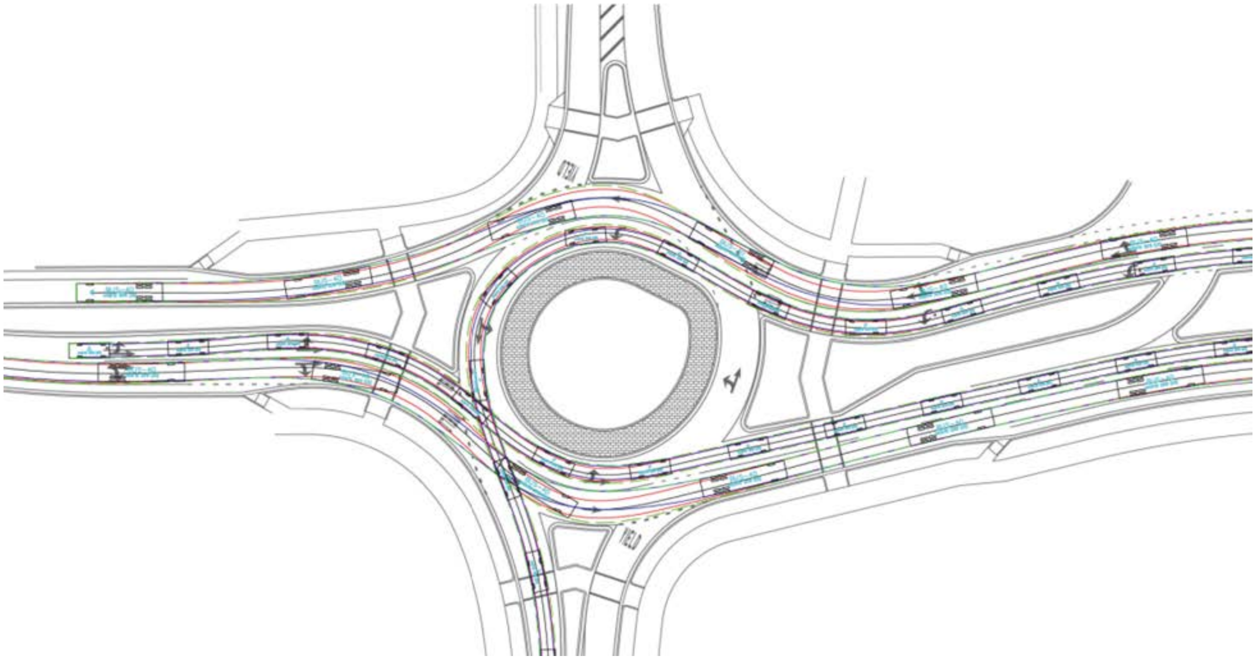
For multilane roundabouts, the design vehicle may operate under one of the following two design cases:

- **Straddle lanes.** For this type of design, the design vehicle is assumed to use the entire curb-to-curb width for entering, circulating, and exiting along with the truck apron as needed. Both trucks and large passenger vehicles (e.g., buses) may straddle lanes.
- **Stay-in-lane.** For this type of design, the design vehicle is assumed to stay in-lane on entry, while circulating, and while exiting. Truck aprons are commonly used to serve large vehicles in the inside lane, but they typically cannot be used by large vehicles in the outside lane. Large passenger vehicles (e.g., buses) should stay in either lane without using the truck apron.

The anticipated frequency of a particular design vehicle guides roundabout design. For instance, a location with expected infrequent use by a WB-67-size tractor-trailer may allow the occasional WB-67 to straddle lanes in the roundabout. A different location could have frequent bus service that would necessitate accommodating buses within their own lane to travel adjacent to a passenger car. Anticipated design vehicle volumes and patterns dictate design evaluations and decisions. A particular roundabout may have multiple design vehicles depending on the unique site characteristics; vehicle combinations beyond WB-62 and WB-67 vehicles may be applicable to serve a specific location's need. Exhibit 10.39 shows an example of side-by-side navigation for a bus and passenger car.

As noted in Chapter 4: User Considerations, some states have amended their vehicle codes to address trucks at roundabouts. An example of state-specific signs associated with these laws is provided in Chapter 12: Traffic Control Devices and Applications.

Exhibit 10.39. Side-by-side navigation for bus and passenger car.



SOURCE: Kittelson & Associates, Inc.

10.5.4 Designing for Oversize and/or Overweight Vehicles

This section presents the horizontal geometric aspects for accommodating OSOW vehicles; Chapter 11: Vertical Alignment and Cross-Section Design presents vertical aspects. Techniques for checking OSOW passage through a design—both CAD-based techniques and field test techniques—are like those used for other truck types and are provided in Chapter 9: Geometric Design Process and Performance Checks and Appendix: Design Performance Check Techniques. Additional information on international examples can be found in the *Kansas Roundabout Guide,* second edition (*24*).

OSOW vehicles, discussed in Chapter 4: User Considerations, are vehicles having one or more characteristics that require a permitting process to use the roadway system. This can include dimensions that exceed allowed parameters without a permit, such as length, height, width, or weight. Some of these vehicles also have low ground clearance. The inherent characteristics of roundabout design—using horizontal geometry to control vehicle speeds and separate movements—must be adapted to support the passage of an OSOW vehicle, which benefits from as straight an alignment as possible.

On roadway systems where OSOW vehicles are allowed, a successful roundabout design accommodates them under permitted conditions while meeting the performance objectives for the roundabout under regular operating conditions. A variety of techniques are available for successfully accommodating OSOW vehicles. Each depends on the site's context and the OSOW check vehicle's specific characteristics and intended travel patterns. An OSOW vehicle is typically treated as a check vehicle, not a design vehicle, because its passage requires permits for travel and is typically accompanied by pilot vehicles and flaggers. This creates circulation options unavailable to other vehicles.

One technique for accommodating OSOW vehicles is to provide bypass lanes for truck movements. This is different than a right-turn bypass for all vehicles. An example of this is shown in Exhibit 10.40 for a roundabout in Marion County, Kansas. This type of treatment may be feasible in rural environments, where sufficient land is available to provide the bypass lanes. These bypass lanes are preferably gated for authorized vehicles only and are not intended for general traffic use. If signs for authorized vehicles are provided instead of gates, the bypass lanes may be used

Exhibit 10.40. Example of OSOW bypass lanes.

NOTE: Gates are preferred over signs to control the bypass lanes to prevent unauthorized use.
LOCATION: US 56-K-150/US 77, Marion County, Kansas. SOURCE: Google Ea

by unauthorized drivers, thus adding unsignalized intersections as points of potential conflict. In some cases, the bypass lane can be part of construction staging to support the construction of the roundabout under traffic.

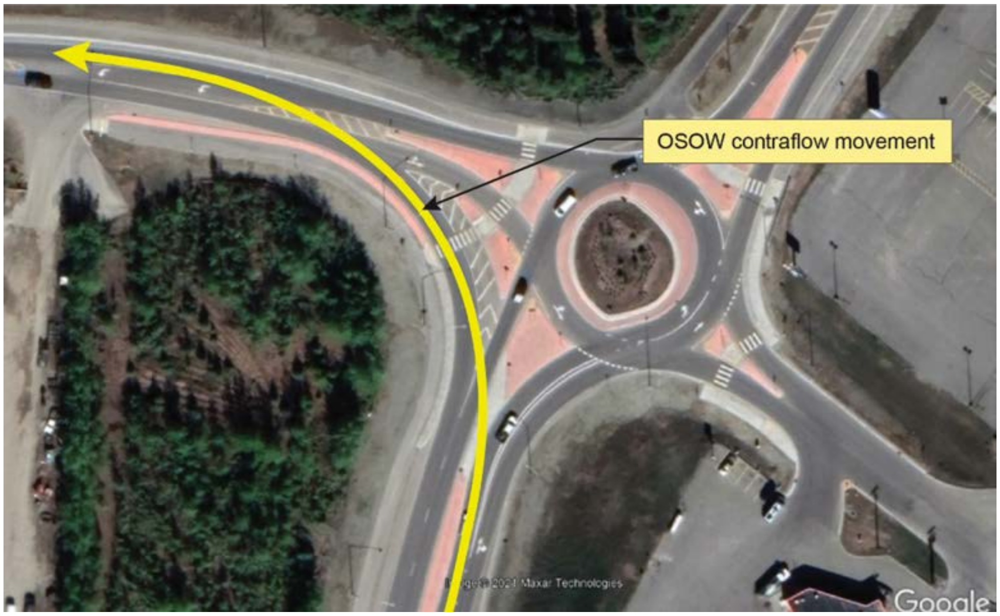
Another technique for accommodating OSOW vehicles is to use a bypass lane in either normal or contraflow patterns. This technique may be especially effective if the OSOW pattern is restricted to turns between two adjacent legs. An example of this is shown in Exhibit 10.41. The right-turn bypass lane is used in both directions for OSOW trucks. When a contraflow OSOW left-turn movement is needed, flagging is used to enable the OSOW vehicle to traverse the right-turn bypass lane in a contraflow direction using traversable sections in the median. While the contraflow bypass lane is used for the longest OSOW vehicles, standard trucks and shorter OSOW vehicles can circulate normally using straddle-lane operation with the extended truck apron.

For roundabouts where OSOW vehicles make through movements along only one axis (e.g., the major street), it may be desirable to provide a bypass lane through the central island. An example of this technique is shown in Exhibit 10.42. For example, this technique could be used along state highways as well as at interchange ramp terminal intersections where the OSOW vehicle must temporarily depart from the freeway because of bridge restrictions.

For most applications where OSOW vehicles can travel in either direction, a bypass lane that connects the two exits is preferred. Under flagging operation, the OSOW vehicle crosses over in advance of the splitter island, travels contraflow through the exit, passes through the central island, and then resumes travel along the exit as normal. The advantages of this method include:

- Roundabout exits usually have larger radii or tangents than roundabout entries, which are designed with geometric speed control as a primary objective.
- The central island immediately in front of the entry is retained for signs, landscaping, or other treatments to provide terminal vista for the roundabout entry.

Exhibit 10.41. Example of OSOW contraflow movement using a bypass lane.



LOCATION: Danby Street/Wembley Street, Fairbanks, Alaska. SOURCE: Google Earth.

Exhibit 10.42. Example of roundabout with OSOW truck accommodation diagonally across the central island.

LOCATION: L555/Hoeber-und-Mandelbaum-Straße, Waghäusel, Germany.
SOURCE: Google Earth.

- The bypass lane does not line up with normal operations, thus reducing the need for gated operation. Gated operation may still be preferred to prevent unauthorized access to the central island.

Exhibit 10.43 presents a roundabout with a gated central island cut through at a location in Green Bay, Wisconsin.

Another common treatment is to use an enlarged truck apron around the central island, external truck aprons on one or more entries or exits, or a combination. When using an enlarged truck apron, practitioners must verify that the roundabout's visibility to drivers approaching the intersection is appropriate for the context. Exhibit 10.44 and Exhibit 10.45 show examples of these applications. In these cases, sign placement, landscaping, and other treatments may be compromised.

Exhibit 10.43. Plan view of a roundabout with a gated central island cut through for OSOW vehicles.

LOCATION: Mid Valley Drive/Scheuring Road, Green Bay, Wisconsin.
SOURCE: Google Earth.

Exhibit 10.44. Enlarged truck apron for OSOW through movements.

LOCATION: GA 16/Holonville Road, Griffin, Georgia.
SOURCE: Georgia Department of Transportation.

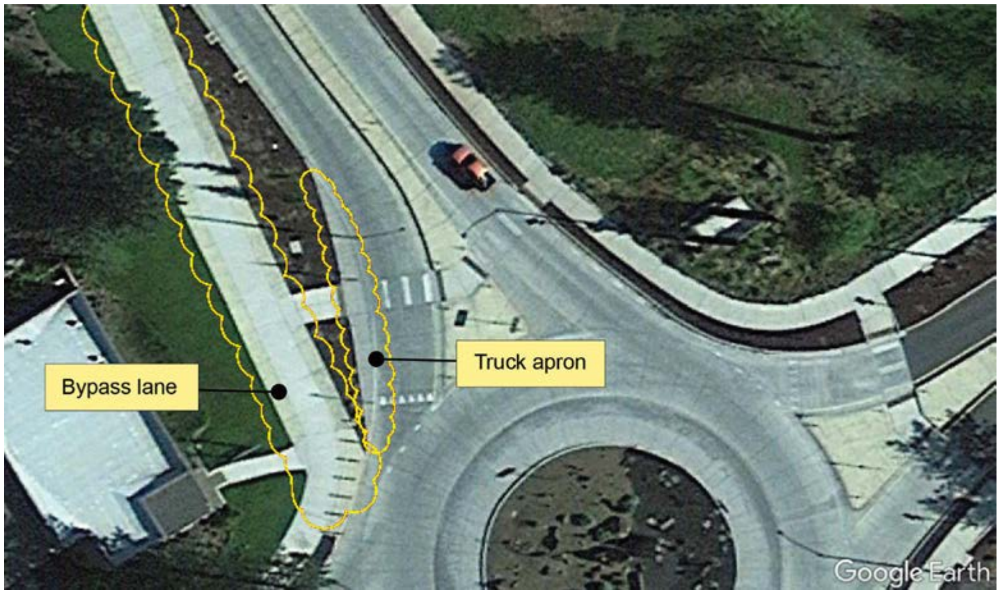
At interchange ramp terminal intersections or in other cases where OSOW travel is one-way, an extended truck apron lined up from entry to exit in the direction of OSOW travel may be preferable. In these cases, sign placement, landscaping, and other treatments may be compromised.

An external truck apron may serve OSOW vehicles for some applications. External truck aprons are to be avoided where they intersect pedestrian facilities because of the potential confusion they can create for people who are blind or have low vision. If the external truck apron crosses a pedestrian crossing, pedestrian accessibility must be maintained at the pedestrian crossing by

Exhibit 10.45. OSOW truck accommodation on one side of the central island.

LOCATION: County Road T/I-94 Westbound Ramps, Saint Croix County, Wisconsin. SOURCE: Google Earth.

Exhibit 10.46. Example of external truck apron and OSOW bypass lane.



LOCATION: US 20/West Barclay Drive, Sisters, Oregon. SOURCE: Google Earth.

dropping the external truck apron to the level of the crossing and then resuming after the crossing. Exhibit 10.46 shows an example of this application. A bypass lane reserved for OSOW use was also used during staged construction.

10.6 Single-Lane Roundabouts

This section presents parameters and guidelines for designing horizontal geometric elements at single-lane roundabouts. Many of the same principles also apply when designing multilane roundabouts, although techniques for designing multilane roundabouts are often different and more complex because of additional factors.

A fundamental part of single-lane roundabout design is whether a central island will include a non-traversable portion (i.e., a landscaped or hardscaped area) or if design vehicles may traverse the entire central island. A mini-roundabout or compact roundabout is well suited for constrained locations and could be considered in other applications. As presented in Chapter 2: Roundabout Characteristics and Applications, there is a continuum of single-lane roundabouts ranging from the smallest ICD with fully traversable features to larger ICD, single-lane forms with non-traversable features.

The design of a roundabout with a traversable central island applies the same principles as the design of a roundabout with non-traversable features in the central island. Key considerations include vehicle channelization, design vehicle paths, and intersection visibility. Given that the central islands for mini-roundabouts and some compact roundabouts are fully traversable, the entries need to guide drivers to the intended path. Sub-optimum designs may result in drivers turning left in front of the central island (or driving over the top of it), improperly yielding, or traveling at excess speeds through the intersection.

There are many ways to initiate a roundabout layout. One method is based on locating the roundabout and begins by assessing the intersection constraints and considering approach alignment and entry configurations that support speed control. This generally includes an iterated approach and entry configuration while considering the footprint of the roundabout. With an initial ICD and roundabout location established, the next step is to refine the roadway approaches, entries, and exits so they will serve design vehicles and manage entry speeds. While it may not be intuitive, establishing the pedestrian crossing, refuge space, and channelization needs of the painted taper and splitter island is an early activity that sets the foundation for configuring the entries and exits. Adapting the splitter island shape and length is part of attaining target speed control needs on the approach and at the entry.

Once channelization and pedestrian refuge needs are established, the roadway approaches, entries, and exits can be developed. Following this order establishes and protects the pedestrian crossing and refuge configuration and allows the entries and exits to meet speed and design vehicle performance needs. Starting from the inside and working outward (i.e., left edges of the traveled way to the right edges) eliminates the risk of having insufficient pedestrian refuge and waiting areas.

With each approach configured, performance checks can evaluate the design. Performance check results will support subsequent design iterations that can include adjusting the ICD, roundabout location, approach alignments, and entries and exits to best meet user needs and target performance for all users.

10.6.1 Splitter Island Types

Splitter islands (also called *separator islands*, *divisional islands,* or *median islands*) serve a variety of purposes:

- They can provide refuge for pedestrians if sized appropriately.
- They assist in controlling speeds.
- They guide motor vehicles with the correct direction of circulation to deter wrong-way movements.
- They physically separate entering and exiting traffic streams.
- They provide space for placing traffic control devices.

This section presents a discussion of the overall splitter island design. Section 10.4 discusses key features and considerations for serving pedestrians and bicyclists through the splitter island; Section 10.6.2 presents other splitter island dimensions; and Chapter 13: Curb and Pavement Details presents design details, such as curbing options, sloped noses, and other features.

The splitter island will be the first design consideration after sizing, positioning, and selecting each approach alignment. The size of the splitter island (i.e., length and width) is considered before designing the approach entries and exits. Practitioners can consider a painted taper that initiates the transition from the roadway segment (i.e., the typical section of the adjacent roadway segments) at the first iteration of the splitter island configuration. In some cases, the length of the splitter island may be an outcome of the approach alignment needed to support speed control (e.g., applying reverse curvature), such as with an offset-left approach configuration.

Early consideration of the full transition from the roadway segment to the roundabout entry allows the design to account for speed reduction (if needed) and a flowing and natural progression of geometric elements that communicate the appropriate driving demands (i.e., self-describing and self-enforcing roadway). Establishing control points for the splitter island envelope (i.e., width, length, and shape) before designing the entry and exit geometry greatly increases the success of establishing properly sized splitter islands as the first concepts. As the design is refined and adapted based on performance checks, the final raised island portion of the approach will eventually meet the appropriate dimensions (i.e., offsets, tapers, length, widths).

For mini-roundabouts and compact roundabouts, splitter islands serve the same purpose that they serve at other roundabout forms. They align entering and exiting vehicles, promote deflection

Exhibit 10.47. Splitter island types.

Design Aspect	Raised and Non-Traversable	Raised and Traversable	Flush and Painted
Overall recommendation	Preferred	Acceptable if needed	Least desirable
Design vehicle	All design vehicles can navigate the roundabout without tracking over the splitter island area.	Some design vehicles may safely travel over the splitter island area; truck volumes are low.	Vehicles are expected to travel over the splitter island area with relative frequency to navigate the intersection.
Pedestrian use	Provides refuge for two-stage pedestrian crossings if sized appropriately	Requires one-stage pedestrian crossings	Requires one-stage pedestrian crossings
Area	50 ft^2 (4.6 m^2) or greater	50 ft^2 (4.6 m^2) or greater	Less than 50 ft^2 (4.6 m^2)
Approaching motor vehicle speeds	All speeds	All speeds	25 mph (40 km/h) or less

and counterclockwise circulation, and provide pedestrian refuge. Splitter islands may be traversable or flush depending on the size of the island and whether design vehicles need to track over the top of the splitter island to navigate the intersection.

Splitter islands can be raised and non-traversable by motor vehicles, raised and traversable by motor vehicles, or flush and painted. In general, **raised islands are to be used where possible**, and flush or painted islands are generally discouraged. However, in some constrained locations, one or more splitter islands may need to be fully traversable or painted. Depending on site conditions and design vehicle travel patterns, some combinations of these splitter islands may be appropriate. For example, a splitter island may be flush or traversable between the ICD and the pedestrian crossing area but raised from the crossing upstream on the approach. Exhibit 10.47 presents a summary of design aspects for each type of splitter island.

Exhibit 10.48 depicts a single-lane roundabout that uses a painted splitter island on one leg to avoid a large underground utility. Raised islands are used on the other three legs.

Exhibit 10.48. Example of roundabout with one painted splitter island.

LOCATION: SW Bond Street/SW Wilson Avenue, Bend, Oregon.
SOURCE: Kittelson & Associates, Inc.

10.6.2 Splitter Island and Approach Taper Dimensions

This section discusses the overall dimensions of the splitter island and its associated approach taper if one is present. Section 10.4 discusses key dimensions for serving pedestrians and bicyclists through the splitter island; Section 10.6.1 presents a discussion of splitter island types; and Chapter 13: Curb and Pavement Details presents design details, such as curbing options, sloped noses, and other features.

The length of the raised island generally needs to be at least 50 ft (15 m), although 100 ft (30 m) or longer can be beneficial. Longer splitter islands may be beneficial on horizontal curves leading to the roundabout where the roundabout may not be visible from the upstream approach. Longer splitter islands are to be considered where a crest vertical curve obstructs the view of the roundabout. Extending the splitter island so that it is visible to approaching drivers helps with navigation and speed reduction. Longer islands may be beneficial with offset-left approach alignments that channelize reverse curves to support speed control on the approach and at the entry. Longer splitter islands may be beneficial in locations where approach speeds are 45 mph (70 km/h) or greater. Treatments for high-speed approaches are detailed in Section 10.14.

The painted taper transitioning from the roadway segment (i.e., the upstream typical section) to the nose of the splitter island is an additional length beyond the splitter island itself. The painted taper provides the initial indication that the roadway typical section is changing and the road user is entering the roundabout influence area. To determine taper length, practitioners may consult the MUTCD formulas or apply Green Book principles for freeway exit ramp diverges in constrained locations (*25, 1*). The design intent is to provide a smooth transition from the roadway segment to the roundabout splitter island.

The MUTCD formulas provide a smoother transition than the exit ramp model, and the two methods are provided to support design decisions commensurate with project opportunities and constraints. According to the MUTCD, the formulas for a shifting taper are as follows (*25*):

$$L = WS, \text{ for } S \geq 45 \text{ mph}$$

$$L = \frac{WS^2}{60}, \text{ for } S < 45 \text{ mph}$$

where

L = the length of the taper (ft), subject to a minimum length of 100 ft in urban areas and 200 ft in rural areas and extended as required by sight distance conditions;
W = the offset distance (ft); and
S = the posted, 85th-percentile, or statutory speed (mph) (with 1 ft = 0.3048 m and 1 mph = 1.609 km/h).

For example, when developing one-half of a 14-ft (4 m) median or splitter island on a 45-mph (70 km/h) posted speed roadway, the painted taper length in advance of the splitter island would be approximately (7 × 45) = 315 ft (96 m). Therefore, a roundabout entry with a splitter island that is 100 ft (30 m) long and a painted taper that is 315 ft (96 m) long would match the typical section of the upstream roadway about 415 ft (127 m) from the ICD.

Practitioners may also consider the freeway exit ramp model in constrained site conditions. Freeway exit ramp diverge angles commonly range from 2 degrees to 5 degrees (29:1 and 12:1). Considering a 2.5-degree diverge (23:1), developing one-half of a 14-ft (4 m) median or splitter island on the roadway center line results in a 161-ft (49 m) painted taper length in advance of the splitter island. The painted taper could be approximated to 160 ft (49 m). Using this method, a roundabout entry with a splitter island that is 100 ft (30 m) long and a painted taper that is 160 ft (49 m) long would match the typical section of the upstream roadway about 260 ft (79 m) from the ICD.

Principles of channelization include using larger nose radii at approach corners to maximize island visibility and offsetting curb lines at the approach ends to create a funneling effect. The funneling treatment also aids in reducing speeds as vehicles approach the roundabout. These features are consistent with themes for island delineation and approach treatment presented in the Green Book (*1*). Exhibit 10.49 shows typical splitter island nose radii and offset dimensions from the entry and exit traveled ways.

10.6.3 Approach Design

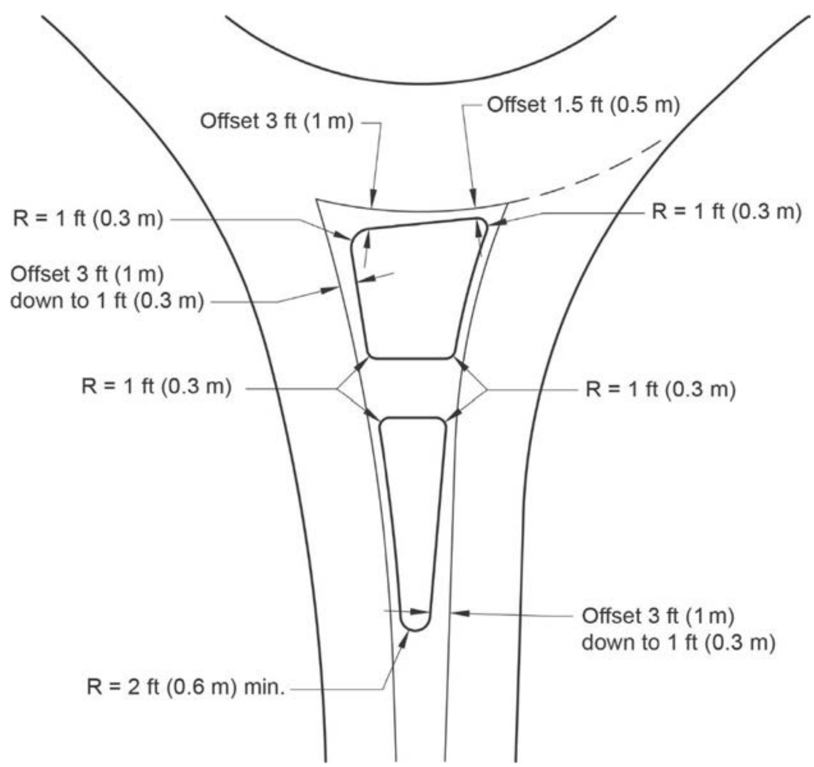
Approach design includes the horizontal geometry associated with roundabout approaches and the roundabout entry. Designs need to account for approach alignment, design speeds, and speed profiles between the upstream approach and the entry. Each combination of roundabout approach and departure is a unique alignment, and this provides significant design flexibility in customizing configurations to meet an array of project needs.

Roadway approach design works integrally with roundabout size and location to achieve target geometric performance. Approach, entry, and exit design can begin after the splitter island needs have been established. This includes identifying pedestrian waiting areas and refuges as well as longitudinal considerations that provide a painted taper and develop the splitter island length.

The roadway approach and departure horizontal alignment directly affect the speed performance of the roundabout entry and exits. Speed transition needs to be established between the upstream roadway segments and the roundabout entry. An overall objective is to provide horizontal curvature commensurate with the anticipated vehicle speeds at that location.

Roadways with travel speeds of 45 mph (70 km/h) or higher away from the roundabout may need speed transitions leading to the roundabout entry. Transition and deceleration lengths will

Exhibit 10.49. Typical splitter island nose radii and offsets.



SOURCE: Adapted from *NCHRP Report 672* (*2*).

influence the roundabout's geometric influence area (i.e., the transition from the segment typical section). For approaches on roadways with speeds 45 mph (70 km/h) or higher, longer painted gores (the painted area between the roadway typical section and the splitter island) and longer splitter islands support speed transitions. Reverse curvature (i.e., a chicane) may be used to support speed transitions. Tangent sections must be used between reverse curves. Treatments for high-speed approaches are covered in Section 10.14.

10.6.4 Entry Design

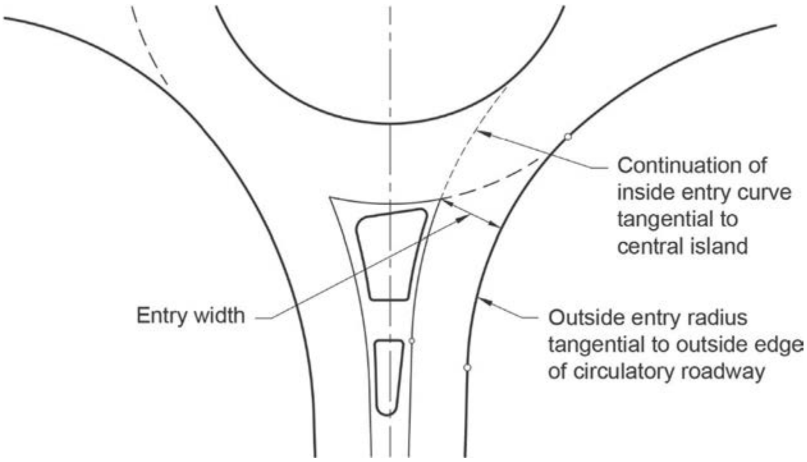
Roundabout entry design is founded on providing horizontal deflection that reduces vehicle speeds and provides curb radii and entry widths that meet design vehicle needs. Accommodating larger control or check vehicles requires considering the area outside the curb line and if there are special needs for landscaping, traffic furniture, signing, and truck aprons.

The roundabout entry is the area bounded by the curb or the edge of pavement consisting of one or more curves leading into the circulatory roadway. The roundabout entry is different from the entry path curve, which is defined by the fastest vehicular travel path through the entry geometry (measured by R_1). The entry curb radius, in conjunction with the entry width, the circulatory roadway width, and the central island geometry, controls the amount of deflection imposed on a vehicle's entry path.

Entry radii at urban single-lane roundabouts typically range from 50 ft to 100 ft (15 m to 30 m). A common starting point is an entry radius in the range of 60 ft to 90 ft (18 m to 27 m); however, a larger or smaller radius may be needed to accommodate large vehicles or serve small-diameter roundabouts, respectively. Curb radii greater than 100 ft (30 m) have a higher potential to produce faster entry speeds than desired but anecdotally may increase entry capacity under conditions with low conflicting flow rates. The entry curb radius can be reduced or increased as necessary in combination with the entry width and alignment to produce the desired entry path radius.

There are various ways to configure the roundabout entry. For each, the outside curb line of the entry is commonly designed curvilinearly tangential to the outside edge of the circulatory roadway. One method projects the inside (left) edge of the entry roadway curvilinearly tangential to the central island. This configuration promotes positive guidance and is often a starting point that may need to be adapted to serve the design vehicle. Exhibit 10.50 shows a typical single-lane roundabout entrance design with the continuation of the entry curve tangential to the central island.

Exhibit 10.50. Single-lane roundabout entry design with the entry curve tangential to the central island.



SOURCE: Adapted from *NCHRP Report 672* (*2*).

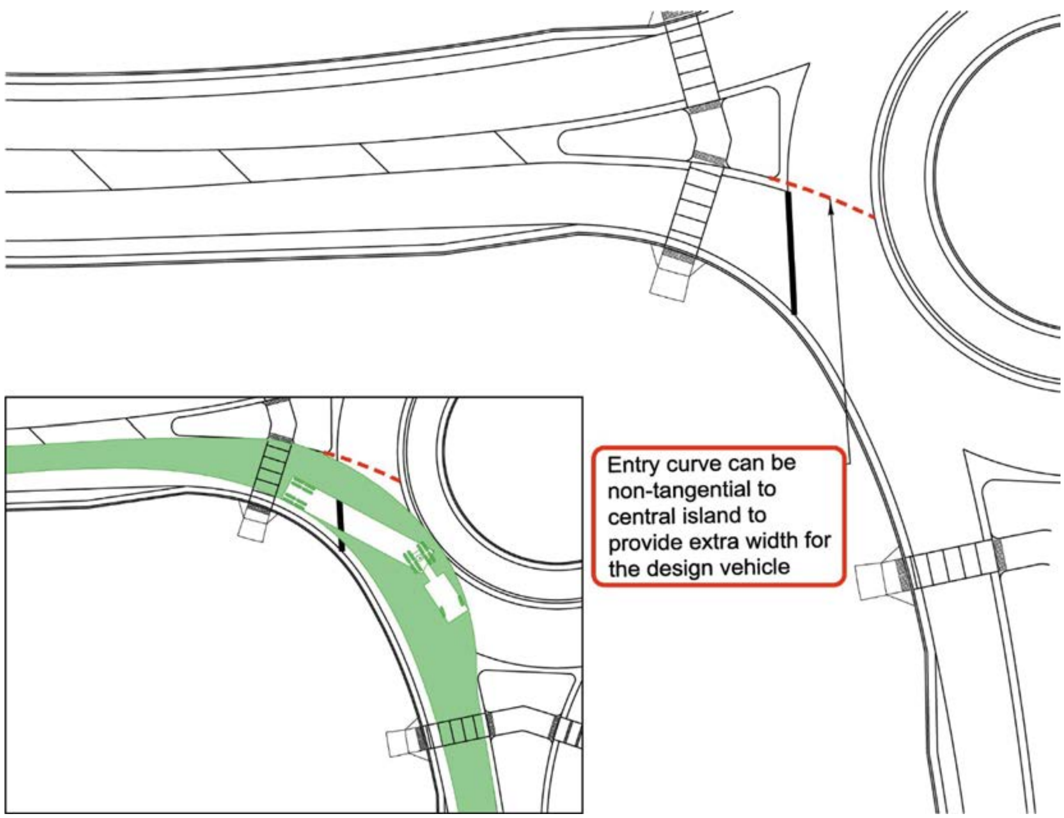
Exhibit 10.51 shows a typical single-lane roundabout entrance design with the entry curve tangential to the central island while having the edge of the splitter island cut back to serve large vehicles. This shows the projection of the left edge of the splitter island non-tangential to the central island. Drivers follow curbing, and this configuration diminishes the positive channelization of the splitter island as a means of serving right-turning large vehicles. However, this configuration could be a potential design approach in constrained site conditions.

The entry geometry needs to provide adequate horizontal curvature to channelize drivers into the circulatory roadway to the right of the central island. It is also often desirable for the splitter island to have enough curvature to block a direct path to the central island for approaching vehicles. This helps avoid vehicles errantly hitting the central island and further discourages drivers from making a wrong-way, left-turn maneuver.

Entry design is also based on attaining intersection and stopping sight distance and appropriate view angles. The view angle to the left must be adequate for entering drivers to comfortably view oncoming traffic from the immediate upstream entry or from the circulatory roadway. Chapter 9: Geometric Design Process and Performance Checks discusses these principles further.

Typical entry widths for single-lane entrances range from 14 ft to 18 ft (4.2 m to 5.5 m) at the ICD; these are often flared from upstream approach widths and to the circulatory roadway width. Entry width is measured from the point where the entrance line intersects the left edge of the traveled way to the right edge of the traveled way along a line perpendicular to the right curb line. Each entry width is commonly dictated by serving the design vehicle while meeting speed management and pedestrian crossing needs.

Exhibit 10.51. Single-lane roundabout entry design serving the design vehicle.



SOURCE: Adapted from Georgia Department of Transportation (*3*).

A nominal entry width of 15 ft (4.6 m) is a common starting value for a single-lane roundabout. Where entry widths are nominally greater than 18 ft (5.5 m) or wider than the circulatory roadway width, drivers may interpret the wide entry to be two lanes when there is only one receiving circulatory lane. If curb-to-curb widths must be that wide for design vehicles, pavement markings may help provide a narrower travel lane. Chapter 12: Traffic Control Devices and Applications discusses this further.

10.6.5 Exit Design

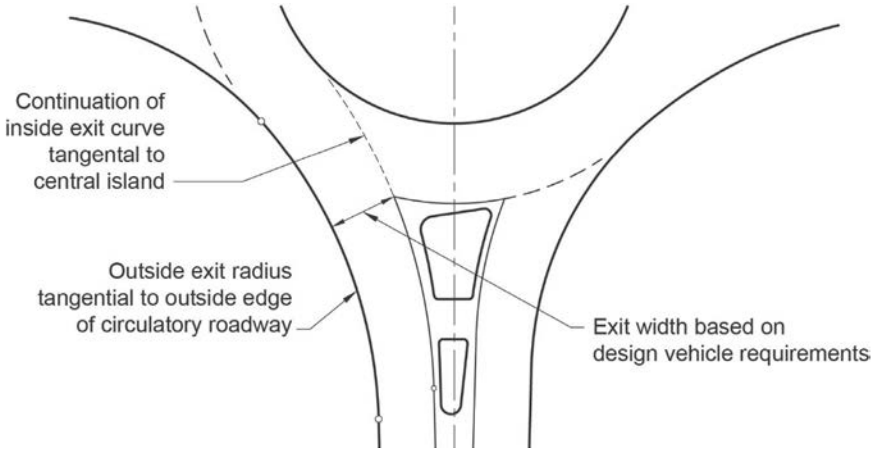
The exit curb radii are usually larger than the entry curb radii. The exit design is influenced by the design environment (i.e., land-use environment, context classification, and project type), pedestrian demand, design vehicle, and physical constraints. Each exit on a given roundabout needs to be customized to the project context and site-specific needs.

Generally, exit curb radii are to be no less than 100 ft (30 m), with common values ranging from 200 ft to 400 ft (60 m to 120 m). The exit curb is commonly designed to be curvilinearly tangential to the outside edge of the circulatory roadway. Likewise, the projection of the inside (left) edge of the exit roadway is commonly curvilinearly tangential to the central island and outside of the splitter island envelope that was established earlier.

Exit path radii are influenced by the exit curb radii. Exit widths and curbs need to accommodate the design vehicle paths within the curb lines. Slower exit speeds are preferable because higher exit speed configurations reduce yielding rates to pedestrians and increase the severity of pedestrian crashes. However, if adequate deflection is achieved at the entry and maintained in the circulatory roadway, resulting in lower circulating speeds, the exit geometry can use flatter curves or tangents.

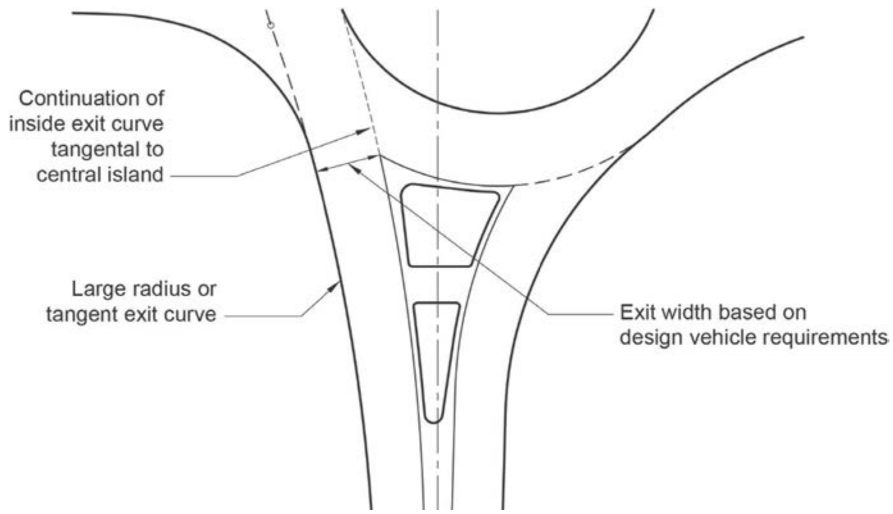
Single-lane exit curb-to-curb widths may range from 18 ft to 20 ft (5.5 m to 6 m) to serve design vehicles. The exit lanes taper in width from the ICD to the typical traffic lane widths downstream of the exit curb line radius. The exit curvature provides a natural location to begin the narrowing. This narrowing also corresponds to the decreasing width of a truck swept path as the trailer begins tracking directly behind the tractor. Exit lane transition widths are to be developed in conjunction with design vehicle checks and the transition from the ICD to the selected standard lane width based on serving the design vehicle swept path. A curvilinear exit configuration is illustrated in Exhibit 10.52.

Exhibit 10.52. Single-lane roundabout curvilinear exit design.



SOURCE: Adapted from *NCHRP Report 672* (*2*).

Exhibit 10.53. Single-lane roundabout large radius exit design.



SOURCE: Adapted from *NCHRP Report 672* (*2*).

Offset-left designs can result in tangent or near-tangent exits. For configurations using an offset-left approach alignment, the exit design may require much larger radii, ranging from 300 ft to 800 ft (90 m to 250 m) or greater. Larger exit radii may also be desirable in areas with high truck volumes to reduce the potential for trailers to track over the outside curb. Exhibit 10.53 presents an exit configuration with tangential or large exit radius qualities commonly associated with offset-left entry configurations.

Exhibit 10.54 presents the exit and entry of a roundabout with an offset-left entry. Of note is the curvature on the roadway approach to support the offset-left entry design. This configuration results in an exit configuration with a large radius or tangent alignment.

10.6.6 Circulatory Roadway Width

The circulatory roadway and central island design are directly influenced by the selected ICD and design vehicle. If the site is constrained and smaller ICD values are selected, the central island

Exhibit 10.54. Example of single-lane roundabout large radius exit design.

SOURCE: Georgia Department of Transportation.

may need fully traversable features, depending on the design vehicle. Roundabouts with fully traversable features in the central island (i.e., mini-roundabouts and compact forms) may be appropriate. Section 10.3.1 explains the variety of context considerations that affect these choices.

The required width of the circulatory roadway is determined from the design vehicle's turning requirements. Except opposite a right-turn-only lane, the circulating width is typically at least as wide as the maximum entry width. Typical circulatory roadway widths range from 16 ft to 20 ft (4.8 m to 6.1 m) for single-lane circulatory roadways. This width usually remains constant throughout the roundabout. Single-lane circulatory roadway widths greater than 20 ft (6.1 m) may lead drivers to assume two vehicles are allowed to circulate side by side.

The circulatory roadway width needs to be wide enough to accommodate a design vehicle up to a bus without using a truck apron. A truck apron will often need to be provided within the central island to accommodate larger design vehicles (including the WB-62 [WB-19] or WB-67 [WB-20] design vehicles) while maintaining a relatively narrow circulatory roadway to adequately constrain smaller vehicle speeds.

Section 10.5.2 discusses truck aprons further. Appropriate templates or a CAD-based computer program can determine the swept path of the design vehicle through each of the turning movements. Usually, the right-turn movement is the critical path for determining circulatory roadway width. This assumes truck drivers making a right turn will not drive their cabs onto the truck apron. In accordance with AASHTO policy, a minimum clearance of 1 ft (0.3 m) (preferably 2 ft [0.6 m]) is provided between the outside edge of the vehicle's tire track and the curb line to allow for variations in driver performance and truck dimensions.

10.6.7 Central Island Design

The central island is the area bounded by the circulatory roadway. It may include a non-traversable central area surrounded by a traversable truck apron. The central island shape of a single-lane roundabout typically matches the overall diameter or shape of the roundabout. The diameter of the central island depends on the ICD and the required circulatory roadway width. The resulting island is typically configured or includes features to enhance driver recognition of the roundabout upon approach.

Raised central islands for single-lane roundabouts are preferred over depressed central islands, as depressed central islands are more difficult for approaching drivers to recognize and may have drainage challenges. Central islands for mini-roundabouts and compact roundabouts may be fully traversable. Raindrop-shaped islands may be used where certain movements do not exist, such as service interchange ramp terminal intersections.

10.6.8 Mini-Roundabout and Compact Roundabout Design

Mini-roundabouts and some compact roundabouts have fully traversable central islands. The location and size of a mini-roundabout or compact roundabout's central island (and the corresponding width of the circulatory roadway) are dictated primarily by passenger car swept path requirements. The central island needs to allow all movements to be served at the intersection with counterclockwise circulation. Designing the central island size and location to provide deflection through the roundabout encourages proper circulation and reduced speeds through the intersection.

The central island may either be domed, which is common for mini-roundabouts, or it may be raised with a mountable curb and flat top for larger islands, which is common for compact roundabouts. More detail is provided in Chapter 11: Vertical Alignment and Cross-Section

Design. Flush central islands are generally discouraged to maximize driver compliance but may be used on roadways with speeds of 25 mph (40 km/h) or less and appropriate signs and pavement markings. Longer painted tapers, splitter islands, curbs, and other features (e.g., advance signing, pavement markings, reflecting delineators, or illumination) may be applicable in locations with approach speeds of 45 mph (70 km/h) and greater. Although fully traversable and relatively small, the central island needs to be clear and conspicuous. Islands with a mountable curb are to be designed similarly to truck aprons at other roundabouts.

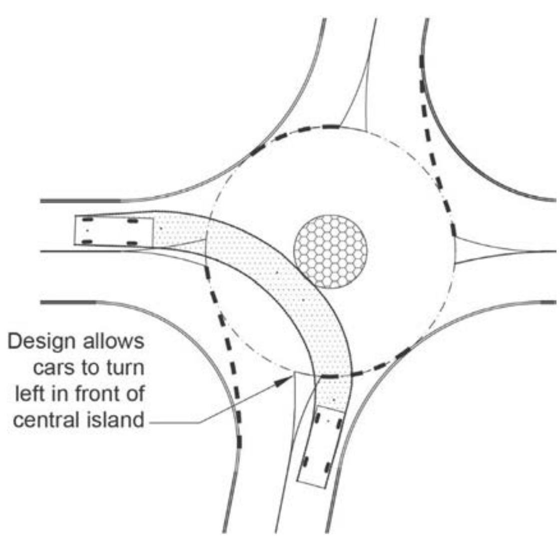
The central island size and location of the entrance line affect mini-roundabout design. Placing the entrance line at the outer edge of the inscribed circle diameter, which is common practice for single-lane and multilane roundabouts, allows for a larger central island. However, this may promote left turns in front of the central island.

Exhibit 10.55 illustrates an undesirable configuration that allows passenger cars to turn left in front of the central island. This may be aggravated by the intersection skew angle, small central island, small splitter islands, and relatively large circulatory roadway width. Possible design improvements are illustrated in Exhibit 10.56 and Exhibit 10.57. These include simultaneously enlarging the central island, reducing the circulatory roadway width, and advancing the entrance line forward (in effect, reducing the ICD).

Another option for reducing left turns in front of the central island is enlarging the ICD. Enlarging the ICD allows for a larger turning radius for the design vehicle, which also reduces the width of the vehicle swept path. This allows for a larger central island and narrower circulatory roadway. The larger ICD promotes the counterclockwise travel path around the central island. The larger ICD may require moving curb lines to create the larger roundabout.

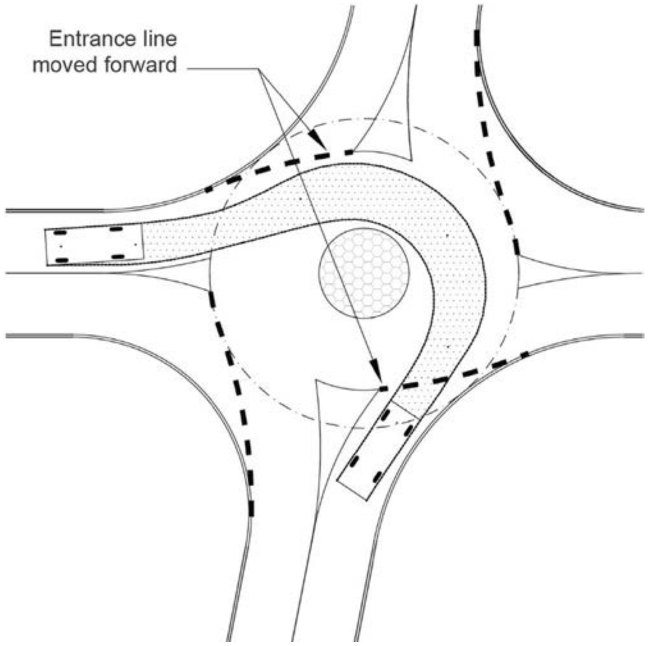
If this is possible, the central island could be developed with mountable (i.e., rolled, chamfered, or rounded top corner) curb and a raised flat central island. **As the mini-roundabout's size increases from within the curb line, the roundabout moves along the design continuum toward a compact design.** Exhibit 10.58 depicts a mini-roundabout with the outside curb line shifted outward.

Exhibit 10.55. Undesirable mini-roundabout configuration that promotes improper left turns.



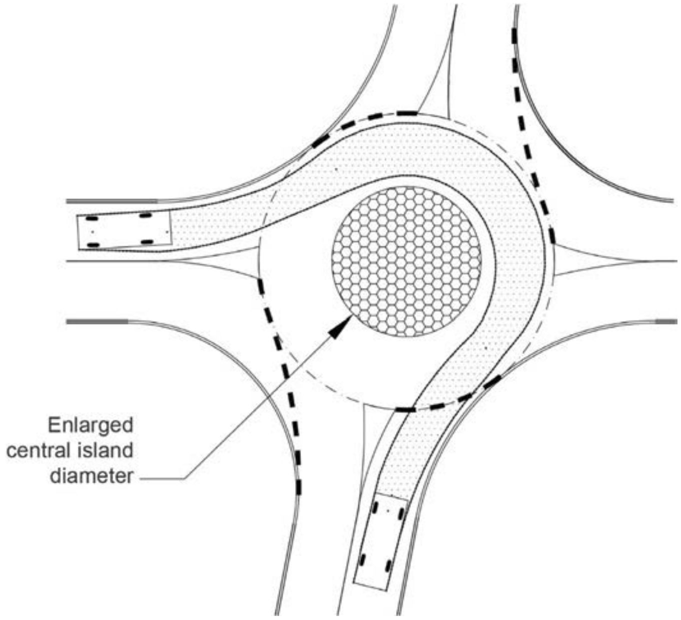
SOURCE: Adapted from *NCHRP Report 672* (*2*).

Exhibit 10.56. Mini-roundabout treatment of moving entrance line forward to discourage improper left turns.



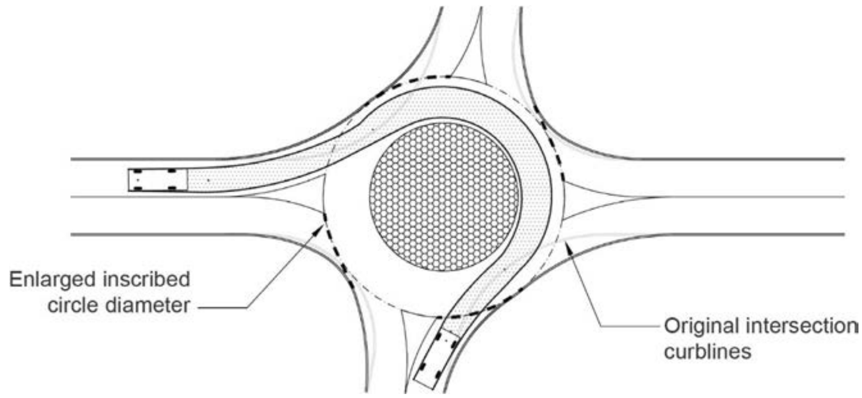
SOURCE: Adapted from *NCHRP Report 672* (*2*).

Exhibit 10.57. Mini-roundabout treatment of enlarged central island diameter to discourage improper left turns.



SOURCE: Adapted from *NCHRP Report 672* (*2*).

Exhibit 10.58. Mini-roundabout treatment of larger inscribed circle diameter to discourage improper left turns.



SOURCE: Adapted from *NCHRP Report 672* (*2*).

10.7 Multilane Roundabouts

Multilane roundabouts carry many of the same design attributes as single-lane roundabouts but introduce new aspects that complicate the design process. Multilane roundabouts include at least two circulating lanes in at least a portion of the circulatory roadway. They include roundabouts with entries on one or more approaches that flare from one to two or more lanes that circulate through the roundabout. In some cases, the roundabout may have a different number of lanes on one or more approaches (e.g., two-lane entries on the major street and one-lane entries on the minor street).

Multilane roundabouts introduce several design concepts that are not present with single-lane roundabouts:

- **Lane assignments in multilane sections.** Multilane roundabouts are multilane intersections with a central island. Because of this, the desired design establishes correct lane assignments for drivers **in advance** of the intersection and then facilitates those movements through the intersection without requiring drivers to change lanes. This requires attention to signs and pavement markings to communicate and facilitate the desired movements in advance of the roundabout and throughout each movement's passage through the roundabout.
- **Horizontal geometry that supports specific lane assignments.** This includes aligning vehicles at the entrance line into the correct lane within the circulatory roadway, positioning lanes within the circulatory roadway to facilitate smooth movements (including spiraling as needed, as discussed in Section 10.7.7), and minimizing the likelihood of drivers straying from their intended lane while circulating and exiting.
- **Continued attention to performance objectives.** The larger and more complex multilane footprint makes each performance objective more challenging to meet. These performance objectives, discussed in detail in Chapter 9: Geometric Design Process and Performance Checks, include
  - Geometric speed control with wider entries, exits, and circulatory roadway;
  - Truck circulation using the intended method (straddling lanes versus staying in-lane);
  - Path alignment for each lane through the roundabout; and
  - Providing the necessary measures to make bicycle and pedestrian crossings across multilane sections accessible to all users.

Each of these concepts requires strategic layout consideration as well as attention to design details that facilitate the intended strategy. Single-lane roundabout design principles and processes set the foundation for multilane roundabout design. However, multilane operations having vehicles adjacent to each other while approaching, navigating, and exiting a roundabout creates new complexities and risks that must be addressed in special design treatments and configurations.

In general, the size of the roundabout is influenced by the number and assignment of lanes, strategy for truck accommodations (straddling lanes versus staying in-lane), and site context. Size is also a byproduct of achieving target performance metrics. This often occurs by balancing the need to achieve geometric speed control with providing adequate space for trucks, intended lane discipline, and path alignment. Typically, achieving the performance objectives requires a larger diameter than that of a single-lane roundabout. As such, there is no single answer to the question: "What is the best ICD for a multilane roundabout?" Further discussion is provided in Section 10.7.5 for straddle-lane design and Section 10.7.6 for stay-in-lane design.

Multilane roundabout performance begins with appropriate geometric design paired with complementary and supporting traffic control devices. Multilane roundabout design tends to be less forgiving than single-lane roundabout design, with the potential for more frequent property damage crashes if the principles in this section are overlooked. Research for an FHWA Pooled Fund Study (*26*) has found the most common property damage crashes at some multilane roundabouts include

- Drivers in the outside entry lane failing to yield to a driver circulating in the inside lane,
- Drivers making left turns from the incorrect outside lane, and
- Drivers making right turns from the incorrect inside lane.

These crash patterns are influenced by a combination of geometry and traffic control devices (principally signs and pavement markings) and driver behavior. Other patterns commonly observed at multilane roundabouts are passenger car drivers straddling lanes and changing lanes through the entry or (especially) the exit.

For multilane roundabouts, the entry geometry is typically established first to identify a design that adequately controls entry speeds, provides appropriate path alignment, and accommodates the design vehicle. The splitter island is then developed in conjunction with the exit design to provide adequate median width for the pedestrian refuge and sign placement. The size and shape of the splitter island forming the left side of the entry, for example, helps with motor vehicle alignment at entry. The design also plays a critical role in providing for two-stage pedestrian crossings, with sufficient room in the splitter island where people may pause while crossing.

Many splitter island design aspects discussed for single-lane roundabouts also apply to multilane designs. However, because active traffic control devices are more common at multilane crossings to provide accessibility for all pedestrians, it is more common for multilane crossings to be designed to operate with two crossing stages. Section 10.4 discusses pedestrian and bicycle crossings further.

Single-lane roundabouts have some design elements (such as central islands and approach treatments) that apply to multilane roundabouts and are not described again in this section. Many aspects of single-lane roundabout design and general performance objectives also apply to multilane roundabout planning and design. However, single-lane roundabout design techniques may be problematic if applied to a multilane configuration.

10.7.1 Determining the Appropriate Lane Configuration

Determining the appropriate lane configuration for a roundabout is based on two interdependent aspects:

- The lane configuration needs of the roundabout itself to serve each mode.
- The roundabout's interaction with the surrounding roadway network.

In general, it is best that a roundabout (like any intersection) have as few lanes as possible while still achieving the desired performance. Providing additional lanes that are not needed for capacity purposes increases crash risk by increasing the number of conflict points. If additional lanes are needed for future conditions, practitioners can consider a phased design approach to allow for future expansion when conditions warrant, rather than initially overbuilding a roundabout and reducing safety performance. This is discussed further in Section 10.8.

A detailed study of field operations at a series of multilane roundabouts in the United States found that at some multilane roundabouts with a history of property damage crashes, turning movements from the incorrect lane were common contributors to erratic maneuvers, conflicts, and near-crashes (as seen in video observation) (*26*). These included improper left turns from the right entry lane and improper right turns from the left entry lane for entries with a typical shared left-through, shared through-right configuration. Among potential causes of improper turns, the study identified several that are system-related and became more prominent under heavier peak period conditions, including

- Closely spaced intersections that preclude lane changes between intersections.
- Upstream signals that release drivers in platoons, making it difficult for drivers to select the correct lane prior to entering the roundabout.
- Upstream origins or downstream destinations close to the roundabout. For close upstream origins, drivers would change lanes once they perceived the best opportunity, which was often while circulating or exiting. For close downstream destinations, drivers would either position themselves for the downstream destination before entering the roundabout and make an incorrect turning movement, or they would change lanes within the roundabout or while exiting to position for the downstream turning movement.

These system effects require considering more than the isolated operational analysis of the roundabout. In some cases, reducing the number of lanes may be the best option for mitigating these patterns, rather than relying solely on lane-use restrictions within the roundabout (e.g., with raised lane dividers), which may simply shift lane changing upstream or downstream of the roundabout.

10.7.2 Designing for the Needed Lane Configuration

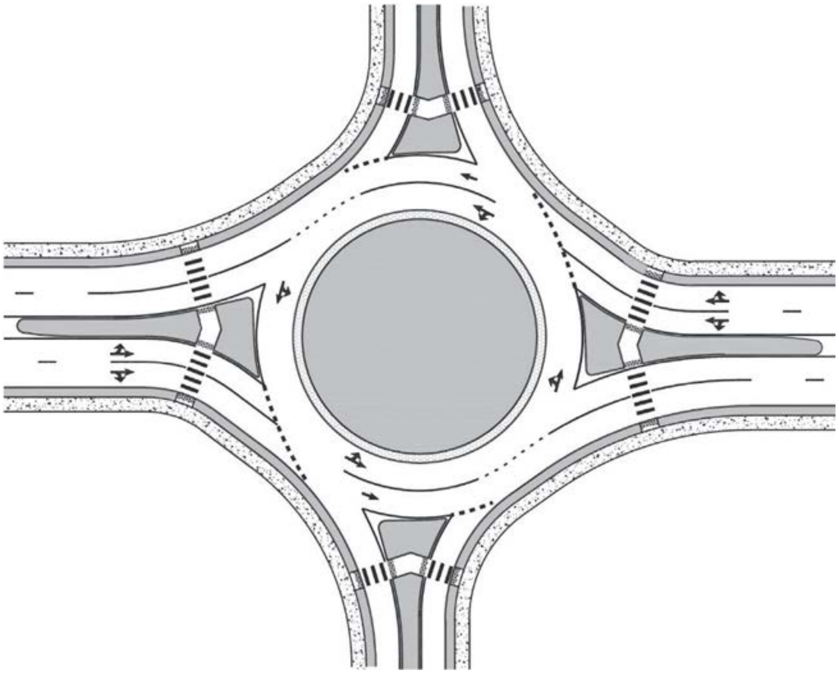
Because the lane configuration needed for each entry or exit may be different, it is often preferred to adjust the number of circulating and exiting lanes to match the needed entry lane configuration. As a result, the circulatory roadway width may vary throughout the roundabout based on the number of needed lanes.

This concept is illustrated with two examples. In the first example, shown in Exhibit 10.59, two through lanes are needed on the major street, with left-turn and right-turn movements operating as shared lanes with the through movements. Both minor approaches in this example need one lane to function acceptably. This is a common multilane roundabout configuration and is sometimes referred to as a *hybrid* or *2 × 1 (two-by-one)* roundabout.

When additional lanes are needed for turning movements, practitioners need to adjust the lane configuration throughout the roundabout to match. A complex example is shown in Exhibit 10.60, as two intersecting roadways each have heavy left-turn movements needing double left-turn lanes. To support this without requiring lane changes within the roundabout, an extra circulating lane in one quadrant and a circulating lane alignment that spirals to the outside is needed to enable all vehicles to reach their intended exits without changing lanes. The alignment of these spirals requires careful attention to geometric detail and is discussed further in Section 10.7.7.

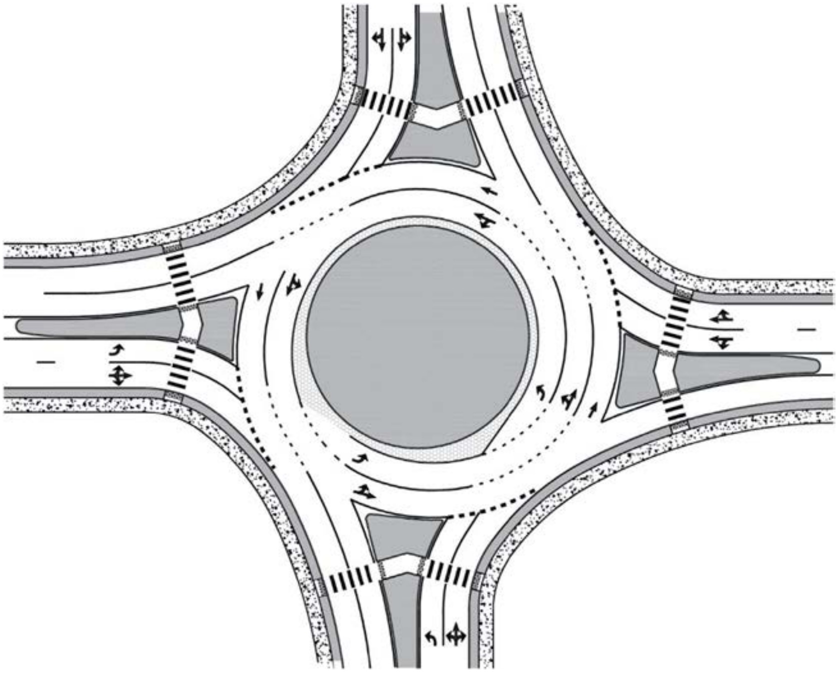
A roundabout can provide capacity by adding and dropping lanes before and after the roundabout. Exhibit 10.61 illustrates an example.

Exhibit 10.59. Multilane major street with single lane on minor street.



SOURCE: Adapted from *NCHRP Report 672* (*2*).

Exhibit 10.60. Two-lane roundabout with consecutive double-left turn movements.



SOURCE: Adapted from *NCHRP Report 672* (*2*).

Exhibit 10.61. Example of adding and dropping a lane upstream and downstream of a roundabout.

LOCATION: County Road G/Monroe Road, De Pere, Wisconsin.
SOURCE: Google Earth.

10.7.3 Managing Separation Between Legs

Separation between adjacent legs that creates sufficient distance resulting in circulating traffic merging and then diverging at the exits can increase crash risk. Roundabout entries need to be configured so that entering and circulating vehicles cross, rather than merge and diverge. At roundabouts where the design favors merging and diverging, research has found that drivers in the outside entering lane are less likely to yield to circulating traffic, which commonly results in an exit-circulating conflict downstream (*11*). This can occur in several situations:

- Roundabouts with an angle between two legs that is significantly greater than 90 degrees.
- Roundabouts at or near 90-degree angles between legs but with a large enough ICD to create a segment of circulatory roadway between legs.

Separations between legs have been shown to reduce the likelihood of drivers yielding to all circulating vehicles in front of the subject entry. Drivers in the outside lane may not perceive a conflict with traffic that is exiting at the next leg. As such, drivers in the outside lane enter the roundabout next to circulating traffic in the inside lane. This can create conflicts at the exit point between exiting and circulating vehicles (an **exit-circulating conflict**), as shown in Exhibit 10.62.

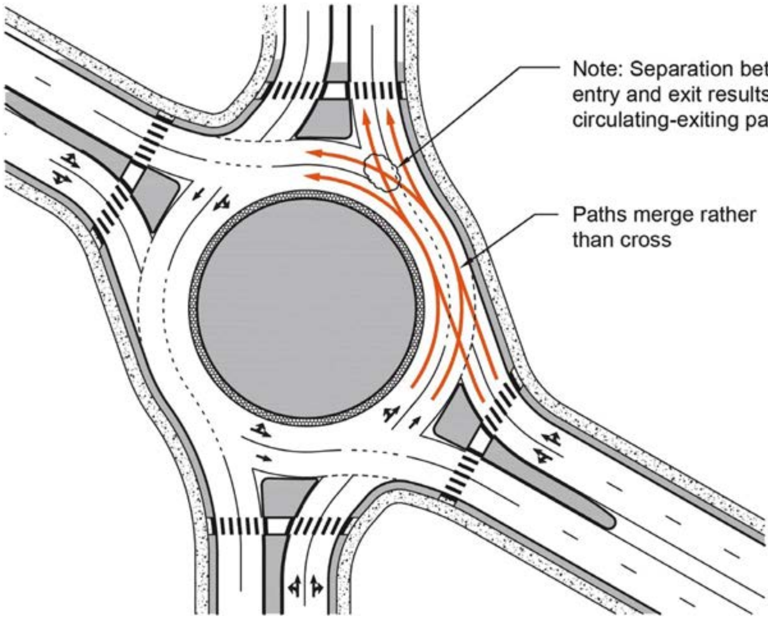
An overly large ICD can result in separation and create a pattern of exit-circulating crashes. Exhibit 10.63 shows an example of a multilane roundabout with an overly large ICD that results in a segment of circulatory roadway between legs. In addition, from the circulating driver's perspective, the exiting alignment of reverse curve with no tangent directly contributes to drivers naturally crossing the lane line while exiting. This concept, called *path alignment,* is discussed next.

Exhibit 10.64 illustrates an operational means of addressing the exit-circulating conflict by adjusting the lane configuration. This could be a possible low-cost design configuration that addresses the issue, but it may come at the expense of traffic operational performance. This may be an acceptable trade-off for a given site and context where exit-circulating crashes are documented. If the changes in traffic operations and safety performance of this configuration are not acceptable for the site and context, it may be necessary to realign the approach to minimize the segment of circulatory roadway between legs, as illustrated in Exhibit 10.65.

10.7.4 Vehicle Path Alignment

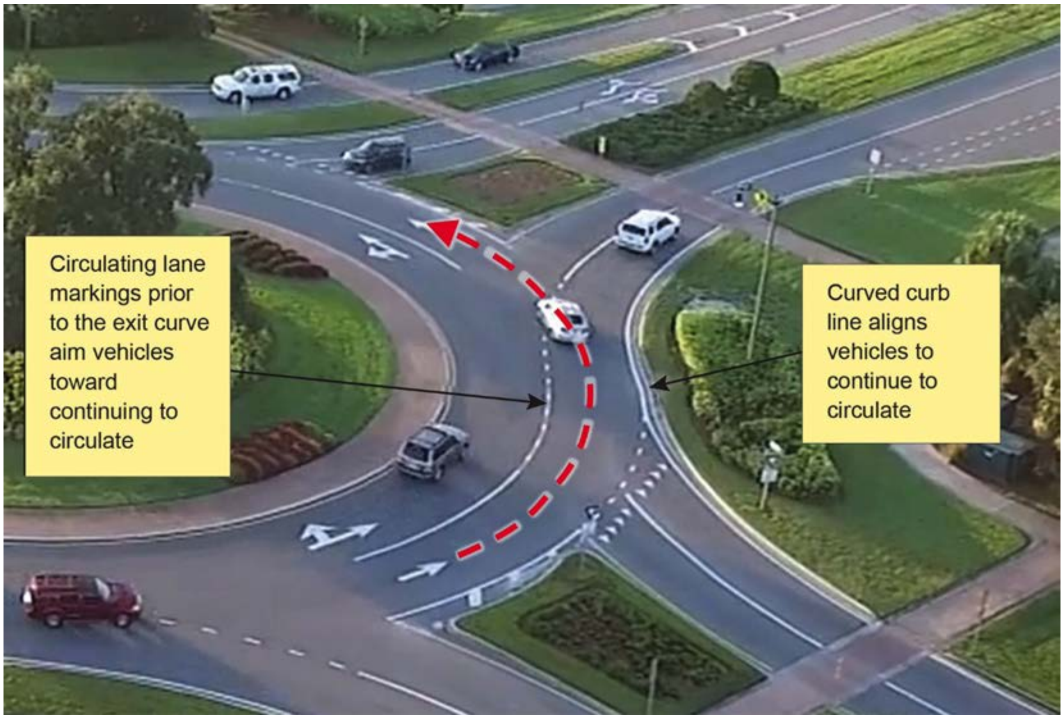
Multilane design focuses on aligning entering vehicles into the appropriate lane within the circulatory roadway and aligning exiting vehicles into the appropriate lane when exiting. These

Exhibit 10.62. Exit-circulating conflict caused by large angle between legs.



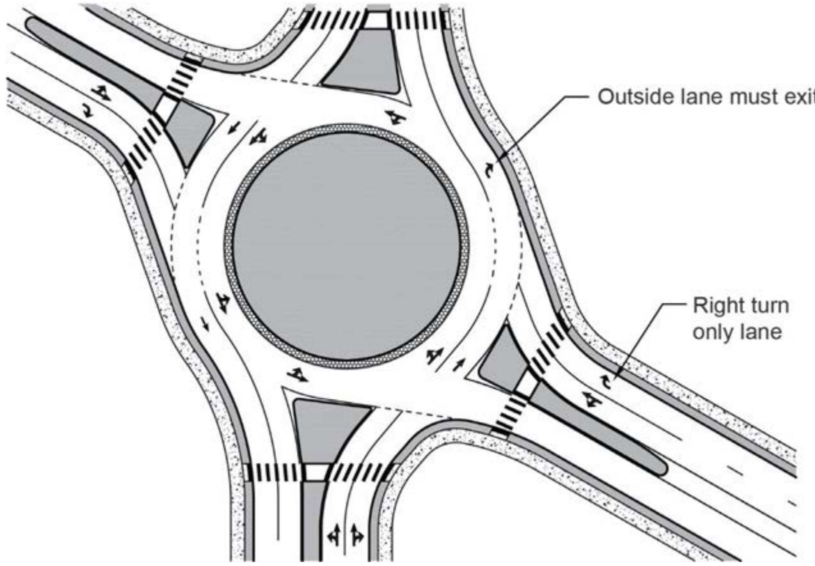
SOURCE: Adapted from Tian et al. and *NCHRP Report 672* (*27*, *2*).

Exhibit 10.63. Exit-circulating conflict caused by large inscribed circle diameter.



SOURCE: Medina et al. (*26*).

Exhibit 10.64. Possible lane configuration modifications to resolve exit-circulating conflicts.

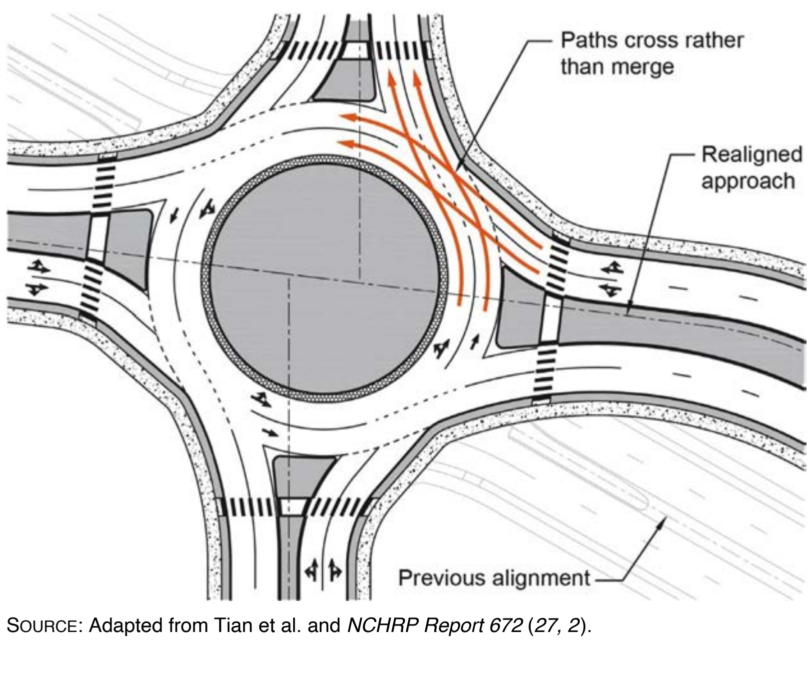


SOURCE: Adapted from Tian et al. and *NCHRP Report 672* (*27, 2*).

alignment considerations often compete with geometric speed objectives, but both are important: geometric speed objectives affect crash severity, while path alignment objectives directly address common property damage crashes. There are many ways to balance geometric speed control and path alignment, and these vary by site-specific conditions, project type, and project content and objectives. Because of this, no single technique will always work for a given context and location.

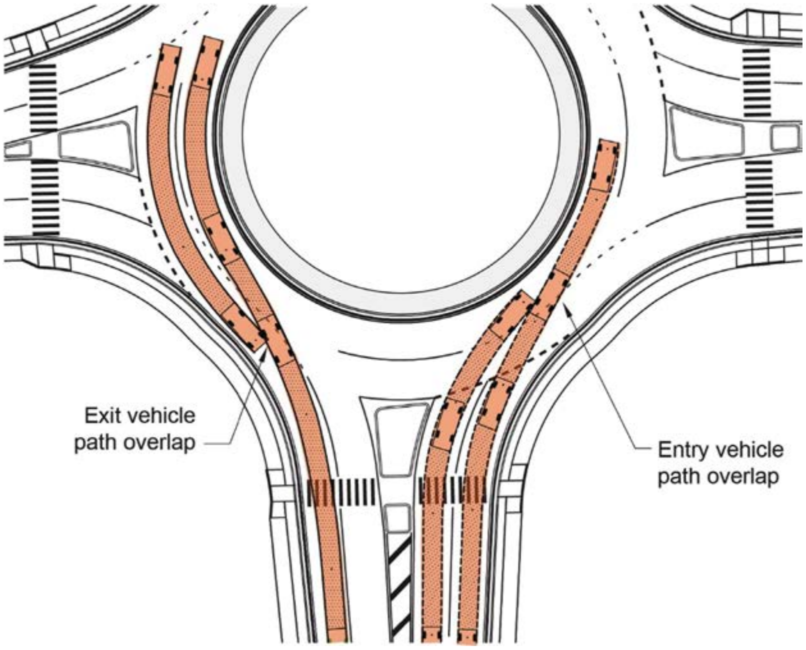
As discussed in Chapter 9: Geometric Design Process and Performance Checks, if proper vehicle path alignment is not attained, the paths of side-by-side entering, circulating, or exiting

Exhibit 10.65. Realignment to resolve exit-circulating conflicts.



SOURCE: Adapted from Tian et al. and *NCHRP Report 672* (*27, 2*).

Exhibit 10.66. Examples of poor path alignment.



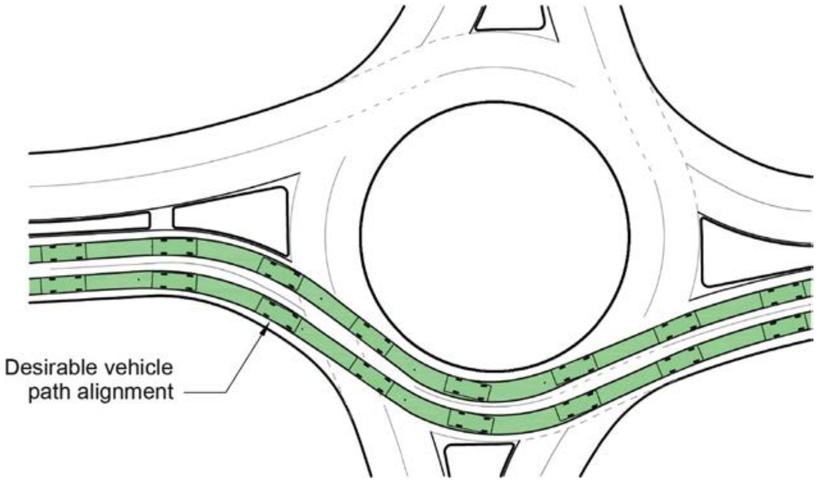
SOURCE: Adapted from *NCHRP Report 672* (*2*).

vehicles may overlap. A common case occurs at entries where the geometry of the right (outside) lane tends to lead vehicles into the left (inside) circulatory lane. Research for an FHWA Pooled Fund Study found that path alignment problems were common on exit and were either caused by poor geometry (the geometry tends to lead vehicles from the left-hand circulating lane into the right-hand exit lane) or by drivers changing lanes in preparation for a downstream turning movement (*26*). Exhibit 10.66 illustrates examples of path alignments that create path overlap.

The desired result of the entry design is for vehicles to be aligned into their correct lane within the circulatory roadway, as illustrated in Exhibit 10.67.

The techniques to address these challenges are best implemented early in the design process, given the strategic nature of design decisions that may affect the viability of an alternative.

Exhibit 10.67. Desirable vehicle path alignment.



SOURCE: Adapted from *NCHRP Report 672* (*2*).

Techniques for addressing path alignment vary depending on truck treatments and are discussed in the following sections.

10.7.5 Principles and Techniques for Straddle-Lane Design

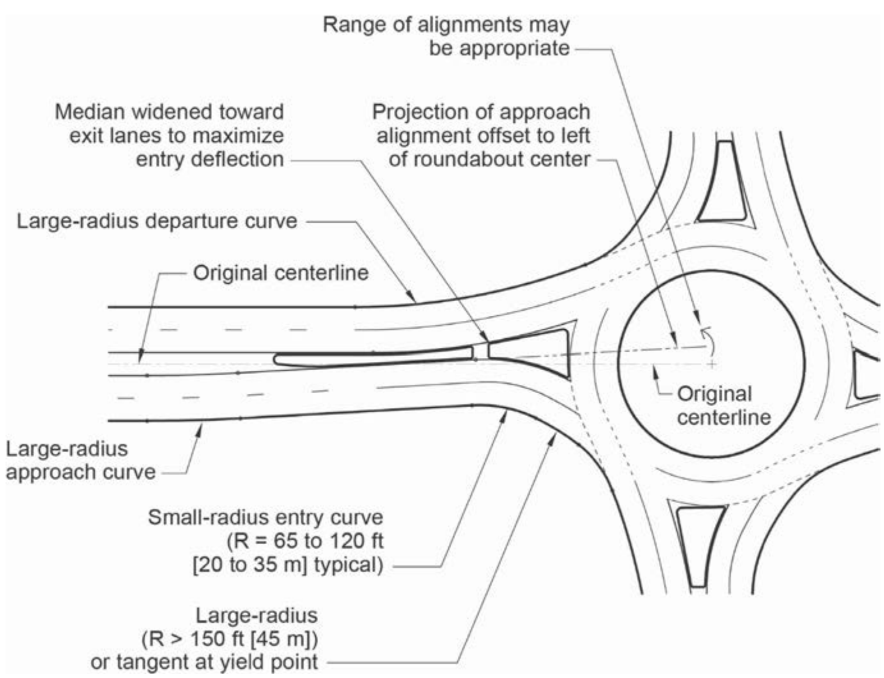
By definition, a straddle-lane design has trucks occupying more than one lane as needed when entering, circulating, and exiting. Passenger cars, however, form most of the motor vehicle stream, and multilane roundabouts need to be designed to maintain lane discipline by using target path alignment, as discussed in Chapter 9: Geometric Design Process and Performance Checks. As such, path alignment, along with the associated objective of acceptable view angles (also discussed in Chapter 9), are objectives for straddle-lane designs that require additional attention to detail beyond single-lane design. These two objectives are related:

- Each entering vehicle in each lane needs to be aligned with its receiving lane (path alignment).
- Each entering vehicle needs an alignment that provides a clear line of sight toward conflicting vehicles (view angle).

These two objectives require that vehicles be staggered at the entrance line so that vehicles in the outside lane can see in front of the vehicle in the adjacent lane to the left. There are many possible techniques to achieve good path alignment and view angles, and practitioners need to adapt them to the specific geometry and constraints of the roundabout under consideration. **Regardless of the technique, performance checks presented in Chapter 9 are necessary to confirm that each objective is met.**

Exhibit 10.68 shows a possible method to attain desired path alignment using a compound curve or tangent along the outside curb. The design consists of an initial small-radius entry curve set back from the edge of the circulatory roadway. A short section of a large radius curve or tangent is provided between the entry curve and the circulatory roadway to align vehicles into

Exhibit 10.68. Approach offset to increase entry deflection.



SOURCE: Adapted from *NCHRP Report 672* (*2*).

the proper circulatory lane at the entrance line. Finding the location of the entry curve from the entrance line is an iterative process. If it is located too close to the circulatory roadway, the entry may have path alignment issues. However, if the entry curve is located too far away from the circulatory roadway, it can result in inadequate geometric speed control.

For the method illustrated in Exhibit 10.68, entry curve radii commonly range from approximately 65 ft to 120 ft (20 m to 35 m) and are set back at least 20 ft (6 m) from the edge of the circulatory roadway. A tangent or large radius curve (greater than 150 ft [45 m]) is then fitted between the entry curve and the outside edge of the circulatory roadway.

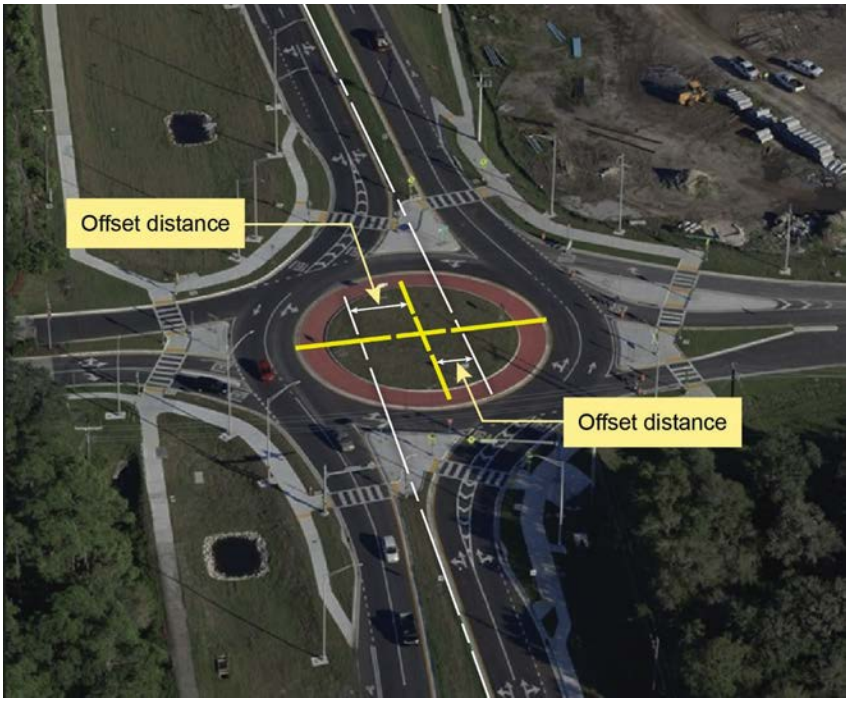
Exhibit 10.69 is an example of this method at a roundabout in Florida.

An alternative method for designing the entry curves to a multilane roundabout is to use a single radius entry curve rather than a small curve and tangent. In some ways, this is like a single-lane design; however, larger radii are typically required to provide adequate vehicle alignment. A single-entry curve configuration often helps with geometric speed control but may result in poor path alignment.

If the circulatory roadway is sufficiently wide relative to the entry, entry curves can be designed tangential to a design circle offset 5 ft (1.5 m) from the central island. This improves the curvature and deflection achieved on the inside (splitter island) edge of the entry. Regardless of the method, it is desirable for the inside (splitter island) curb to block the through path of the left lane to promote adequate deflection.

Achieving adequate geometric speed control on entry and meeting design objectives are independent of the control line (i.e., centerline or profile grade line) of the approaching roadways. The centerlines of approach roadways do not need to pass through the center of the inscribed

Exhibit 10.69. Example of approach offset.



LOCATION: SR 64/Greyhawk Boulevard/Pope Road, Manatee County, Florida.
SOURCE: Kinard and Stone.

circle. It is common design practice for multilane roundabouts to have an offset-left alignment. This may provide a useful method for achieving speed control and path alignment.

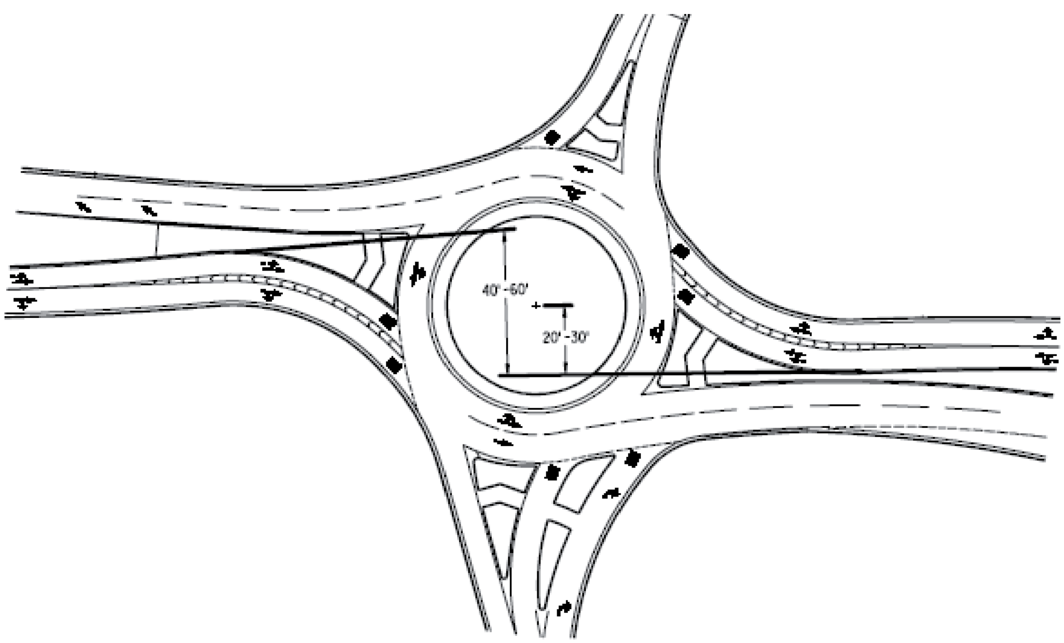
Exhibit 10.70 illustrates a design technique to enhance geometric speed control on the entry by shifting the approach alignment toward the left of the roundabout center. This technique can effectively increase entry geometric speed control; however, it is often at the expense of geometric speed control on the exit of the same leg.

The radii of exit curves are commonly larger than those at the entry because of factors such as entry alignment, diameter, and design vehicle tracking. Larger exit curve radii typically promote desired vehicle exit path alignment. The need to serve each of these elements often requires additional treatments beyond horizontal geometry to make the pedestrian crossing at the exit accessible to all pedestrians. These crossing treatments are discussed further in Section 10.4.5.

The exit side is perhaps more critical for path alignment, given that drivers may travel at faster speeds than at the entry. A tangent or large radius arc helps connect the circulatory roadway to the exit (see Exhibit 10.71). This reduces the likelihood of drivers drifting out of their lane when exiting, and it reduces the tendency of drivers continuing to circulate (i.e., making an improper left turn from the outer entry lane) rather than exiting from the outside lane. **This technique also promotes visibility of the entire crosswalk and associated traffic control devices on the exit, recognizing that it does not inherently provide geometric speed control.**

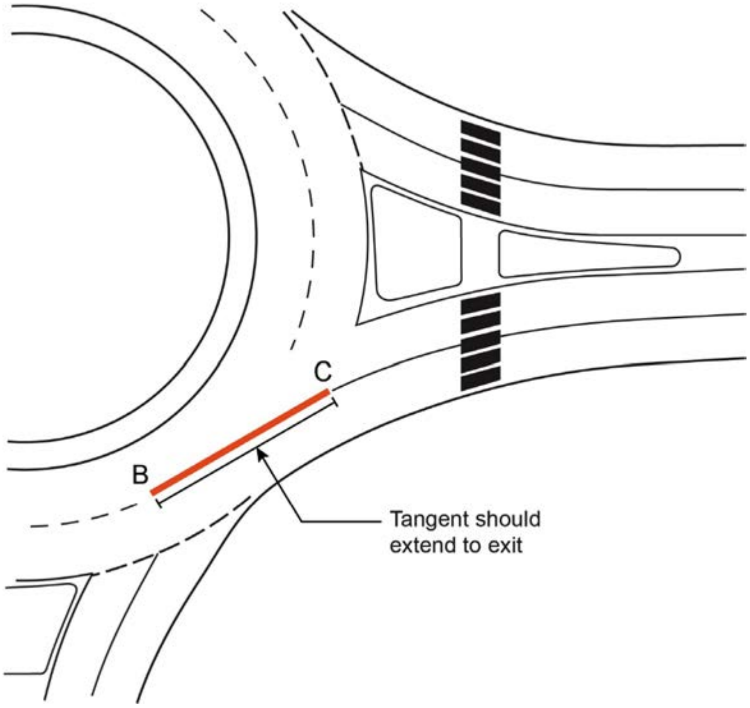
Some states have used a hybrid approach in which trucks share space between entry lanes under the presumption that trucks will not travel side by side (formerly known as Case 2 design). This shared space is often marked using a gore-striping technique sometimes used at freeway exit ramps, consisting of two white lines and chevrons between the lanes. Exhibit 10.72 illustrates this technique. The actual dimensions may vary depending on the individual design. For example, the New York State Department of Transportation has used two entry lanes that are 12 ft (3.6 m) wide and a gore area that is 6 ft (1.8 m) wide for a total width of 30 ft (9 m) (*29*).

Exhibit 10.70. Example of major approach offset.



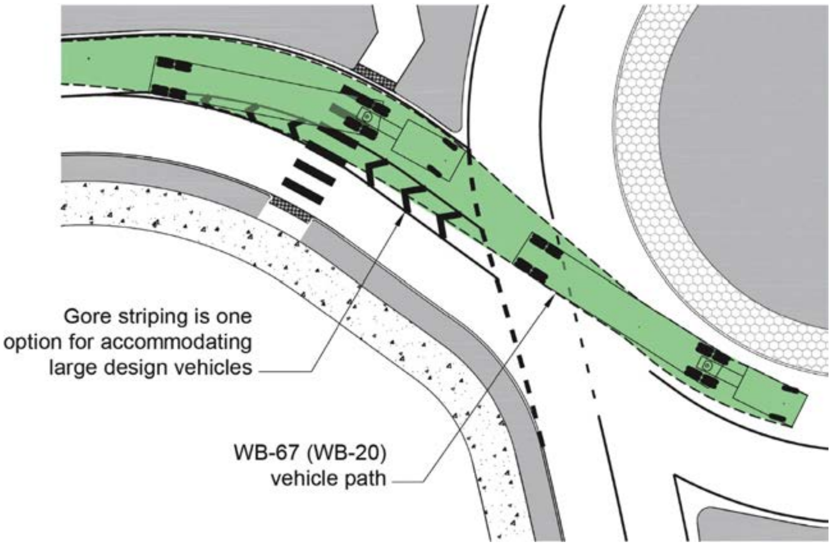
SOURCE: Wisconsin Department of Transportation and *NCHRP Report 672* (*28, 2*).

Exhibit 10.71. Exit vehicle path alignment.



SOURCE: Adapted from Wisconsin Department of Transportation (*28*).

Exhibit 10.72. WB-67 (WB-20) truck path with gore striping at entry.



SOURCE: Adapted from McCulloch and *NCHRP Report 672* (*29, 2*).

This technique does not represent true stay-in-lane operation because it requires truck drivers to understand three concepts:

- They must drive on the gore area to complete their movements.
- Only one truck can use the gore area at a time.
- In the circulatory roadway, the truck may have to straddle lanes.

Research conducted for this Guide suggests that this type of design is not universally understood by truck drivers (*30*). Truck drivers often occupy both lanes beyond the extent of the gore striping. **As such, this Guide advises designing for trucks straddling lanes as the default for most situations.**

The required entry width for a straddle-lane design depends on the number of lanes and the design vehicle. A typical entry width where trucks straddle lanes ranges from 24 ft to 30 ft (7.3 m to 9.1 m) for a two-lane entry and from 36 ft to 45 ft (11.0 m to 13.7 m) for a three-lane entry. Typical widths for individual lanes at each entry range from 12 ft to 15 ft (3.7 m to 4.6 m). It may be beneficial to retain the ability for smaller large vehicles (e.g., buses) to stay in-lane and allow side-by-side circulation with passenger cars.

Multilane circulatory roadway lanes in a straddle-lane design are commonly 14 ft to 16 ft (4.3 m to 4.9 m) wide. Using these values results in a total circulating width of 28 ft to 32 ft (8.5 m to 9.8 m) for a two-lane circulatory roadway segment and 42 ft to 48 ft (12.8 m to 14.6 m) total width for a three-lane circulatory roadway segment. The circulatory roadway width is usually governed by the types of vehicles that may need to be accommodated adjacent to one another through a multilane roundabout. For straddle-lane design, vehicles smaller than the design vehicle will form most of the traffic within the circulatory roadway.

If the entering traffic is predominantly passenger cars and single-unit trucks (AASHTO P and SU design vehicles, respectively) and semi-trailer traffic (e.g., WB-40 and larger) is infrequent, it may be appropriate to design the width for two P vehicles or a P and an SU truck side by side. If semi-trailer truck traffic is relatively frequent, it may be preferable to provide sufficient width for the simultaneous passage of a semi-trailer truck in combination with a P or SU vehicle. There is no available research on the quantity of truck traffic to define "relatively frequent."

10.7.6 Techniques for Designing for Trucks Staying In-Lane

For a roundabout that intends for trucks to stay in their own lane, several design considerations come into play. For stay-in-lane design, a larger ICD, larger entry and exit radii, and wider lanes may be required to accommodate the design vehicle while working to meet other performance objectives. However, these objectives conflict with one another. For example, larger entry and exit radii needed for truck movement make geometric speed control more difficult, as do the larger lane widths needed for truck tracking.

The circulatory roadway in stay-in-lane design commonly has a narrower inside lane—where trucks can also use the truck apron—and a wider outside lane—where trucks are unable to use the apron. Exact widths depend on the ICD, the specific design vehicle being served, and other site-specific factors. In general, the outside lane will be narrower with larger ICDs and wider with smaller ICDs because of the associated off-tracking of truck trailers. Some agencies have used striping to reduce the apparent width of the outside lane. The combination of vehicle types to be accommodated side by side depends on the specific site traffic conditions, and requirements for side-by-side design vehicles are to be established and documented in early project planning.

10.7.7 Spiraling in Multilane Roundabouts

A spiral is a circulating lane alignment needed for some multilane roundabout configurations. Spirals are common for straddle-lane designs with certain lane configurations and are an integral part of stay-in-lane designs. Spirals are commonly needed in the following situations:

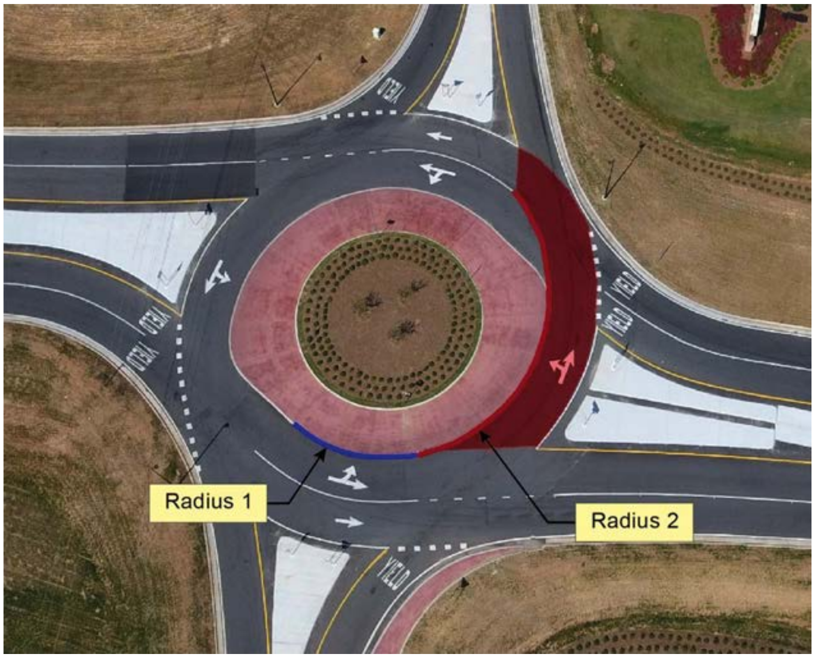
- Where one or more entries require exclusive left-turn lanes.
- Where a combination of entering and exiting lanes requires a spiral to maintain lane continuity.
- Where a circulating driver must shift to the outside lane when transitioning from single-lane to multilane portions of the circulatory roadway.
- At a 2 × 1 multilane design and similar configurations to improve the likelihood of entering drivers in the outside lane yielding at entry.

Exhibit 10.73 illustrates a 2 × 1 multilane roundabout with spirals. In the exhibit, Radius 1 is the original circle radius, and Radius 2 provides the spiral. The combination of Radius 1 and Radius 2 is a compound curve, not a true spiral with a continuously variable radius. However, when Radius 1 and Radius 2 are sufficiently similar, the net effect is to create a smooth path to help circulating drivers shift to the outside circulating lane and to reduce the likelihood of entering drivers in the outside lane from entering next to a circulating vehicle.

10.7.8 Turbo Roundabouts

Multilane roundabout design continues to evolve, with a variety of techniques developed around the world to achieve desirable roundabout performance. One technique initiated in the Netherlands for multilane roundabout design is called a *turbo roundabout* (*31*). As discussed in Chapter 2: Roundabout Characteristics and Applications, a turbo roundabout is a multilane roundabout that uses spiral road geometry and physical channelization to maintain driver lane discipline in the circulatory roadway.

Exhibit 10.73. Example of using spiral to shift circulating lane to the outside.



SOURCE: Georgia Department of Transportation.

Exhibit 10.74. Example of roundabout with turbo roundabout features.

LOCATION: University Boulevard/Merrill Road, Jacksonville, Florida.
SOURCE: Federal Highway Administration.

The Dutch turbo roundabout originates from a style of European multilane roundabout with perpendicular entries and no substantive channelization or raised lane dividers. This form has been found to have poor safety performance. The specific turbo roundabout version developed and implemented in the Netherlands to address undesirable operational characteristics has two key features that distinguish it from other multilane roundabouts around the world, including in the United States:

- Entries are perpendicular to the circulatory roadway, which is common practice for many roundabouts in northern Europe (both single lane and multilane).
- Raised lane dividers are used within the circulatory roadway to prevent lane changing and guide drivers to the appropriate exit.

Spiraling and lane dividers are used to discourage lane changes that may result in weaving conflicts within the circulatory roadway. Conceptually, the intent is to guide users to appropriate lanes before entering the roundabout, which eliminates lane changes while inside the roundabout. Other European countries have implemented variations of the Dutch turbo roundabout, typically with modifications to geometric alignment and the type of lane divider, such as mountable lane dividers, flush lane dividers, or solid pavement markings—all of which discourage lane changing and promote lane discipline. Further detail on turbo roundabout design practices can be found in FHWA's synthesis report, *Advancing Turbo Roundabouts in the United States* and FHWA's informational primer, *Turbo Roundabouts* (*32, 33*).

The specific combination of geometry and lane divider treatment used in the Netherlands is new to the United States. One of several proposed variations uses raised lane dividers and is shown in Exhibit 10.74. Another variation uses pairs of double white lines and raised pavement markers to separate circulating lanes and is shown in Exhibit 10.75. **The key to successful multilane roundabout design, as with all roundabout design, is achieving performance objectives while designing a roundabout appropriate for its context. The means (i.e., techniques) used are less important than the outcome (i.e., performance), and variations in techniques are possible if they achieve the desired performance.** Techniques used for turbo roundabouts may help achieve these objectives.

10.8 Design for Interim and Ultimate Configurations

This section illustrates a common technique for designing a single-lane roundabout configuration as an interim configuration. This section also discusses how practitioners can consider a future expansion to a multilane configuration. The techniques presented in this section can also apply

Exhibit 10.75. Example of roundabout with turbo roundabout features.

LOCATION: N Tamiami Trail/Fruitville Road, Sarasota, Florida.
SOURCE: Ken Sides.

to many other cases, such as conversion from a hybrid 2 × 1 configuration to an ultimate 2 × 2 configuration or between other combinations of multilane roundabouts.

When projected traffic volumes indicate that a multilane roundabout is required for future-year conditions, practitioners need to evaluate the duration of time that a single-lane roundabout would operate acceptably before requiring additional lanes. Where a single-lane configuration will be sufficient for much of the roundabout's design life, it may be appropriate to evaluate whether it is best to first construct a single-lane roundabout until traffic volumes dictate expanding to a multilane roundabout. Another reason to stage the construction of a multilane roundabout is the uncertainty of traffic predictions for a 10-year horizon year or 20-year design year, as discussed in Chapter 8: Operational Performance Analysis. Traffic predictions may never materialize because of the significant number of assumptions that practitioners must make when developing volume estimates for horizon or design years.

Single-lane roundabouts, as well as single-lane approaches to multilane roundabouts, are generally simpler for motorists to learn, are more readily accepted in new locations, and have fewer vehicle conflicts and crashes. This allows for a gradual transition into the ultimate multilane build-out of the intersection. Single-lane roundabouts also introduce fewer conflicts to bicyclists and pedestrians and provide increased safety benefits and usability to bicyclists and pedestrians by minimizing the crossing distance and limiting exposure time to vehicles while crossing an approach. Single-lane roundabouts are also safer and easier for bicyclists to use when circulating with motor vehicles, should that be desired.

When considering an interim single-lane roundabout, the practitioner needs to evaluate the right-of-way and geometric needs for both the single- and multilane configuration as well as future construction staging for the additional lanes.

There are many potential ways to expand from an interim to an ultimate configuration. The following sections illustrate two common ways: expanding to the inside and expanding to the outside.

10.8.1 Expanding to the Inside

Expanding to the inside involves adding any necessary lanes for the ultimate configuration to the inside of the interim roundabout configuration, with the outer curbs and ICD remaining the same in both the interim and ultimate configurations. This allows for setting the outer limits of the intersection during initial construction and limits the future construction impacts to surrounding properties during widening, as sidewalks and outer curb lines will not typically require adjustment.

The roundabout first needs to be configured for the ultimate multilane configuration. An interim single-lane design is established within the ultimate multilane configuration by providing wide splitter islands and an enlarged central island that occupy the space required for the inside travel lanes. Future expansion would be accomplished by narrowing the splitter island and widening the inside of the existing travel lanes. Typically, this could require replacing the splitter islands, central island curbing, and truck apron. However, cold pavement joints support removing only the unnecessary portion and adding new curbing.

This process typically requires short-term lane closures and, therefore, may be best accomplished by working on one approach at a time and implementing localized detours for the approach that is undergoing demolition. The remainder of the intersection can continue to operate. If demolition is staged from the entry lanes of the intersection, the exit on the leg where demolition is occurring may be able to remain open.

Once the original splitter island is removed, work on forming and pouring concrete for the new splitter island can be accomplished from the new inside lane developed as part of the demolition. This may allow for the original outside entry lane to be re-opened to traffic, subject to flagging or other necessary traffic control. Once the new splitter island has been constructed and the additional roadway pavement is placed for an approach, the new inside lanes may remain coned off until the remaining approaches have been completed and the final markings and signing have been placed for the full intersection.

10.8.2 Expanding to the Outside

Expanding to the outside involves adding lanes for the ultimate configuration to the outside of the interim roundabout configuration, with the central island and splitter islands built for the interim condition and retained for the ultimate configuration. Assuming the right-of-way was purchased for the ultimate design, the interim sidewalks and landscaping could also be constructed in their ultimate location.

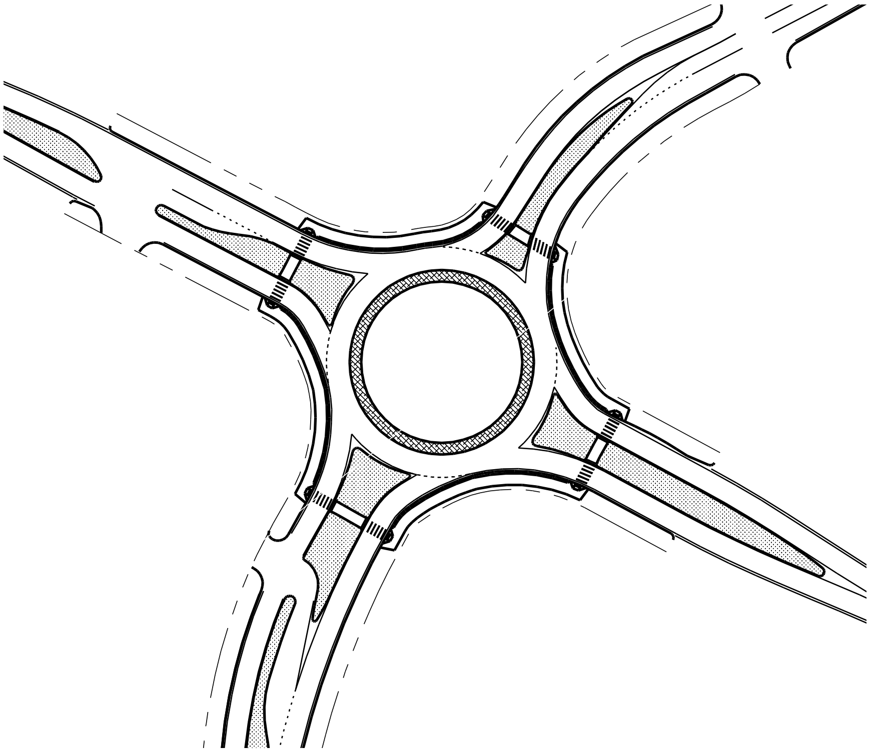
When using this option, the roundabout is first designed to meet the performance objectives for the ultimate multilane configuration. The interim single-lane design can be established within the ultimate configuration by adjusting the outer curb positions. The ultimate multilane design is needed for establishing right-of-way needs and reserving or purchasing what is needed for the ultimate roundabout footprint.

This method can be less disruptive to motor vehicle traffic since most of the improvements are added to the outside of the roadway. Expanding to the outside could result in the need to relocate drainage structures along with new outside curb lines. The original curb lines must be demolished and replaced with pavement. It is best to remove the original pavement markings; final markings and signs are then placed before the additional lanes of traffic are opened. In locations where concrete pavement is used, grinding pavement markings may leave a permanent mark on the roadway surface that could confuse drivers.

Exhibit 10.76 and Exhibit 10.77 provide interim and ultimate configurations, respectively, for an example of a staged multilane roundabout that is expanded to the inside.

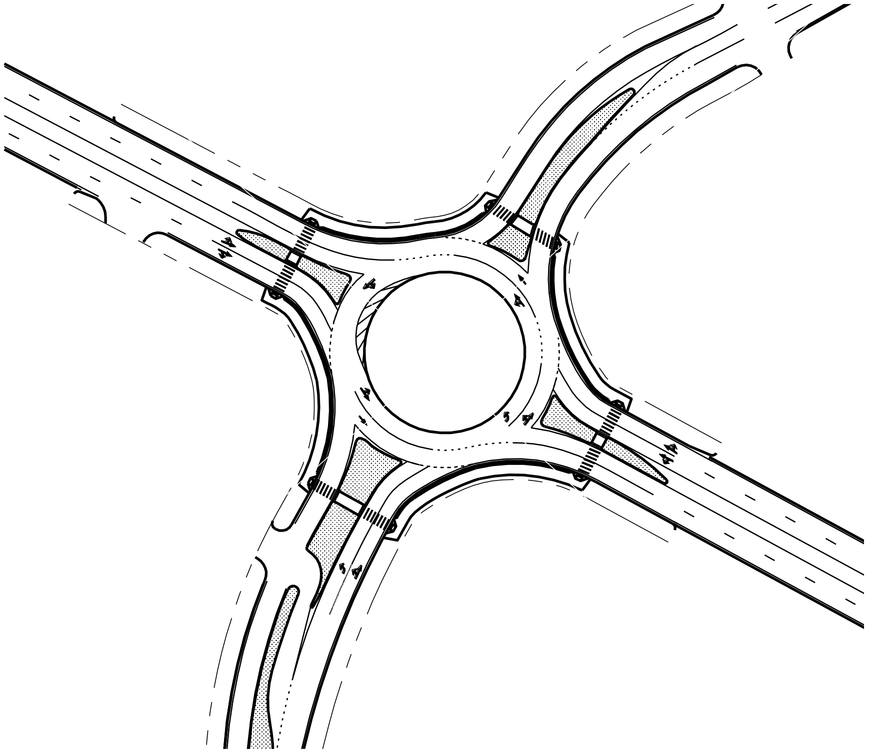
It may seem advantageous from a cost perspective to build curbs in their ultimate configuration and use signs and pavement markings to mark the interim configuration. However, research has

Exhibit 10.76. Staged multilane roundabout, interim configuration.



SOURCE: *NCHRP Report 672* (*2*).

Exhibit 10.77. Staged multilane roundabout, ultimate configuration.



SOURCE: *NCHRP Report 672* (*2*).

found that lanes and spiraling channelization that are designated solely with pavement markings and not with curbing are less effective and can contribute to poor safety performance (*26*, *34*). As such, definition of the interim configuration using curbing is preferred.

10.9 Bypass Lanes

Bypass lanes, sometimes called *channelized turn lanes* or *slip lanes*, may be included at any roundabout (as with any other type of intersection). The most common type of bypass lane at roundabouts is a right-turn bypass lane. However, at T-intersections, a through bypass lane is sometimes used across the top of the T. The principles presented in this section are the same for both types of bypass lanes, even though most examples are for right-turn bypass lanes.

If applied to single-lane configurations, design consideration for bypass lanes may include principles of multilane roundabout design as they relate to helping drivers select their lane in advance of the intersection. Extending the life of the single-lane roundabout (or precluding the need for a multilane roundabout) by incorporating a bypass lane may be desirable, as doing so gives the relative safety performance benefit of a single-lane roundabout. However, the bypass lane needs to be carefully designed to support safety for all modes, especially bicyclists and pedestrians. The following are some bypass lane considerations:

- A bypass lane creates one or two additional pedestrian crossings. The potentially higher speeds of bypass lanes and the lower expectation of drivers to stop may require active traffic control and increase the risk of pedestrian collisions. Bypass lanes also introduce additional complexity for pedestrians who are blind or have low vision navigating the intersection.
- The bypass lane creates additional conflicts on the exit between motor vehicles, depending on its configuration.
- The transitions to and from a bypass lane can create conflicts with bicycle facilities as well as conflicts at each crossing location.
- A bypass lane provides an opportunity to serve right-turning design vehicles on movements with acute angles between intersecting streets.

Providing a bypass lane allows right-turning traffic to bypass the roundabout, providing additional capacity for the through and left-turn movements at the approach. However, considering reverse traffic patterns during the opposite peak period is necessary to completely assess traffic operations during each peak period. A heavy right-turn volume during one peak period is often a heavy left-turn return volume during another peak period.

The radius of the right-turn bypass lane cannot be significantly larger than the radius of the fastest entry path provided at the roundabout. The goal is to create vehicle speeds for drivers decelerating into the bypass lane that are similar to speeds within the roundabout. A small radius also offers greater safety performance benefits for pedestrians who must cross the right-turn bypass lane.

Exhibit 10.78 and Exhibit 10.79 show examples of right-turn bypass lanes.

10.9.1 Yielding Bypass Lanes

The yielding bypass lane is the preferred bypass lane option whenever bicycle or pedestrian use is intended. The concept is illustrated in Exhibit 10.80. A common challenge is that the view angle for a driver in the right-turn-only lane may be insufficient, depending on overall roundabout geometry. In addition, the pedestrian crossing on the exit is located farther from the end of the right-turn-only lane to provide drivers with sufficient time to react to and stop for pedestrians.

Exhibit 10.78. Example of right-turn bypass lane.

LOCATION: Avon Road/I-70 Westbound Ramps, Avon, Colorado.
SOURCE: Lee Rodegerdts.

The advantage of a yielding bypass lane is that it may allow the roundabout to remain as a single-lane roundabout with a slower right-turn movement, which results in safer operation for all users.

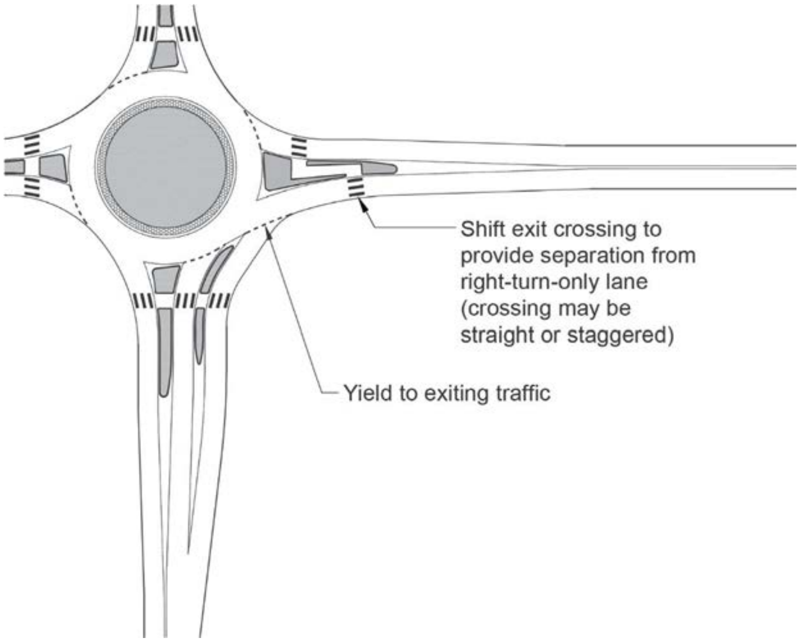
The disadvantage is that the crosswalk immediately downstream needs to be located far enough from the bypass lane yield point to allow drivers to shift their attention from conflicting traffic to the downstream crosswalk and provide enough time for them to react to and stop for pedestrians and bicyclists at the crossing. This may require a staggered pedestrian crossing, as discussed in Section 10.4.

In some cases, it may be desirable to use a right-turn-only lane rather than a separated right-turn bypass lane. Exhibit 10.81 shows two of these options, both of which are designed to have the right-turn-only lane terminate into the splitter island rather than aligning it partially or completely with the circulatory roadway. Without that design characteristic, drivers in the right-turn-only lane may more readily enter the circulatory roadway.

Exhibit 10.79. Example of right-turn bypass lane.

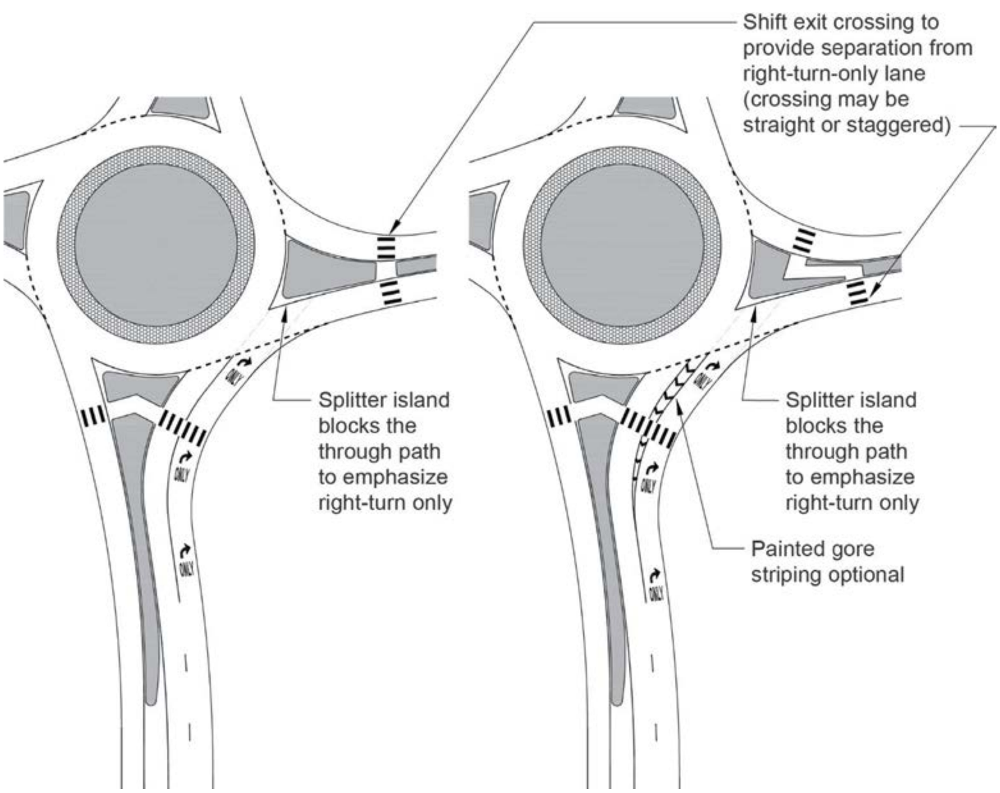
LOCATION: Main Street/Marlboro Street/Winchester Street, Keene, New Hampshire. SOURCE: Google Earth.

Exhibit 10.80. Yielding right-turn bypass lane.



SOURCE: *NCHRP Report 672* (*2*).

Exhibit 10.81. Yielding right-turn-only lane.



SOURCE: *NCHRP Report 672* (*2*).

The exhibits are conceptual only to reflect this bypass type. The view angle for a driver in the right-turn-only lane may be insufficient, depending on overall roundabout geometry. In addition, the pedestrian crossing on the exit needs to be located farther from the end of the right-turn-only lane to provide drivers with sufficient time to react to and stop for pedestrians.

A painted traffic separator between the through and right-turning lanes channels right-turning drivers and promotes a right turn for drivers yielding at the exit. This separation may also create space for the swept path of right-turning design vehicles. The right turn creates a multilane crossing for pedestrians on the entry that may require additional treatments for accessibility, such as raised crosswalks and active traffic control. It will also create a potential sudden conflict for pedestrians on the exit. As part of the design, the entry lane and right-turn-only lane are checked for adequate view angles to the left, following the principles presented in Section 10.7 for multilane design. The crossing on the exit is located away from the end of the right-turn-only lane so that drivers have time to react to and stop for pedestrians.

For right-turn lanes of all forms, it may sometimes be possible to develop the right-turn-only lane well in advance of the intersection and place a through bike lane to the left of the right-turn-only lane, similar to the standard design for conventional intersections. If this design is used, the through bike lane is then terminated or connected to a separated bicycle facility or multiuse path around the roundabout before bicyclists enter the roundabout (as with normal entry design for bicyclists). This would make the presence of a right-turn bypass lane less challenging for bicyclists.

10.9.2 Merging Bypass Lanes

Merging bypass lanes are designed for vehicles in the right-turn bypass lane to enter the exiting roadway at a shallow angle at similar speeds to exiting vehicles. Under this option, the bypass lane is carried alongside the main roadway for a sufficient distance to allow vehicles in the bypass lane and vehicles exiting the roundabout to accelerate to comparable speeds. The bypass lane is then merged at a taper rate according to AASHTO guidelines for the appropriate design speed (*1*). Merging bypass lanes are not advised in environments where bicycle and pedestrian use is intended (because motor vehicle speeds are higher in the bypass lanes) unless supplemental crossing treatments are used (such as raised crosswalks). An example of a merging bypass lane is illustrated in Exhibit 10.82.

Merging bypass lanes have two advantages:

- A merging bypass provides a higher motor vehicle capacity than a yielding bypass.
- The merging area reduces the departure roadway to a single lane, which is compatible with many two-lane highway cross sections.

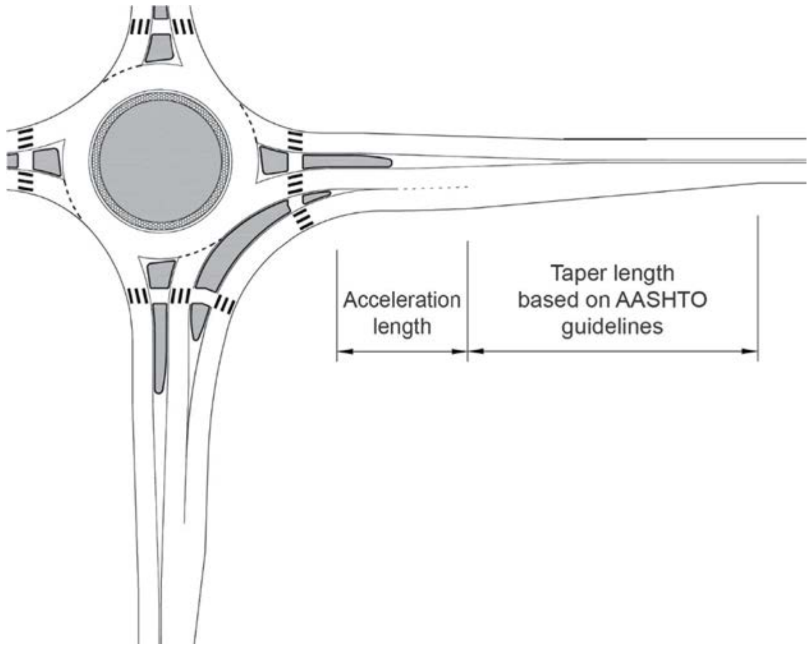
The arrangement has two disadvantages:

- The merging bypass lane generally promotes higher motor vehicle speeds than the yielding bypass option and creates additional conflicts for bicyclists and pedestrians.
- The downstream merge could create secondary conflicts if driveways or public streets are located beyond the merge where drivers may be decelerating to make a right turn.

10.9.3 Add-Lane Bypass Lanes

Add-lane bypass lanes may be desirable when the overall roadway cross section increases in number of lanes downstream of the roundabout. The geometry of the add-lane bypass lane in the vicinity of the roundabout is like that of a merging bypass lane. Add-lane bypass lanes are not advised in environments where bicycle and pedestrian use is intended (because motor vehicle speeds are higher in the bypass lane) unless supplemental crossing treatments are used (raised crosswalks, active traffic control, or both).

Exhibit 10.82. Merging right-turn bypass lane.



SOURCE: *NCHRP Report 672* (*2*).

The advantage of an add-lane bypass lane is that it provides the highest motor vehicle capacity.

The arrangement has several disadvantages:

- The add-lane bypass lane promotes the highest motor vehicle speeds of the three options.
- The high motor vehicle speed creates the potential for less yielding to pedestrians.
- The add-lane on the exit creates a weaving conflict for bicyclists exiting the roundabout who need to change lanes to enter whatever bicycle facility is provided on the outside of the departing roadway.
- The add-lane creates potential weaving conflicts for destinations immediately downstream of the roundabout, which may compromise its effectiveness in environments with nearby intersections or access points.
- If a downstream intersection or access point is located within the merge area, there are additional conflicts for motor vehicles and any bicyclists and pedestrians present.

10.9.4 Pedestrian and Bicycle Crossings for Bypass Lanes

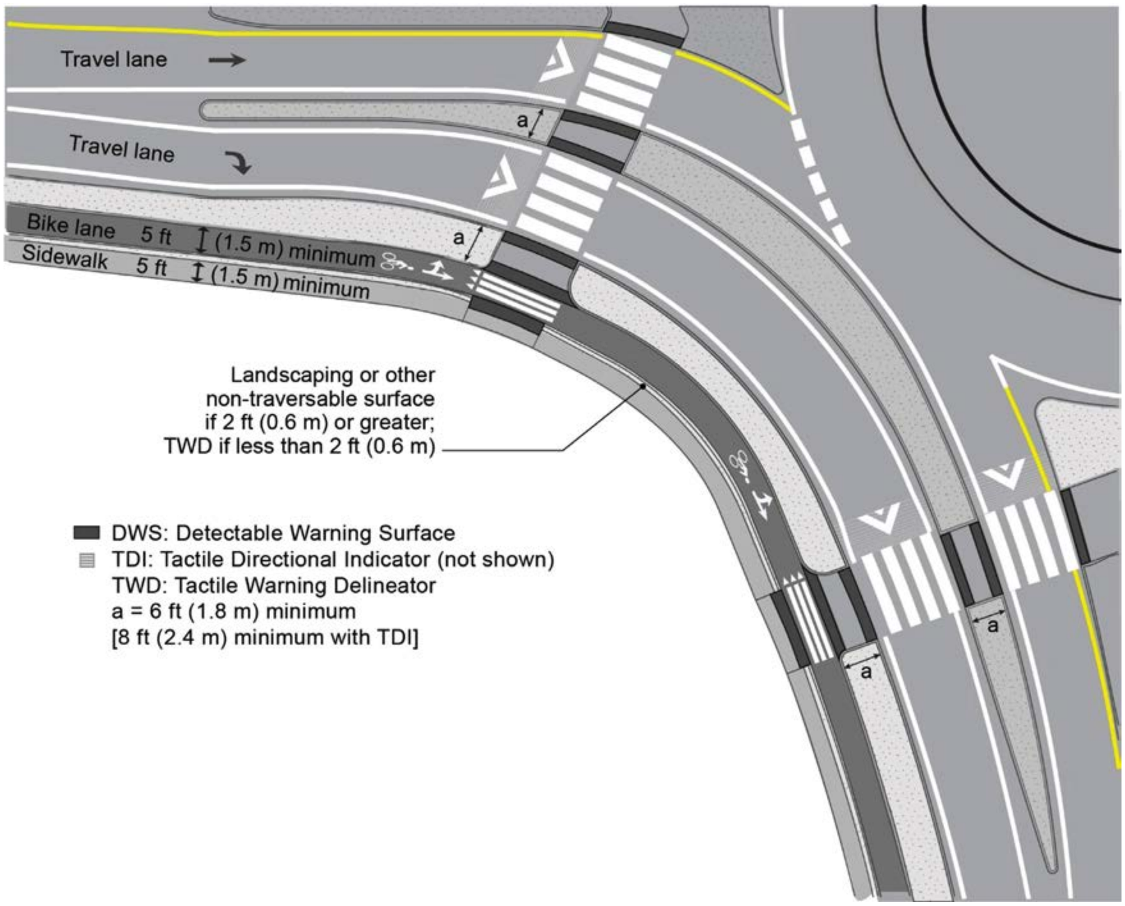
Section 10.4 presents a variety of concepts for designing for people walking and biking through a roundabout. The concepts in that section can be extended to bypass lanes. For yielding bypass lanes, the same range of options used at roundabout entries can be used across the yielding bypass lane.

As discussed previously, merging or add-lane bypass lanes are more challenging than yielding bypass lanes for bicyclists and pedestrians at roundabouts and other intersection forms, especially for people who are blind or have low vision. Because of these challenges, raised crosswalks can be beneficial to improve driver speed control and yielding behavior. Exhibit 10.83 illustrates an add-lane or merging bypass lane with a raised shared-use crossing.

This arrangement has several advantages:

- The raised crossing provides vertical geometric speed control for motor vehicles, provides greater driver visibility of people walking, and promotes better driver yielding behavior.

Exhibit 10.83. Pedestrian crossing with raised crosswalks at the roundabout entry with a right-turn bypass lane.



- The raised crossing has pairs of detectable warning surfaces for each interaction with vehicles.
- The raised crossing is straight, resulting in the fewest turns for bicyclists and pedestrians. This is especially helpful for people who are blind or have low vision.

However, it also has two disadvantages:

- Pedestrians and bicyclists use the same shared-use crossing. The shared-use crossing creates more conflicts between bicyclists and pedestrians than separated crossings, especially considering that the crossing is bidirectional for both bicyclists and pedestrians.
- The raised crossing may be more difficult to maintain during snow conditions and may introduce drainage challenges.

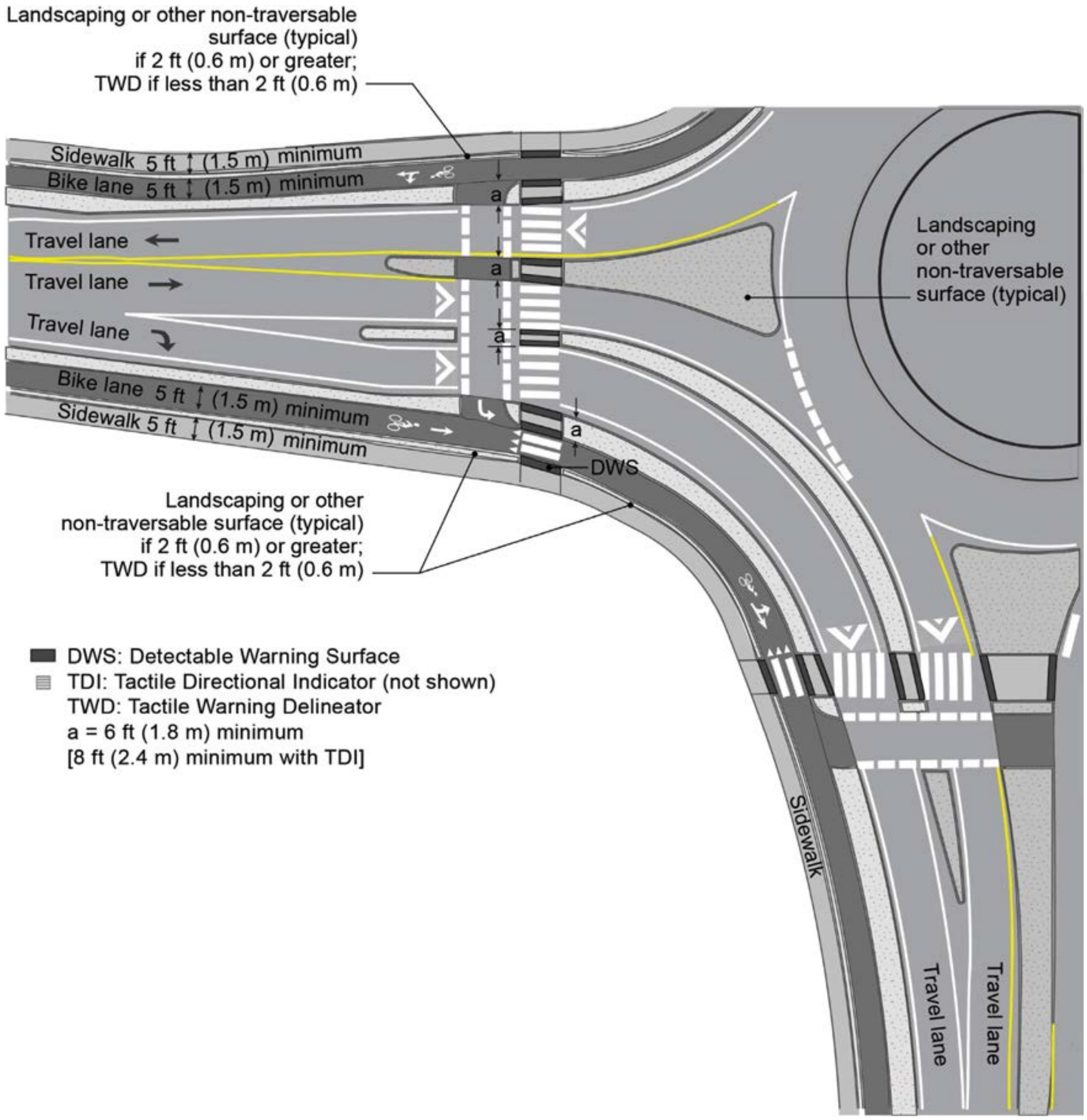
Other arrangements are possible by adapting the concepts used for shared-use crossings of roundabout entries and exits.

Exhibit 10.84 illustrates a roundabout bypass lane with a possible arrangement of separated bicycle and pedestrian crossings. Other variations are possible by adapting the concepts presented previously for entry and exit crossings.

Advantages of this arrangement:

- The raised crossing provides vertical geometric speed control for motor vehicles, provides greater driver visibility of people walking, and promotes better driver yielding behavior.
- The raised crossing has pairs of detectable warning surfaces for each interaction with vehicles.

Exhibit 10.84. Separate raised bicycle and pedestrian crossings with one-way separated bicycle lane at sidewalk level at roundabout with a right-turn bypass lane.



- Pedestrians and bicyclists are separated, minimizing conflicts between modes and maximizing accessibility for the pedestrian crossing.
- The raised crossing is straight, resulting in the fewest turns for bicyclists and pedestrians. This is especially helpful for people who are blind or have low vision.
- The narrow separation between the bicycle and pedestrian crossings creates a single yielding point for drivers at each crossing.
- The straight alignment facilitates the possibility of one-stage operation to minimize delay for bicyclists and pedestrians.

Disadvantages of this arrangement:

- The raised crossing may be more difficult to maintain during snow conditions and may introduce drainage challenges.
- Depending on the overall length of the crossing, the pedestrian clearance time under one-stage operation is much longer than a typical two-stage crossing because of the additional travel

time for both crossing and within the splitter island. This may increase vehicular queuing at the crossings, which may require shifting the crossings further from the roundabout to avoid extended interruptions within the circulatory roadway.

- If active traffic control devices are used with two-stage operation, the two-stage operation for bicyclists and pedestrians may not be obvious given the linear alignment of crossings. This may result in confusion to bicyclists and pedestrians over which display controls each crossing (including accessible pedestrian signals).

Other arrangements are possible by adapting the concepts used for separated crossings of roundabout entries and exits.

10.10 Interchanges

This section discusses roundabouts as part of interchanges. Interchanges involve grade separating one or more movements. They are most common on freeways but can occur on other facility types. Freeway interchanges include system and service forms. Service interchanges apply stop, yield, or signal control at the crossroad ramp terminal intersections. Roundabouts may be used at ramp terminal intersections and have been successfully applied at traditional diamond and partial cloverleaf forms. Roundabouts have also been applied at displaced left-turn forms that include transposed travel directions between ramp terminal intersections (i.e., a diverging diamond interchange). Roundabouts may take many shapes and forms as isolated intersections or connected forms.

Ramp terminal intersections have interdependency that requires practitioners to understand the roadway network's lane configurations and operational characteristics and needs, which allows for verifying that each intersection can operate effectively and serve each user. Ramp terminal intersection configuration selection may occur as part of an interchange selection process, a separate study (e.g., ICE), or a combination of the two. Regardless of the interchange type or the roundabout form, the fundamental performance objectives apply to roundabout ramp terminal intersections at interchanges.

10.10.1 Isolated Roundabouts

Roundabouts at service interchange ramp terminal intersections operate like other intersection forms. Roundabouts may be separated and operate independently; they are essentially isolated. U-turns are not traditionally provided along the arterial street at non-roundabout ramp terminal intersections for capacity and safety reasons as well as to discourage wrong-way movements on the freeway exit ramps. Interchanges are significant investments that intend to serve movements between the primary roadway (typically a freeway) and a secondary roadway (typically an arterial street). Arbitrarily providing U-turns to support access along the secondary roadway puts the burden on the interchange to serve third-order traffic (public or private access), which degrades the primary interchange function.

However, U-turns at roundabout ramp terminal intersections may be necessary to serve two-way frontage roads or connecting roadways and could be essential to an access management plan for the arterial. If U-turns are provided but are only occasional occurrences, drivers may become accustomed to not needing to yield to conflicting U-turning vehicles. In addition, the segment of circulatory roadway that serves only the occasional U-turn movement is more likely to accumulate road debris from a lack of use.

Exhibit 10.85 depicts a diamond interchange with isolated ramp terminal intersections. The configuration in Exhibit 10.85 uses a raindrop form at each ramp terminal intersection that does

Exhibit 10.85. Example of raindrop-shaped roundabouts at diamond interchange.

LOCATION: Dike Access Road/I-5 Ramps, Woodland, Washington.
SOURCE: Google Earth.

not allow cross-street U-turns. This configuration removes the yielding condition between the roundabouts and essentially eliminates the likelihood of queuing between the ramp terminals. This may be beneficial in reconstruction projects that retain the cross section on the minor roadway between the ramp terminal intersections.

One of the major concerns for rural service interchange locations is the potential for wrong-way movements on the freeway exit ramp. The raindrop configuration makes wrong-way movements into the off-ramps more difficult and removes impervious areas in the circulatory roadway.

Exhibit 10.86 depicts a two-quadrant partial cloverleaf form with isolated ramp terminal intersections. The configuration in Exhibit 10.86 allows U-turns.

Exhibit 10.87 depicts a trumpet interchange form with a single, isolated ramp terminal intersection. The configuration in Exhibit 10.87 allows U-turns as a byproduct of serving two-way traffic on the leg opposite the freeway exit ramp.

Exhibit 10.88 depicts a diverging diamond interchange (DDI) with an isolated ramp terminal intersection. The configuration in Exhibit 10.88 supports the crossover configuration that allows contraflow travel between the ramp terminal intersections. This DDI combines a

Exhibit 10.86. Example of circular roundabouts at an interchange.

LOCATION: Austin Chaney Road/US 74 Bypass Ramps, Monroe, North Carolina. SOURCE: Google Earth.

Exhibit 10.87. Example of isolated roundabout at an interchange that allows U-turns.

LOCATION: SR 68 / SR 1 Off-Ramp/17 Mile Drive, Monterey, California.
SOURCE: Google Earth.

roundabout at one ramp terminal intersection with a signalized intersection at the other ramp terminal intersection. A DDI could be configured with roundabouts located at each ramp terminal intersection.

10.10.2 Connected or Single Roundabouts

Roundabouts at service interchange ramp terminal intersections may also be connected and operate as a single roundabout, which may be appropriate at non-interchange locations. The name *connected* or *single* roundabout acknowledges the proximity of the two ramp terminal intersections and how they operate compared with the isolated forms. These forms have sometimes been informally called *raindrop*, *peanut*, *dumbbell*, or other names describing their shape.

When multilane roundabouts are connected to one another in proximity, there is an overarching need to guide drivers for key movements throughout the length of the roadway segments without the need to change lanes. The highest priority movements are those to and from the freeway ramps, and these should be served with minimal lane changing if intersections are closely spaced. This requires attention to many system-related details, including operational

Exhibit 10.88. Isolated roundabout as part of DDI.

LOCATION: MO 291/SW Blue Parkway/US 50 Ramps, Lee's Summit, Missouri.
SOURCE: Google Earth.

Exhibit 10.89. Example of diamond interchange with connected raindrop-shaped roundabouts.

LOCATION: W Main Street/US 31 Ramps, Carmel, Indiana.
SOURCE: Google Earth.

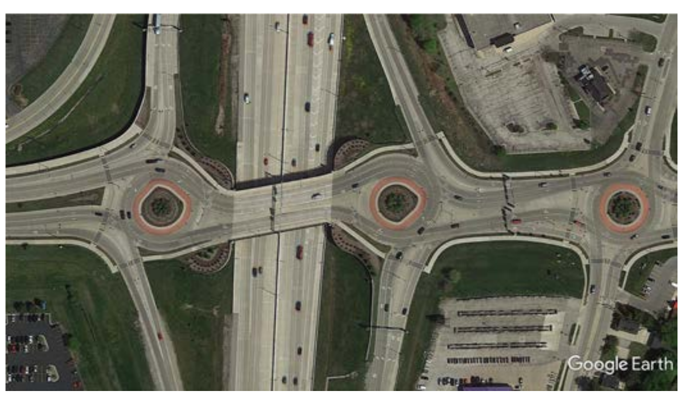
performance, coordinated signs and pavement markings, and geometric configurations that support the overall intended system operation. Further guidance on signs and pavement markings for these applications is provided in Chapter 12: Traffic Control Devices and Applications.

Exhibit 10.89 depicts a diamond interchange with connected ramp terminal intersections. The configuration does not allow U-turns. The configuration in Exhibit 10.90 has two isolated intersections that allow U-turns at the ramp terminal intersection. Each of these forms has the crossroad passing over the freeway and, coincidently, an adjacent roundabout on the crossroad. These interchange forms are also applicable where the freeway passes over the crossroad.

Exhibit 10.91 depicts a diamond interchange with connected ramp terminal intersections, with the freeway passing over the crossroad. The configuration does not allow U-turns and operates in the same manner as the form in Exhibit 10.89. This form allows single-span bridges on the freeway.

Exhibit 10.92 and Exhibit 10.93 present diamond interchanges where a crossroad has been configured as elongated roundabouts (oval shaped). These forms could also be configured as a single circular roundabout. Regardless of shape, the fundamental traffic operations are the same between the forms presented in Exhibit 10.89 through Exhibit 10.91. Roundabout capacity is based primarily on the lane configuration at each entry-circulating point; the size and shape of

Exhibit 10.90. Example of diamond interchange with separate circular-shaped roundabouts.



LOCATION: W Mason Street/I-41 Ramps, Green Bay, Wisconsin.
SOURCE: Google Earth.

Exhibit 10.91. Example of connected roundabouts with crossroad underpass.

LOCATION: E 191st Street/US 31 Ramps, Westfield, Indiana.
SOURCE: Google Earth.

Exhibit 10.92. Example of single roundabout with crossroad underpass.

LOCATION: E Broadway Street/I-135 Ramps, Newton, Kansas.
SOURCE: Google Earth.

Exhibit 10.93. Example of single roundabout with crossroad underpass.

LOCATION: S. Anderson Road/US 50 Ramps, Newton, Kansas.
SOURCE: Google Earth.

the circle have less effect, if any, on roundabout capacity relative to lane configuration. The oval or circular form may require four shorter bridges or two longer bridges, depending on its size. These forms could be used with the crossroad passing over the freeway, in which case the crossroad bridges would be curved rather than straight.

Regardless of the interchange type or the roundabout form, the fundamental performance objectives apply to roundabouts at interchanges.

10.11 Access Management

Roundabouts can be a useful tool within an access management plan. They can provide U-turn opportunities at intersections that may allow the number and location of full access points along the roadway to be reduced. Roundabouts offer the ability to serve U-turn movements more safely and efficiently than other intersection forms. This enables access points between roundabouts to be served by right-in, right-out movements or, in some cases, right-in, right-out, left-in movements. This promotes corridor operations and reduces crash risk by shifting the most difficult movements—left-out movements from access points—to U-turn movements at roundabouts.

Access points near a multilane roundabout can directly affect the operational and safety performance of the access point and the multilane roundabout. Research has found a likely link between the presence of nearby access points and improper lane use at a multilane roundabout, which is a key contributing factor to crash patterns at some multilane roundabouts (*26*). Where downstream access points are located close to a roundabout, drivers may pre-position themselves by choice in advance of the roundabout, in some cases turning from the incorrect lane to avoid a late lane change at the access point. Because of these potential interactions, access management is an important component of ICE activities, especially when determining the number and assignment of lanes at a roundabout and the connecting roadway system.

Access management at roundabouts follows many principles used for access management at conventional intersections. For public and private access points near a roundabout, two scenarios commonly occur:

- Access into the roundabout itself.
- Access near the roundabout.

This section addresses considerations for access into or near the roundabout and considerations for locating a full access near a roundabout.

10.11.1 Access into the Roundabout

In general, it is preferable to have private access points connect to the roadway system away from public intersections, including roundabouts. However, it may be possible to provide direct access from a private access point into a roundabout if the access point can be configured in a way that does not adversely affect the roundabout's safety or operation.

One objective during planning and design is to find alternatives to direct private access at the roundabout. This includes looking for potential alternative access points for the same property, options for shared access points, and other strategies. These are discussed in more detail in other references, including the TRB *Access Management Manual* (*35*).

If private access must be integrated into a roundabout, there are two primary considerations:

- If the access point is a low-volume generator with trips primarily by drivers familiar with the location, such as residents of one to three single-family homes, the access will take the form of a driveway. This reduces the likelihood of drivers on the public street misconstruing the private

access as a public destination. However, traditional driveway configurations do not incorporate features to discourage wrong-way movements, as a splitter island does.
- If the access point is to be a more significant traffic generator (e.g., a commercial or retail property, larger residential use, or public or private institution) or trips are primarily taken by people less familiar with the location, the entry will be configured like a normal roundabout leg, with a full splitter island and other associated features.

Exhibit 10.94 depicts private driveway access to a college that has been configured to resemble a public access street.

Site constraints sometimes make it necessary to provide direct access into a roundabout. For a driveway to be located where it has direct access to the circulatory roadway of a roundabout, it needs to satisfy the following criteria:

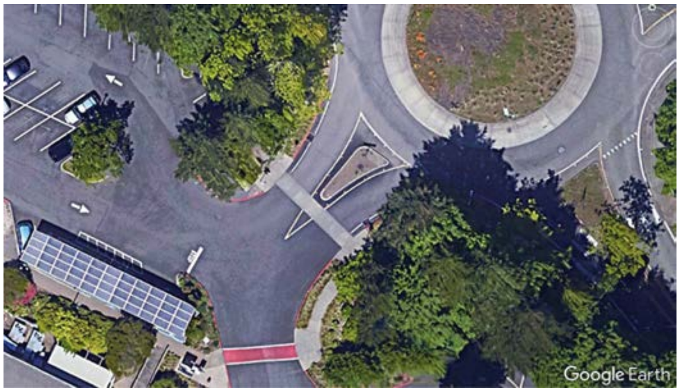
- No alternative access point is reasonable.
- Traffic volumes are sufficiently low to make the likelihood of errant vehicle behavior minimal. Driveways carrying the trip generation associated with a few single-family houses are typically acceptable; driveways with higher traffic volumes need to be designed as a regular approach with a splitter island. In addition, if a high proportion of unfamiliar drivers are expected at the driveway, the practitioner can consider providing more positive guidance.
- The driveway design enables vehicles to exit facing forward, with a hammerhead design or other area on site where vehicles can turn around. Driveways that only allow backing maneuvers into the roundabout are to be used only in low-volume environments.
- The driveway design enables proper intersection sight distance from the driveway location and adequate stopping sight distance for vehicles approaching the driveway and traveling along the primary roadway.
- The driveway designs are distinct from the circulatory roadway (e.g., concrete driveway aprons adjacent to an asphalt concrete circulatory roadway) to provide a clear visual indication that they are private driveways not to be confused with public roadways.
- Pedestrian and bicycle circulation across the driveway are maintained.

Exhibit 10.95 and Exhibit 10.96 depict examples of a private driveway accessing a roundabout.

10.11.2 Access Near the Roundabout

Public and private access points near an intersection can be common in reconstruction projects with existing or proposed development. In some cases, access must be provided near a roundabout

Exhibit 10.94. Private access configured as public street.



LOCATION: SW Terwilliger Blvd/S Palater Road, Portland, Oregon.
SOURCE: Google Earth.

Exhibit 10.95. Example of private driveway with direct access to a roundabout.

LOCATION: Alameda Padre Serra/Montecito Street/Salinas Street/Sycamore Canyon Road, Santa Barbara, California. SOURCE: Lee Rodegerdts.

and within the splitter island vicinity. Such locations will have restricted operations because of the splitter island. It is typically best to avoid these conditions, but the configurations are sometimes unavoidable and may be necessary if impact is expected to be minimal or no reasonable alternatives are available. Access considerations in the roundabout influence area may include

- Closing the access if it is redundant to other access points serving the properties,
- Shifting the access up or downstream to a location outside the splitter island,

Exhibit 10.96. Example of private driveway with direct access to a roundabout.

LOCATION: Route 85A (Maple Road)/Route 155, Voorheesville, New York. SOURCE: Google Earth.

Exhibit 10.97. Example of driveway located between crosswalk and roundabout.

LOCATION: SW Century Drive/SW Simpson Avenue, Bend, Oregon.
SOURCE: Lee Rodegerdts.

- Investigating crossover easements between adjacent parcels,
- Investigating alternative access roads to provide property access from a different location and serve the properties away from the roundabout, and
- Providing a break in the painted taper or splitter island to serve low-volume locations.

When access is developed near the roundabout, driveways are not to be located between the crosswalk and roundabout entrance or exit. Driveways between the crosswalk and the circulatory roadway complicate the pedestrian ramp treatments and introduce conflicts. They can be especially difficult for people with vision disabilities to correctly interpret. This can potentially increase crash risk, degrade traffic operations, or reduce accessibility.

Exhibit 10.97 and Exhibit 10.98 show examples of undesirable driveways located near a roundabout. Driveways blocked by the splitter island will be restricted to right-in and right-out movements.

Exhibit 10.98. Example of driveway improperly aligned with crosswalk.

LOCATION: NE Inglewood Hill/216th Avenue NE, Sammamish, Washington.
SOURCE: Lee Rodegerdts.

Exhibit 10.99. Example of driveway reconfiguration.

LOCATION: Mandalay Avenue/Acacia Street, Clearwater Beach, Florida.
SOURCE: Lee Rodegerdts.

Exhibit 10.99, Exhibit 10.100, Exhibit 10.101, and Exhibit 10.102 show examples of configurations that address access near the roundabout. These examples include relocating an access point or providing a break in the painted taper or splitter island to serve low-volume locations.

Research has found that access points near multilane roundabouts can significantly affect safety performance (*11*). For example, Exhibit 10.103 illustrates a multilane roundabout with a right-in, right-out access point (solid line at lower left corner) upstream of an entry.

Drivers exiting the access point to turn left are required by access management to instead turn right and make a U-turn at the roundabout. However, because the access point is close to the roundabout, drivers at the study location were frequently observed to make an incorrect

Exhibit 10.100. Example of splitter island broken to allow driveway access.

LOCATION: Route 85A (Maple Road)/Route 155, Voorheesville, New York.
SOURCE: Google Earth.

Exhibit 10.101. Example of painted taper broken to provide private driveway access.

LOCATION: Bradshaw Road/Sheldon Road, Elk Grove, California.
SOURCE: Google Earth.

Exhibit 10.102. Example of splitter island broken to allow driveway access.

LOCATION: Powell Butte Highway/Neff Road/Alfalfa Market Road, Deschutes County, Oregon.
SOURCE: Google Earth.

U-turn from the outer lane. This becomes more prevalent with increased volumes during peak periods. The driver making the improper U-turn creates a potential exit-circulating conflict with a through movement on the intersecting street. This type of pattern is possible in many permutations on the entry and exit where access points are close to multilane roundabouts. Major origins or destinations upstream or downstream of the roundabout, such as shopping center access points or freeway interchange ramps, can have similar effects.

These lane positioning challenges are not unique to roundabouts and can occur with similarly spaced signalized intersections. However, field research suggests that drivers appear to be more willing to make turning movements from incorrect lanes at multilane roundabouts, with poor safety performance over time as a result (*26*). Single-lane roundabouts eliminate these issues and are to be strongly considered where possible. If multilane roundabouts are necessary, the roundabout design needs to consider overall access needs and design influences. During corridor or intersection planning activities, creating an access management plan will inform the best lane configurations for the intersection and connecting roadways.

10.11.3 Locating Full Access Near a Roundabout

Locating an access point that allows all ingress and egress movements (hereafter referred to as *full access*) is influenced by four primary technical considerations. However, other issues and

Exhibit 10.103. Example of incorrect U-turn at multilane roundabout initiated from nearby access point.

SOURCE: Medina et al. (*26*).

needs may be influenced by optimizing the roundabout design for project context and user types, as outlined in Section 10.1. The location and level of access for access points in the vicinity of a roundabout, especially a multilane one, is a valuable part of ICE activities.

Factors to consider include

- **The capacity of the minor movements at the access point.** A standard unsignalized intersection capacity analysis is performed to assess the operational effectiveness of an access point with full access. Unlike the platooned flow typical downstream of a signalized intersection, traffic passing in front of an access point downstream of a roundabout will be more randomly distributed. As a result, an access point downstream of a roundabout may have less capacity and longer delay than one downstream of a traffic signal. Queuing from nearby intersections (the roundabout or others nearby) needs to be checked to see if the operation of the access point will be affected.
- **The need to provide left-turn storage on the major street to serve the access point.** For all but low-volume driveways, it is often desirable to provide separate left-turn storage for access points downstream of a roundabout to minimize the likelihood that a left-turning vehicle will block the major street traffic flow. A probability analysis can determine the likelihood of an impeding left-turning vehicle, and a queuing analysis can determine the length of the queue behind the impeding left-turning vehicle. If the number of left-turning vehicles is sufficiently small or the distance between the access point and the roundabout is sufficiently large, a left-turn pocket may not be necessary.
- **The available space between the access point and the roundabout.** Traffic operations or local criteria will dictate the minimum left-turn storage length and the bay taper length requirements. The distance to the full access point will include at least the minimum length roundabout splitter island and any additional requirements for a turn lane into the access point, if needed. In addition, access will be restricted along the entire length of the splitter island and left-turn pocket channelization.
- **Sight distance needs.** A driver at the access point needs to have proper intersection sight distance and to be visible when approaching or departing the roundabout.

10.12 Parking

Parking considerations on a roundabout approach or in a roundabout are like those of other intersections. Parking within a roundabout is prohibited. Some circular intersections have parking along the circulatory roadway, which creates friction and potential conflicts with circulating vehicles. While these conditions may be appropriate for the context, a circular intersection with parking along the circulatory roadway is not a roundabout and may not have the same safety performance and operational characteristics of a true roundabout.

Practitioners can discourage parking on the roadway approaches and departures to remove vehicle conflicts, friction, and other distractions from users navigating and crossing the roundabout. The traffic operational or geometric influence area of the roundabout may extend well upstream or downstream of the ICD. Parking on roadway approaches and departures is based on assessing and establishing the operational and geometric influence area of the roundabout, with a priority to provide no parking or to locate parking as far upstream or downstream as possible. The needs on each approach of the same roundabout may be unique. The following factors are considered when establishing parking near roundabout entries and exits:

- Parking maneuvers create friction along the roadway. These movements will preferably not interfere with bicycle, pedestrian, or motor vehicle movements at the roundabout.
- Parked vehicles can obstruct visibility of pedestrians and bicyclists.

- Parking along multilane roadways can introduce lane assignment problems similar to those for access points, as discussed in Section 10.11.
- State or local standards or guidelines may dictate a minimum parking setback from intersections. At roundabouts, this setback is be measured from the crosswalk or the point where bicyclists may be entering the travel lane—whichever is farther from the roundabout.

10.13 Bus Stop Placement

Bus stops are commonly located in the vicinity of roundabouts. To provide the best quality of service for bus passengers, bus stops are located as close to pedestrian crossings as possible to minimize out-of-direction travel. However, they also need to be located to be compatible with the roundabout, including having buses in the correct lane in a multilane roundabout. This section presents a discussion of possible options for bus stops.

If a bus stop on the entry side of the roundabout (a near-side stop) is chosen, it will be located and designed as follows:

- On a single-lane approach, the bus stop could be in the travel lane immediately upstream of the pedestrian crossing.
- On a multilane approach, a near-side bus stop in the travel lane is to be avoided because vehicles in the lane next to the bus may not see pedestrians and create a multiple-threat condition. A pullout compatible with the pedestrian and bicycle circulation system is instead used. However, a bus exiting the pullout may obscure the visibility between pedestrians and oncoming motor vehicles; a bus stop on the exit side may be preferable.

If a bus stop on the exit side of the roundabout (a far-side stop) is chosen, it will be located and designed as follows:

- Bus stops are located immediately beyond the pedestrian crossing to improve visibility of pedestrians to other exiting vehicles. Proximity to the crosswalk is preferable to minimize out-of-direction travel for pedestrians.
- Stops on the exit side result in the crosswalk being behind the bus, which helps drivers see pedestrians and allows the bus to depart while pedestrians are still crossing the street.
- Bus pullouts reduce the likelihood of queuing behind the bus into the roundabout. A bus pullout may create sight line challenges for the bus driver to see vehicles approaching from behind as the bus driver attempts to merge into traffic.

Bus stops cannot be located along the circulatory roadway for the following reasons:

- Bus stops along the circulatory roadway eliminate the detectable buffer that is required between the circulatory roadway and pedestrian path per proposed PROWAG. Detectable buffers are discussed further in Section 10.4.
- Bus stops within the circulatory roadway, either in-lane or in a pullout, introduce conflicts within the circulatory roadway that cannot be present at a roundabout.

10.14 Treatment for High-Speed Approaches

Roundabouts have been successfully located at the intersection of high-speed roadways. Roundabouts provide geometric features that create low speeds. However, roadway facility type, context, or context classification may create conditions at which additional treatments are beneficial for speed reduction in advance of the roundabout. For roadway approaches with posted speeds of 45 mph (70 km/h) or greater, the roundabout configuration may include treatments on those approaches. This could include considerations for possible transition treatments or features between the upstream segment and the roundabout to support speed reductions. When conducting in-service reviews at an existing circular intersection, the upstream roadway approach speeds could provide insights into the observed roundabout performance.

Intersections on rural roads often have higher approach speeds than urban or local streets. Most intersections on rural roads are two-way stop-controlled intersections, with the major street uninterrupted. As such, drivers may not expect to encounter speed interruptions or intersections that require stopping—as at an all-way, stop-controlled intersection—or potentially stopping—as at a roundabout or signalized intersection. The primary safety and operational needs at these rural intersections are making drivers aware of the impending intersection and providing ample distance to comfortably decelerate to the appropriate speed.

This challenge is not unique to rural roadways. Suburban roadways and some urban roadways may also have posted speeds of 45 mph (70 km/h) or higher. Creating driver awareness of speed reduction at roundabouts may be necessary. The same general principles apply to creating awareness and providing sufficient distance to reduce speed at the roundabout entries. Mini-roundabouts and compact roundabouts have less conspicuous central islands, so treatments on those approaches may be especially necessary to support desired roundabout safety and operational performance.

A fundamental principle associated with speed transitions is creating self-describing roadways that help an approaching driver interpret and react to the upcoming roundabout correctly and safely. Deceleration distances are provided in the Green Book (*1*); values provided include minimum lengths that represent rapid deceleration conditions that may be uncomfortable for passengers. The deceleration lengths provided in this section represent AASHTO values for comfortable deceleration lengths between an approach speed and roundabout target speeds.

Curvilinear alignments, also called *chicanes*, are not required for speed reduction but are acceptable. In some cases, curvilinear alignments may be a byproduct of the entry design to achieve appropriate entry speeds and other design performance objectives. However, curvilinear alignments can help support incremental speed reduction upstream of the roundabout entry. In constrained locations, however, curvilinear alignments may not be possible.

Geometric design and the transition zone established to meet target speed reduction may be based on the required deceleration length, which includes the painted taper and the splitter island. Geometric design is the foundation for speed transitions. However, signage, pavement markings, lighting, and other treatments (e.g., speed feedback signs, rumble strips, or flashing beacons) support deceleration to the roundabout. Exhibit 10.104 depicts a roundabout approach with a painted taper and extended splitter island as the primary feature supporting the speed transition. The approach also includes complementary optical speed bars to help drivers understand deceleration needs approaching a rural roundabout.

Exhibit 10.105 depicts a tangent roadway approach in a high-speed environment. Exhibit 10.106 depicts a curvilinear roadway approach in a high-speed environment.

10.14.1 Visibility

Visibility enables driver awareness of an approaching roundabout and positively contributes to safety performance. Providing visibility of the roundabout and approaches can reduce the potential for single-vehicle crashes. Where possible, the geometric alignment of approach roadways is constructed to maximize the visibility of the central island and the shape of the roundabout.

The central island of the roundabout and the geometric alignment and channelization on the approaches are primary features to support speed reduction. Cross-section elements, such

Exhibit 10.104. Example of geometric and supplemental features on a rural roundabout approach.

LOCATION: Powell Butte Highway/Neff Road/Alfalfa Market Road, Deschutes County, Oregon. SOURCE: Lee Rodegerdts.

Exhibit 10.105. Example of tangent alignment on approach roadway.

LOCATION: STH 65/80th Avenue/W Graham Street, Roberts, Wisconsin. SOURCE: Google Earth.

Exhibit 10.106. Example of curvilinear alignment on approach roadway.

LOCATION: Bullfrog Road/Suncadia Trail, Cle Elum, Washington. SOURCE: Google Earth.

as introducing curbing on the approach, help drivers interpret the transition from the roadway to the intersection. In addition, adding curbs and dropping shoulders reduces the cross-section width to promote positive guidance. All these features contribute to a self-describing roadway that encourages speed reduction.

Traffic control devices, reflective delineators, and roadway lighting supplement these geometric features to provide additional visibility approaching a roundabout. These are discussed further in Chapter 12: Traffic Control Devices and Applications and Chapter 14: Illumination, Landscaping, and Artwork.

10.14.2 Approach Speed and Speed Transitions

Assessing the influence of the approach roadway and transition lengths to the roundabout can follow operations and design principles for freeway exit ramp deceleration lengths. Practitioners can determine deceleration lengths by considering design or operating speeds at the exit ramp and an associated target speed. At a freeway exit ramp, the deceleration length is typically the distance to a downstream controlling curve or stop condition.

The deceleration distance for a roundabout is based on the assumed stop location and the distance upstream of the roundabout, where the approach speed has been established. Roundabout approach speeds can be the observed, posted, or design speed on the approach roadway. Deceleration lengths can be the distance to a potential stop condition at the roundabout crosswalk, the entry (if no crosswalk is provided), or the estimated back of queue on a given approach—whichever is farthest from the roundabout. The deceleration length includes the painted taper and the splitter island.

Exhibit 10.107 presents the deceleration length concept for a single-lane roundabout. This concept also applies at multilane entries.

Exhibit 10.108 presents minimum deceleration lengths to an assumed stopped condition for flat grades of less than 3 percent. The table and values are adapted from the Green Book, Table 10-6, for freeway exit ramp terminals. For grades greater than 3 percent, adjustment factors from AASHTO may be used to shorten or lengthen the deceleration distance (*1*).

The deceleration length values can inform planning and design decisions and are not intended to be absolute values or requirements. Many roadway, context, and land-use considerations may affect these decisions. For example, existing rural conditions could be evolving to more developed

Exhibit 10.107. Deceleration length roadway approach to crosswalk.

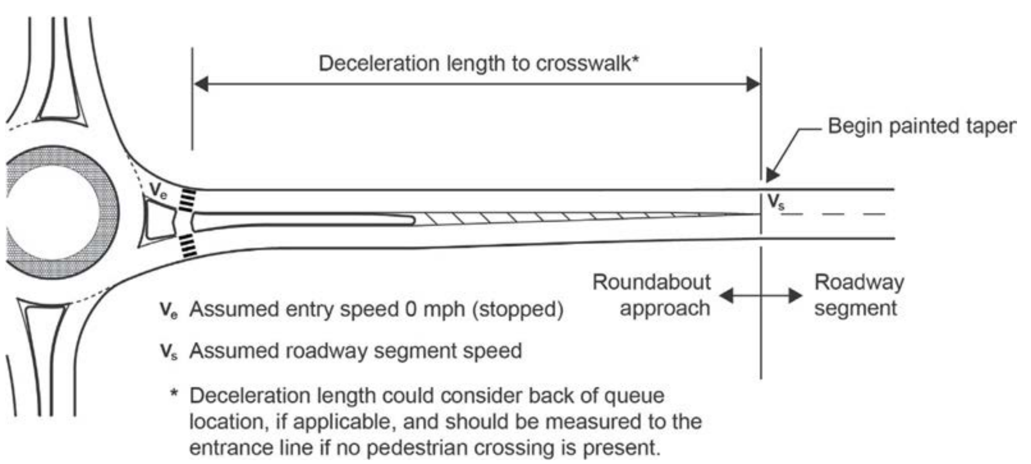


Exhibit 10.108. Minimum deceleration lengths for flat grades.

Approach Roadway Design Speed (mph)	Minimum Deceleration Length to an Assumed Stopped Condition (ft)	Approach Roadway Design Speed (km/h)	Minimum Deceleration Length to an Assumed Stopped Condition (m)
40	320	70	110
45	385	80	130
50	435	90	145
55	480	100	170
60	530	110	180
65	570	120	200
70	615	130	215
75	660		
80	705		

SOURCE: Adapted from Green Book, Table 10-6 (*1*).

conditions along the roadway or near the intersection. However, evaluating roadway approach speeds and speed transition needs early in project development can help identify footprint issues or other access considerations that support ICE activities or other project evaluations. Considering approach speeds may also support in-service roundabout review.

Extended splitter islands alert drivers to the changing condition of an impending roundabout. The splitter island is within the deceleration length that includes the painted taper. Splitter islands provide positive guidance and can aid in reducing approach speeds. Their configuration is based on a horizontal alignment that provides the desired speed transition.

Splitter island lengths of 150 ft to 200 ft (45 m to 60 m) or more have been commonly used to complement the painted taper for overall deceleration needs. Splitter islands need to be customized to each roundabout approach and to be consistent with the horizontal design of each approach. For example, at a roundabout on a rural highway approaching a community, longer splitter islands may be appropriate to support speed reduction on the high-speed approach, while shorter splitter islands may be appropriate for the other approaches with lower approach speeds.

10.14.3 Approach Curves

The change in speed from the upstream roadway segment to the roundabout entry can be established as a speed profile (i.e., speed over distance). The segment speed could be observed speed, posted speed, or design speed, and the assumed speed at the roundabout is a stopped condition. If approach curvature is to be used to manage speed or as a byproduct of desired roundabout entry design, the speed profile can provide insight into the curve radii to be used. A series of progressively sharper curves on the approach creates a self-enforcing roadway that slows motor vehicles to target entry speeds.

Transition alignments to roundabouts with speeds of 45 mph (70 km/h) or less are classified by AASHTO as *low speed* and may use superelevation rates presented in the Green Book, Table 3-13 (*1*). Tangents always need to be provided between reverse curves to support a flowing alignment to the roundabout entry. Because most of these speeds are in the low-speed category (i.e., 45 mph [70 km/h] or slower) a normal crown or reverse crown may be used in many cases. If there are other superelevation needs based on site conditions, practitioners can use published superelevation values based on the anticipated operating speeds along the speed profile, deceleration needs, and curve radii.

Approach curves are commonly reverse curves and need to be separated by a tangent. An initial horizontal curve is not required, and an angle point may be used. This is similar in concept to an angle point used at a highway exit ramp. Angle points may range from 2 degrees to 5 degrees, as presented in Section 10.6.2.

When approach curves are used, they are to match the desired speed along the roadway approach. A broad radius needs to be followed by a moderate radius before the entry radius. Actual speeds associated with these radii will vary by roadway approach speed and deceleration needs. The curve radii selected ideally will not introduce speed differentials of more than 10 mph to 15 mph (16 km/h to 25 km/h) between successive curves.

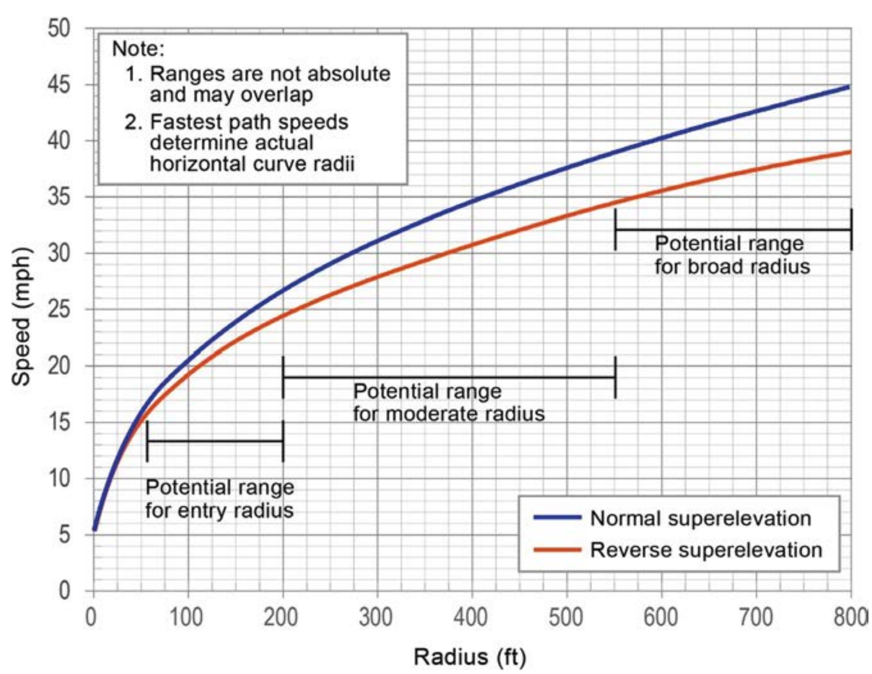
Exhibit 10.109 presents an example of speed-radius relationships for normal crown and reverse crown (i.e., +2 percent and –2 percent superelevation) for speeds of 45 mph (70 km/h) or less. The exhibit generally identifies a range of speeds for broad, moderate, and entry radii.

Exhibit 10.110 presents an example of a design detail for a curvilinear alignment for approach speeds 50 mph (80 km/h) or greater. As shown in the exhibit, these approach curves are progressively smaller radii to minimize the speed reduction between successive curves. The transition from large to small radii matches the speed profile and comfortable deceleration along the approach to the roundabout entry (or to the crosswalk or expected back of the queue).

10.14.4 Curbing

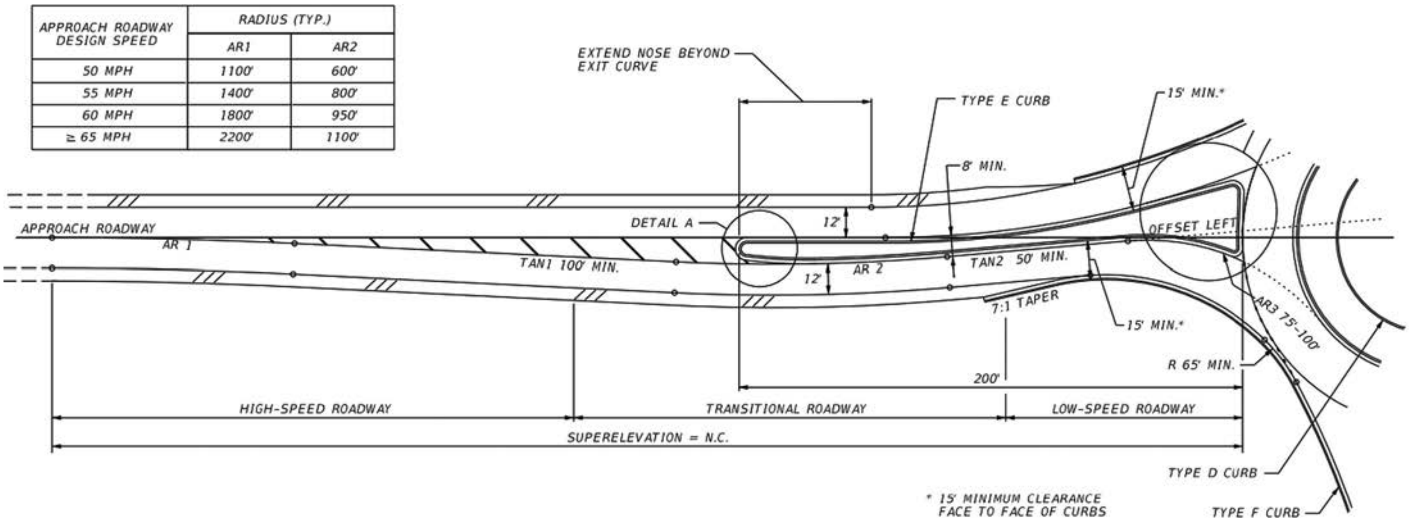
On roadways without curbs, adding outside curbs changes the roadway cross section and indicates a changing roadway and operational environment. Curbing can be introduced coincidentally with the painted taper on the roadway segment approaching a roundabout or coincidentally with the beginning of the splitter island. Curbing creates a funneling effect that supports a driver's

Exhibit 10.109. Example broad and moderate speed/curve relationships.



SOURCE: Adapted from Washington State Department of Transportation (*36*).

Exhibit 10.110. Example approach curve design.



SOURCE: Florida Department of Transportation (*37*).

recognition of the upcoming roundabout while providing positive guidance through the transition to the roundabout entry.

Rural highways typically have no outside curbs. Instead, they often have paved or gravel shoulders. Adding curbs on the outside edges of pavement provides drivers with a sense that they are entering a more controlled setting that supports speed reduction. Curbing does not necessarily require closed drainage systems. Open drainage can often remain if gaps are provided in the curbs so that stormwater may drain to adjacent drainage ditches. Mountable curbs, if used, are advised on high-speed approaches.

Exhibit 10.111 depicts a rural roundabout approach where curbing was introduced at the beginning of a splitter island on a high-speed approach. Exhibit 10.112 shows an example of a roundabout with gaps in curbing to support open drainage.

Exhibit 10.111. Example of external curbing introduced at the leading end of a splitter island.

LOCATION: Best Road/McLean Road, Mount Vernon, Washington.
SOURCE: Lee Rodegerdts.

Exhibit 10.112. Example of curbing with open drainage.

LOCATION: Best Road/McLean Road, Mount Vernon, Washington.
SOURCE: Lee Rodegerdts.

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CHAPTER 11

Vertical Alignment and Cross-Section Design

Contents

This chapter discusses *roundabout vertical design*. Roundabout vertical design represents a combination of roadway profiles, cross-section elements, and resulting three-dimensional surfaces that must consider the interrelationships of all elements. As with horizontal design, roundabout vertical design is an iterative performance-based process including checks for intersection sight distance, drainage, and user needs (such as pedestrians, trucks, vehicles with trailers, and snowplows).

The fundamentals of vertical design for roundabouts are similar to those for other intersections. However, for vertical alignment and cross-section development, roundabouts differ from other intersection types. Each roadway approaching a roundabout has a control line (also referred to as a *baseline of construction* or *profile grade line*)—which may or may not be in the center of the roadway—outside the roundabout influence area. The control line for each approach will intersect in the roundabout to establish the connection between the roadways and form the basis for subsequent vertical design. However, the control line that defines the approach roadways at roundabouts will differ into and through the circulatory roadway. A variety of design approaches are available to define control lines, for example, along the face of curb on either side of a median or along perimeter curb lines. Any approach a practitioner takes in the roundabout's vertical design should provide sufficient information to support design decisions and allow a contractor to construct the roundabout.

Because of the interrelationship between vertical alignment and cross section, a discussion of vertical alignments is followed by an overview of design goals and considerations related to the roadway cross section. This chapter discusses these elements as they relate to roundabout performance—visibility, drainage, driver comfort and safety, and accessibility—and the need for context-sensitive design. Finally, the chapter presents vertical considerations related to pedestrians, bicyclists, and trucks.

11.1 Profile and Cross-Section Relationships

Once a horizontal alignment is established, vertical design may proceed with the following goals:

- Serve design users:
  - Provide drivers with smooth longitudinal transitions into and out of the intersection.
  - Develop cross slopes and cross-slope transitions in line with speed control targets for the intersection.
  - Accommodate truck movements by minimizing likelihood of load shifting and vehicle rollovers.
  - Provide accessible pedestrian crossings.
  - Avoid under clearance conflicts for low-clearance vehicles with curbs, truck aprons, and circulatory roadways.
- Provide adequate stopping sight distance.
- Facilitate surface drainage and avoid icing in travel lanes.
- Provide a constructible design.

These goals may be associated with jurisdiction-specific requirements (e.g., minimum or maximum grades at certain locations). In general, roadways have to be designed with a cross slope and a longitudinal grade to support stormwater conveyance and to minimize the likelihood of icing. Minimum requirements may vary but are typically 0.5 percent (*1*). However, below 1 percent, contractors often struggle to maintain construction tolerances to attain positive drainage, which can result in ponding and sediment collection (especially at curbs).

Exhibit 11.1 presents a general overview of vertical design decisions and performance checks. The process addresses various components of vertical design and emphasizes adaptability to each project context. Context is key; early project planning and concept assessments may identify vertical design and drainage as critical project design drivers. In such cases, practitioners need to consider vertical elements early when developing horizontal design configurations.

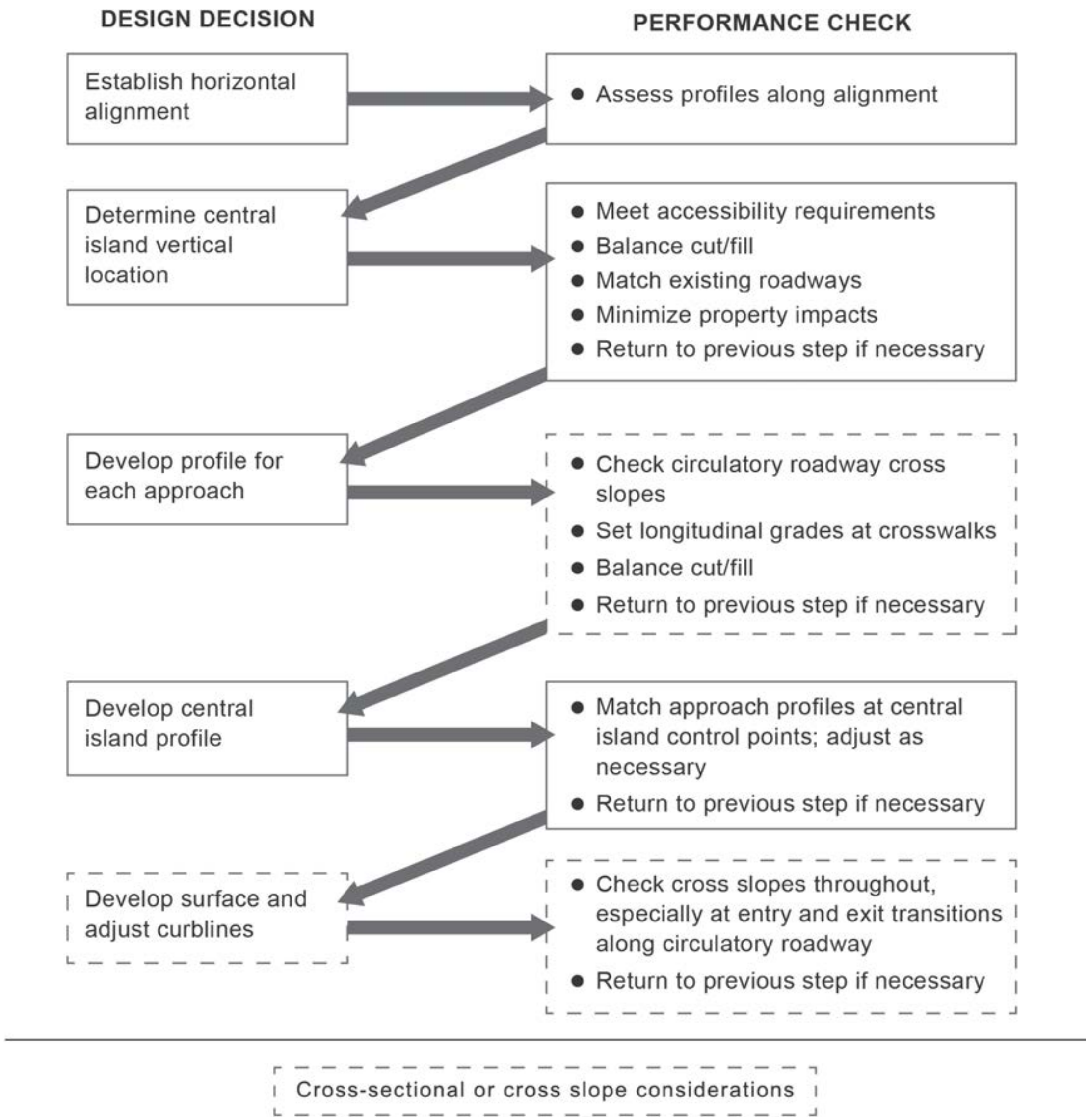
As Exhibit 11.1 demonstrates, the practitioner will iteratively evaluate grades, surfaces, and cross slopes resulting from alignment decisions through a series of assessments that inform vertical design choices. Exhibit 11.1 demonstrates the interconnected nature of these longitudinal and cross-slope considerations by showing decisions or performance checks that include cross-slope elements with a dashed border.

Section 11.2 provides the general approach for developing a profile that considers site context along with key design and performance targets.

11.2 Profile Development

Developing a roundabout profile to support a vertical design is an iterative process. This section presents a procedure that involves tying the elevations of each approach roadway profile along an established baseline into a smooth profile at the roundabout entry, around the central island, and to the exit that transitions to the departure roadway. These elevations, in turn, help guide external curb profiles. The travel paths for each entry, each exit, and the circulatory roadway are unique, each defined by interior and exterior curbs with their own profiles. Together, the profile elements support developing and refining a continuous surface that meets vertical design requirements.

Exhibit 11.1. Overview of vertical alignment development decisions and checks.



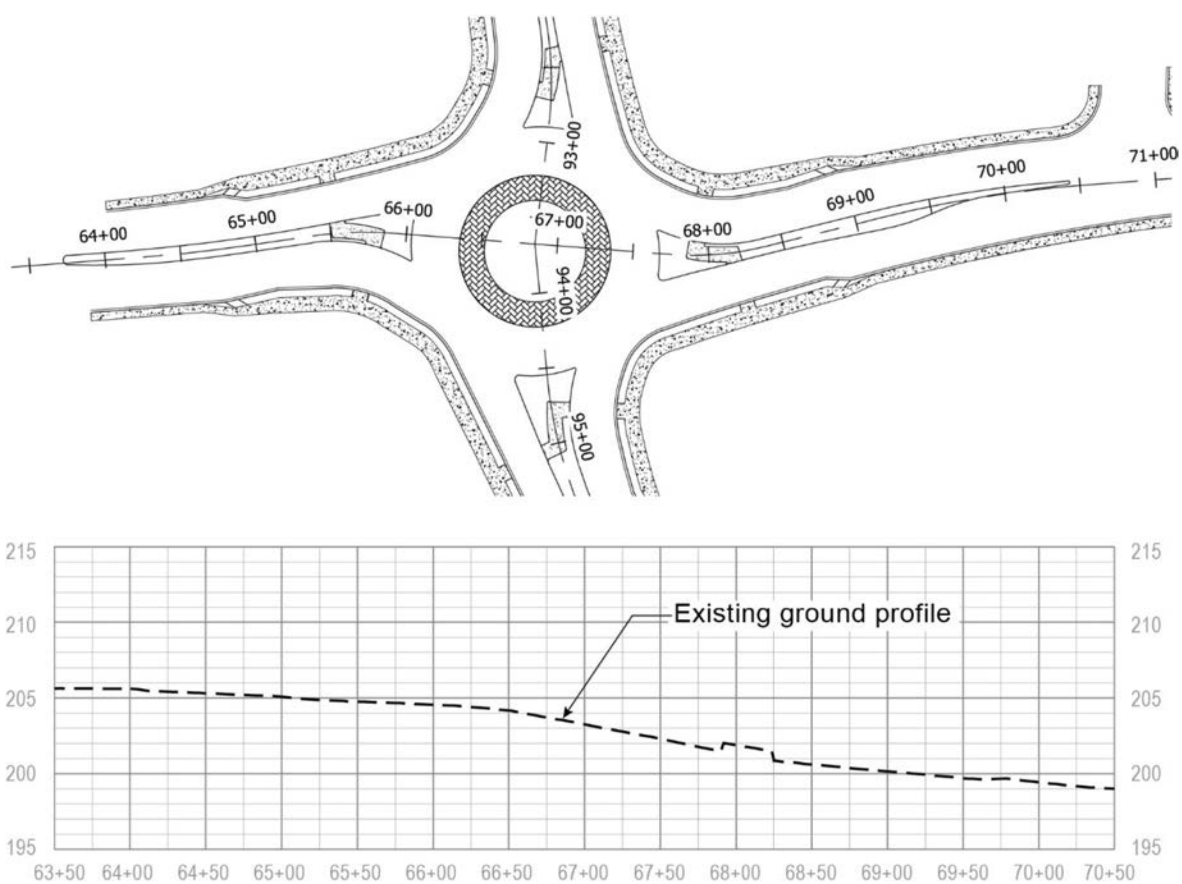
A general procedure to develop a profile is described below. The example is provided to emphasize design principles and intent, but a variety of techniques can be used to appropriately meet vertical design needs.

Vertical alignment design starts with overlaying a horizontal alignment onto the existing roadway approach profiles and assessing the context. The vertical alignment can be assessed along any desired profile grade line. A vertical alignment needs to reflect the natural terrain of the area. However, each design is unique. Constructing a roundabout that matches existing roadway features could mean using existing outside curb elevations and cross sections as design controls; this *outside-in* approach is described at the end of this section. Profile development proceeds as follows:

- **Establish horizontal alignment.** Chapter 10: Horizontal Alignment and Design explains how to develop a horizontal alignment. In reconstruction projects or projects along an existing alignment, the horizontal alignment of the roundabout will likely not match the centerline of the existing roadway. The construction alignment will follow the curvature of the roundabout, and the profile grade line will eventually be established along this horizontal alignment.

- **Assess existing ground profiles along the horizontal alignment.** A sample of existing elevations along each roadway's profile grade line provides the existing topography and roadway approach as well as departure grades. The existing ground profile allows practitioners to match the subsequent profile design decisions to the existing context and condition (to the extent possible). See Exhibit 11.2 for an existing ground profile matching a proposed horizontal alignment.
- **Determine central island vertical elevation.** Using the existing ground profiles as a reference (Exhibit 11.2), select an approximate elevation for the central island. For roundabouts with non-traversable central islands, the elevation of the truck apron's inner edge will be the basis for the vertical design of the non-traversable central island. For mini-roundabouts and compact roundabouts with fully traversable central islands, the established elevations will be the basis for the traversable central island (whether raised or flat). The following priorities will influence the vertical elevation:
  - Meet accessibility requirements at crosswalks (see Section 11.5).
  - Provide positive drainage.
  - Avoid low spots near crosswalks to minimize water ponding where pedestrians will cross.
  - Optimize cut and fill among approaches, either mathematically or visually.
  - Match existing roadway approaches.
  - Minimize impacts to adjacent properties, including any cut, fill, and need for retaining walls.
- **Develop the profile for each leg of the roundabout.** Using the roundabout elevation established in the previous step, practitioners will design a profile for each leg that ties into the existing grade at the extents of construction. The profiles will allow for adequate cross slopes through the circulatory roadway (see Section 11.4) and meet accessibility requirements at all pedestrian

Exhibit 11.2. Example of plan of roundabout alignment and existing ground profile.



crossings (see Section 11.5). Practitioners will then assess the balance of cut and fill again and iterate as needed to optimize the design. Roadway approaches with steep grades (see Section 11.3) may provide additional challenges. Exhibit 11.3 provides an example vertical alignment profile overlaid on an existing ground profile to show how the proposed alignment profiles relate to the existing condition.

- **Develop the central island profile.** Practitioners will design a profile along the truck apron that closely matches elevations with the roadway profiles established in the previous step. This may result in a *tilted* or *warped* circulatory roadway if one side of the roundabout is higher than the other. This is acceptable and often necessary when the existing grade varies on each approach (Section 11.4 discusses these concepts). The central island profile may have one low point and one high point around the circle—see Exhibit 11.4 for an example. Depending on the size of the roundabout, the assumed design speed of the circulatory roadway is between 15 mph and 25 mph (24 km/h and 40 km/h), as discussed in Chapter 9: Geometric Design Process and Performance Checks. Any crest and sag vertical curve values must be compatible with the design speed of the circulatory roadway. The approach profiles can be adjusted to match the outside edge of the circulatory roadway. Practitioners might need to adjust the profiles on the approaches, in the roundabout, or on the roundabout exit to smooth transitions. Practitioners will check vertical clearances (described in Section 11.6) for locations where vehicles may be prone to bottoming out and consider lengthening vertical curves to address low points and to smooth the profile.
- **Develop a continuous surface.** With the centerline and circulatory roadway profiles established, the roadway cross slopes can be laid out. Commercial software can model a continuous surface given the following inputs: a horizontal alignment, profile, and desired crown from the center of

Exhibit 11.3. Example of plan and profile for roundabout alignment.

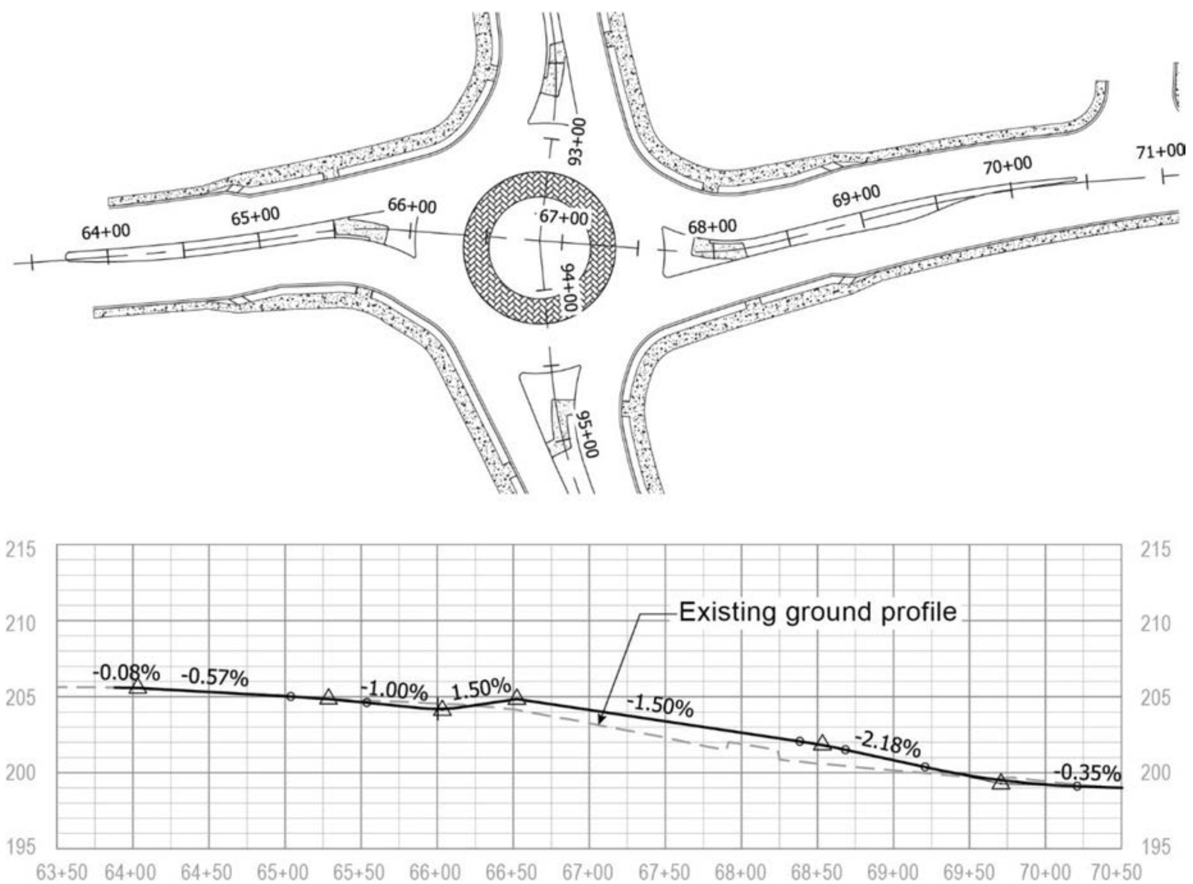
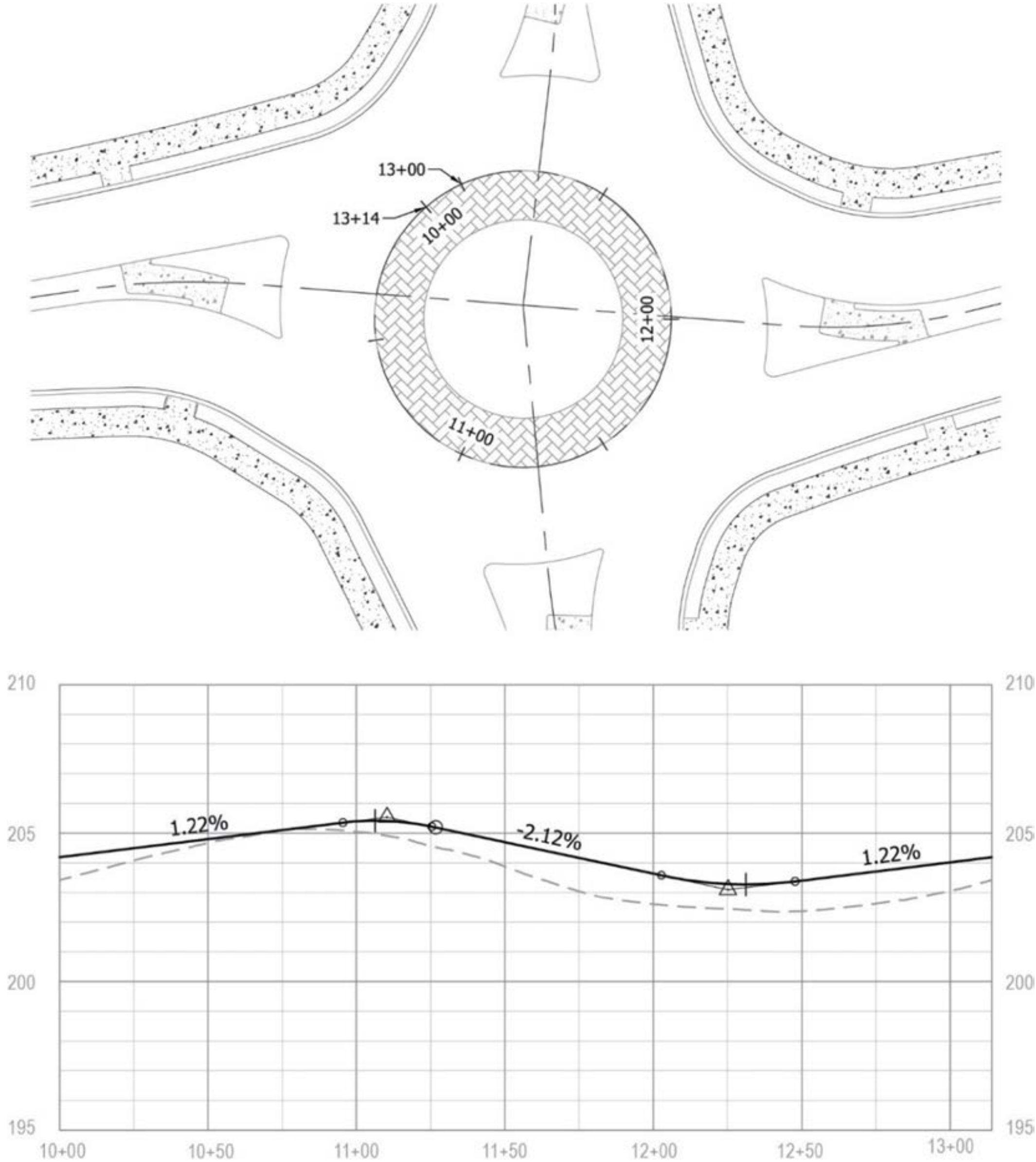


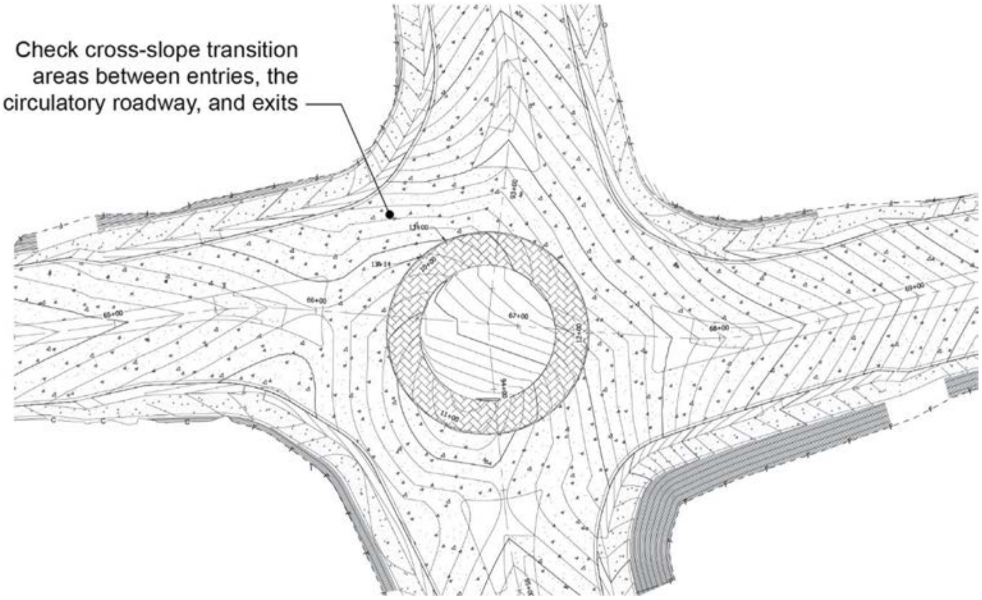
Exhibit 11.4. Example profile along outer edge of central island.



the approach roadways. Exhibit 11.5 provides an example of proposed grading as a result of this step. This example is for an outward sloping circulatory roadway; however, the tools and methods can apply to crowned roadways as well. Desired performance checks for this step include

- **Achieving minimum cross slope and longitudinal slopes for drainage purposes.** Practitioners will check cross slopes throughout, especially at locations where the horizontal curve deviates substantially from the centerlines (see Exhibit 11.5). Requirements may be jurisdictionally specific.
- **Establishing a curb return profile that creates the desired cross slopes.** If cross slopes are below or above the desired thresholds, the curb line elevations can be adjusted. Ultimately, the design cross slope may vary slightly between the entry, circulatory roadway, and exit. The goal is to avoid abrupt changes in cross slope and design drainage patterns so that water will shed in the desired direction.

Exhibit 11.5. Surface development with roadway profiles established.



- **Alternative approach: Proceed from the outside in.** Alternatively, practitioners can develop the outside edges of pavement and the splitter islands first, establishing alignments and setting the circle height on the basis of existing grades at the outside edges of the roundabout. This approach may be more desirable when implementing a retrofit into existing grades and curb lines. Furthermore, this approach may minimize property impacts and set the grades to build up the central island. This outside-in approach implies an iterative process of working from the outside in, followed by setting the inside grades on the central island and working them back out to set the final grades of the gutters and splitter islands. The cross slopes between the central island and the outside edge of the pavement, discussed in Section 11.4, become key variables.

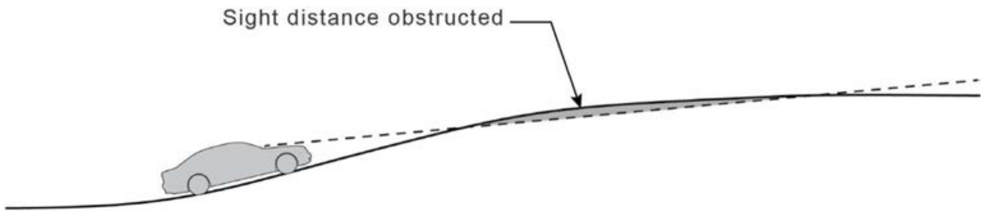
11.3 Roadways with Grades

Roundabouts can be effective and have been successfully implemented on roadways with approach grades. For any intersection located on a grade, including roundabouts, a few considerations apply:

- Motor vehicles making turning movements experience lateral forces affected by the speed of the vehicle and the localized grade and cross slope of the roadway where the vehicle is turning. Vehicle dynamics are especially important for trucks because of the potential for load shifting or for overturning when turning across negative superelevation (*2*).
- It is more difficult for entering drivers to slow or stop on an approach along a downgrade than on a flat approach or an upgrade. As a result, speed reduction and speed management are more critical on downgrades approaching the intersection.
- Crest vertical curves may limit available sight distance (Exhibit 11.6) to the pedestrian crossing or to the intersection entry. In such a circumstance, practitioners can reduce approach speeds through design or flatten the curve to allow adequate sight distance.
- Pedestrian crossings need to meet ADA requirements for longitudinal and lateral grades (refer to Section 11.5).

A primary focus for design is to reinforce slow speeds entering and through the roundabout. This helps to manage the speeds of vehicles, especially trucks, as they traverse through portions

Exhibit 11.6. Sight distance on crest vertical curve.



of negative superelevation. Research using simulation of truck dynamics over a range of conditions has found that speed management, cross section, and truck apron design are important design parameters for managing lateral forces on trucks (*2*). To promote low entry speeds, the designer may modify the location of the roundabout and adjust the horizontal alignment to manage vehicle speeds approaching and entering the roundabout. Practitioners can extend the splitter island upstream beyond the crest vertical curve and beginning outside curbs to help approaching drivers observe a change in the roadway typical section from the segment portion to the roundabout influence area. These techniques are discussed in Chapter 10: Horizontal Alignment and Design.

At the roundabout itself, the maximum negative superelevation for any movement and the speed transition into the negative superelevation are a focus of design evaluation to manage vehicle dynamics. The degree to which an approach grade may challenge specific users depends on the selected design vehicle and anticipated turning movements. The general practice in the United States has been to keep the grades and maximum negative superelevation through the roundabout to no more than negative 4 percent for affected turning movements (*3*, *4*). This may require adjusting the approach profiles to create the desired combination of grades and cross section within the roundabout.

Exhibit 11.7 and Exhibit 11.8 provide examples of vertical design approaches for a roundabout placed along a roadway with a steep grade—in this case, a 10 percent approach grade. Exhibit 11.7 demonstrates the option to carry a 3.5-percent grade through the roundabout along that alignment. This requires flattening the approach grade in advance of the roundabout entry and elevating the roundabout. Exhibit 11.8 demonstrates a second alternative—*benching* the roundabout—whereby the approach grades are increased and a vertical curve is placed to provide a roundabout that drains away from its central island. This configuration creates a more prominent platform for the roundabout; however, it also steepens the approach grade (potentially increasing speeds), requires more earthwork (i.e., roadway cuts), and may result in more environmental and right-of-way impacts. Designing for any location requires considering the trade-offs of each profile alternative and making choices appropriate for that site's location and context.

At the roundabout, the entry design and circulatory roadway require pavement warping or cross-slope transitions through each entry and exit and around the circulatory roadway. Roadway approaches, roundabout entries, and central island design need to establish sight distance associated with predicted approach and entry speeds.

Considerations when benching a roundabout include

- It is necessary that a benched design be configured to meet accessibility requirements at the crosswalk, as described in Section 11.5.
- Entry grade profiles need to strive to create a platform for yielding drivers to maintain a view of the circulatory roadway and avoid the sight distance obstruction shown in Exhibit 11.6. The longitudinal slope of the entry or exit grade also represents the cross slope of a pedestrian crossing.

Exhibit 11.7. Example of profile with modified downgrade profile through the roundabout.

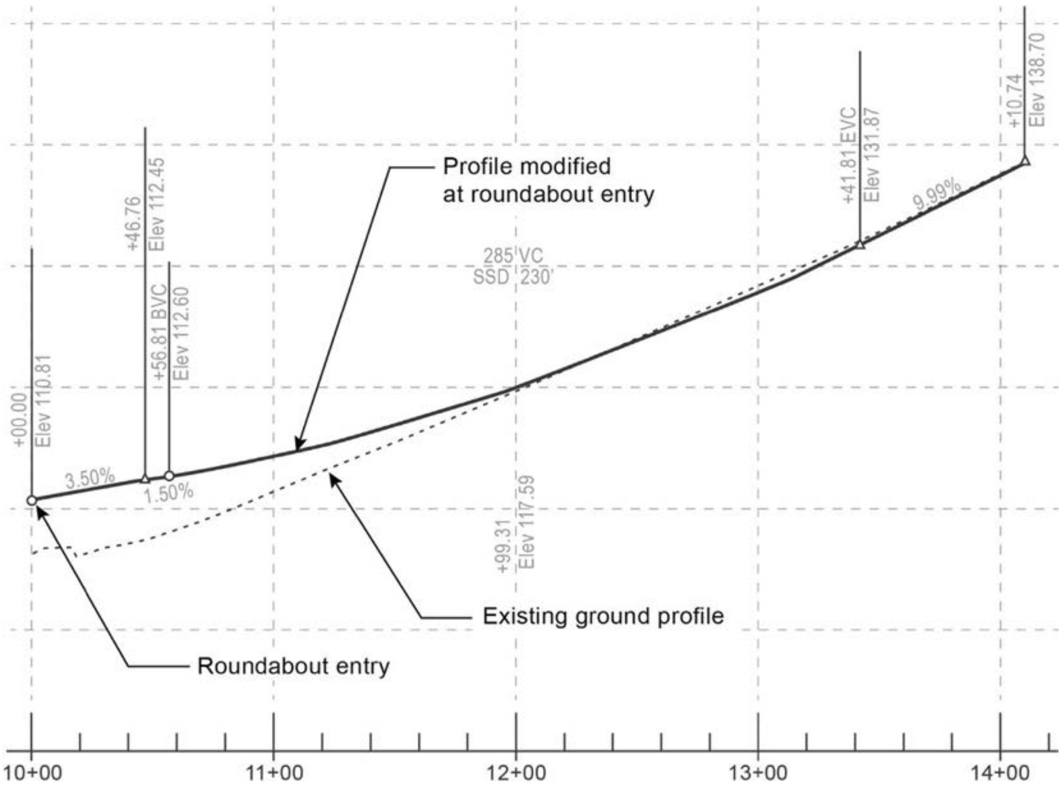
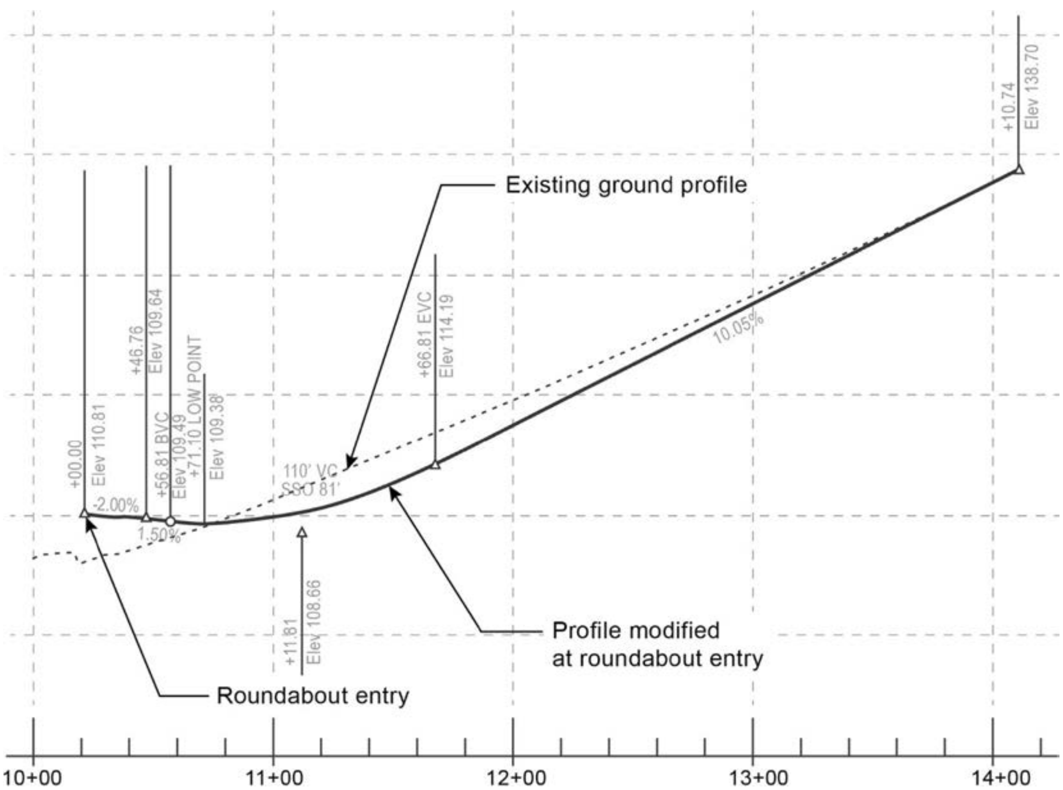


Exhibit 11.8. Example of benched profile with steeper approach grade to achieve a more desirable grade through the roundabout.



11.4 Transverse and Cross-Slope Design

The cross section influences roundabout profiles and surfaces. Together, the profile, cross section, and resulting surface influence roundabout performance in terms of drainage and meeting user needs. This section discusses cross-section design considerations for the circulatory roadway, central islands, and truck aprons.

Practitioners can consider the circulatory roadway vertical design once the central island has been located horizontally and vertically.

11.4.1 Outward Sloping Circulatory Roadway

The most common approach to grading the circulatory roadway is to slope it to the outside. This approach is particularly common for single-lane roundabouts because the overall drainage distance from the inside of the circulatory roadway to the outer curb is limited to a single-lane width.

When developing the circulatory roadway as part of the roundabout profile, it is often desirable to have a cross slope of 2 percent away from the central island to balance drainage needs with driver comfort. A 2 percent cross slope is a common crown section in roadway design but can vary by jurisdictional preference. Sloping outward from the central island is desirable for four main reasons:

- It promotes positive safety performance by raising the elevation of the central island and improving its visibility.
- It promotes lower circulating speeds by placing turning movements on a negative superelevation.
- It minimizes breaks in the cross slopes of the entrance and exit lanes.
- It helps drain surface water to the outside of the roundabout (*5*).

With this approach, the circulatory roadway is graded independently, and the outward slopes are typically at a grade of 1.5 to 3 percent. See Exhibit 11.9, *a* and *b*, for examples. This is most practical in flat terrain, as hilly terrain may require warping of the profile (see Section 11.4.3) and possibly an alternative vertical design. The location where the truck apron meets the circulatory roadway has potential ground clearance concerns for large vehicles and is discussed further in Section 11.6.

Other examples shown in Exhibit 11.9 show different combinations of inward and outward sloping truck aprons and circulatory roadway:

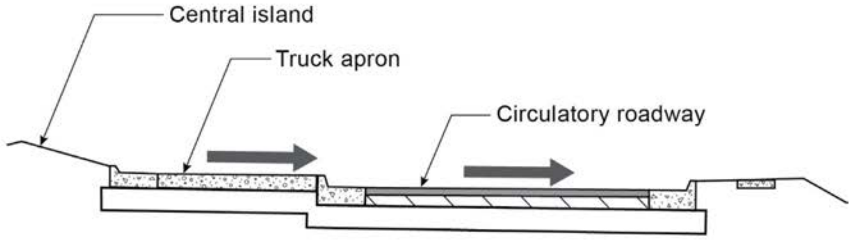
- The example in Exhibit 11.9*a* would provide the most conspicuous central island by making the central island a high point.
- The example shown in Exhibit 11.9*b* has flow lines running to the central island and may need drainage on the interior of the roundabout.
- The example shown in Exhibit 11.9*c* has flow lines running to the truck apron and would require a drainage feature at the apron (shown in Exhibit 11.10).
- The example in Exhibit 11.9*d* may need to capture stormwater runoff at the truck apron and on the interior of the roundabout.

Any of these combinations could be designed to meet vertical design needs.

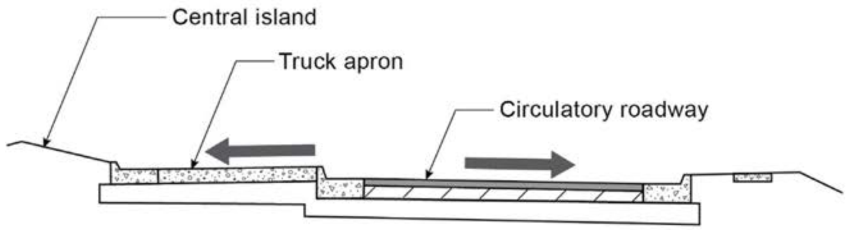
11.4.2 Crowned Circulatory Roadway

An alternative approach common with multilane roundabouts is to crown the circulatory roadway. Typically, the crowning will place two-thirds of the width sloping toward the central island and one-third sloping outward, though this may alternatively be reversed. Smooth crowning

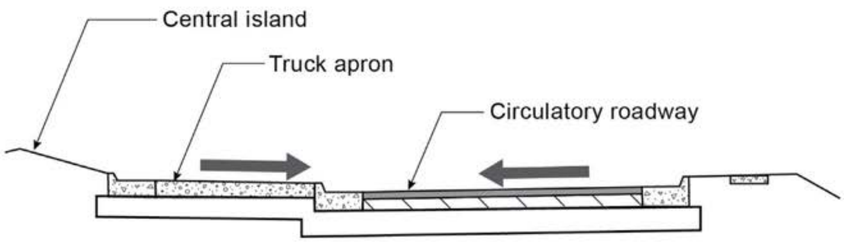
Exhibit 11.9. Variations of circulatory roadway cross sections.



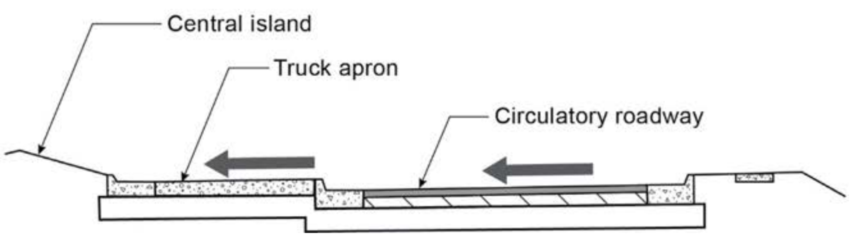
(a)



(b)



(c)



(d)

Exhibit 11.10. Example of circulatory roadway sloped inward to central island with sloped catch basin grate.

LOCATION: De Pere, Wisconsin. SOURCE: Wisconsin Department of Transportation.

may be easier to achieve using asphalt paving. Exhibit 11.11 shows an example of a crowned circulatory roadway.

Crowning the roadway may be beneficial for the following reasons:

- It may support truck movements through the intersection by reducing the slope on the rear wheels as they straddle the truck apron and adjacent lane (*5*).
- It creates shorter travel distances for snowmelt compared with an outward sloped roadway.

Crowning the roadway may also present some challenges:

- It may be more difficult to construct than an outward sloped roadway.
- It presents a need for inlets on the interior of the circulatory roadway and truck apron (see Exhibit 11.10).
- It provides positive superelevation for left-turning drivers, enabling slightly higher speeds compared with a negative superelevation (refer to Section 9.4.3).

11.4.3 Other Circulatory Roadway Grading Techniques

The outward sloping and crowned circulatory roadway approaches may be readily implementable on roadway approaches with modest grades; however, where relatively steep roadway approach grades converge, other options may be appropriate. In some locations where a retrofit is being considered, it may be desirable to use the existing ground elevation to reduce overall changes in profile. At the intersection of two major roadways, using the existing ground elevations may result in two crown lines crossing one another, with the circulating roadway *warping* between the crown lines to provide drainage. This same strategy is often applied in other intersection forms as well. However, it can affect driver comfort and lane discipline through the roundabout.

Exhibit 11.12 depicts a roundabout located and designed within existing vertical constraints and elevation lines. The picture makes clear that the curb lines of the truck apron on the right side of the image are substantially lower than those on the left side of the image, indicating that the design was matched to existing topographic constraints.

At some locations for roundabouts using these techniques, the cross slope from the truck apron to the splitter islands will pass through level (0 percent) at two points around the roundabout. At those points, the circulatory roadway would not resemble any of the examples in Exhibit 11.9, but the grade through the roundabout should be sufficient to drain stormwater. On the high side, water will drain to the truck apron and on the low side, water will drain to the outside.

11.4.4 Fully Traversable Central Islands

A fully traversable central island can be crowned or domed, or it can be sloped in one direction, as demonstrated in Exhibit 11.13. When the intersection profile is developed, the roundabout high point does not need to be placed in the center of the circle. If dictated by vertical clearance from OSOW checks, the central island can be sloped straight across from one side to the other if a high point is not achievable.

Exhibit 11.11. Typical cross section with crowned circulatory roadway.

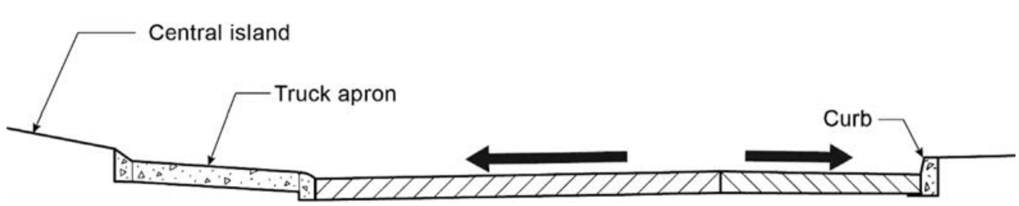
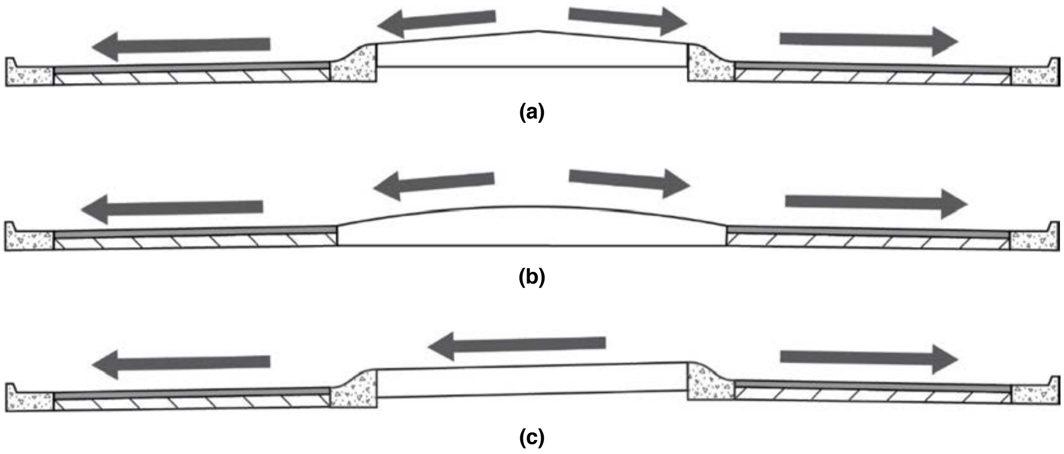


Exhibit 11.12. Example of roundabout fitting within constrained vertical environment.

LOCATION: Oberlin Road/Pullen Road/Groveland Avenue, Raleigh, North Carolina. SOURCE: Lee Rodegerdts.

Exhibit 11.13. Variations of fully traversable central islands for mini-roundabouts and compact roundabouts: (*a*) crowned, (*b*) domed, and (*c*) single slope.



Mini-roundabouts and compact roundabouts should have raised or domed central islands to promote conspicuity (refer to Section 2.3.2). In that case, it is desirable for visibility purposes that the central island be placed at the highest point of the intersection for visibility. Therefore, in most retrofit situations, mini-roundabouts and compact roundabouts may not necessarily require significant intersection re-grading. If raised, a fully traversable central island benefits from having a rolled curb (rather than a vertical curb) to support vehicle encroachment.

11.5 Pedestrian Design Influences

Accessible, ADA-compliant crosswalks are essential to serving pedestrians safely and effectively and are an integral part of the iterative vertical design process. Practitioners must follow the requirements and guidance in proposed PROWAG with regard to grades and cross slopes for the crossings (*6*, *7*). As previously mentioned, a construction tolerance of at most ± 0.5 percent is advisable. Locations with approach or departure grades that exceed PROWAG requirements could require that roadway approach and roundabout entries and exits be changed to meet

Exhibit 11.14. Example of aerial view of roundabout with raised crosswalks.

LOCATION: US 2 (Park Street)/Rangeley Road, Orono, Maine.
SOURCE: Jonathan French.

Exhibit 11.15. Example of ground-level view of raised crosswalks.

LOCATION: US 2 (Park Street)/Rangeley Road, Orono, Maine.
SOURCE: Jonathan French.

accessibility needs. This could increase the roundabout's footprint and require practitioners to reconfigure the vertical alignments of the roadway approach.

Raised crosswalks or speed humps force drivers to slow down; lower speeds have been linked to increased yielding behavior (*8*, *9*). A raised crosswalk can also guide pedestrians who are blind or have low vision to stay within the crosswalk if they can detect the crosswalk's side slopes as boundaries (*10*). The design of a raised crosswalk is a balance of a steep slope with a modest run (which may result in significant speed reductions) versus a gentler slope (which may have a more modest speed reduction but retain a higher capacity). Crosswalk design will also consider design vehicle maneuverability and needs (*10*). *NCHRP Research Report 834: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities: A Guidebook* includes more information on raised crosswalk effectiveness, cost, and considerations (*10*). Exhibit 11.14 and Exhibit 11.15 depict a roundabout with raised crosswalks on entry and exit legs.

11.6 Trucks

Single-lane and multilane roundabouts with non-traversable portions of the central island typically include a truck apron at the outer edge of the central island to provide for truck encroachment. Where truck aprons are used, the slope of the apron should generally be no more than 2 percent, as greater slopes may increase the likelihood of loss-of-load incidents.

Truck aprons are commonly sloped toward the outside of the roundabout (Exhibit 11.9, *b* and *d*). However, some locations have also implemented roundabouts with truck aprons sloped inward toward the central island to minimize both water shedding across the roadway and load shifting in trucks. Agencies using this strategy reported that additional catch basins were provided along the outer edge of the central island (i.e., the inner edge of the circulatory roadway) to collect water and pipe it under the circulatory roadway to connect with the drainage system along the roundabout periphery.

The truck apron has to be elevated above the circulatory roadway to discourage passenger car use. Between the truck apron and the circulatory roadway, a curb is required to accommodate a change in elevation. Practitioners need to review the vertical design of the truck apron to confirm that there is sufficient clearance for trailers with low vertical clearance, some of which may have 6 in. to 8 in. (150 mm to 200 mm) between the roadway surface and the bottom of the trailer.

In areas where concrete curbing is used, a gutter pan incorporated into the truck apron design can create better delineation between the curb face and the roadway. Although a gutter pan is not necessary with an outward sloping circulatory roadway, its inclusion provides structure for the truck apron. Because it is preformed, the gutter pan creates a consistent height of curb visible above the roadway surface.

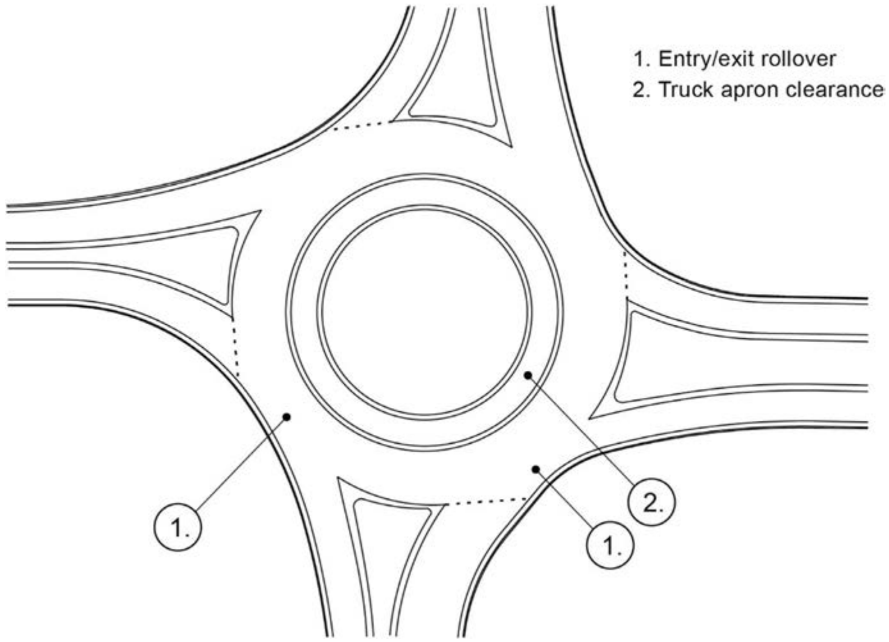
Depending on the design needs to support truck encroachment, an external truck apron may also be added to the exterior of the circulatory roadway. Exhibit 11.16 provides an example of an external truck apron.

For roundabouts that serve large vehicles with low vertical clearance, the profile must account for ground clearance. These vehicles typically have a ground clearance of 6 in. to 8 in. (150 mm to

Exhibit 11.16. Example of external truck apron.

LOCATION: Bryant Road/Greenway Cross, Madison, Wisconsin. SOURCE: Ourston.

Exhibit 11.17. Typical ground clearance concern locations.



SOURCE: Adapted from Wisconsin Department of Transportation (*11*).

200 mm), though it could be less. As part of profile and cross-section development, practitioners need to check these locations for adequate ground clearance (illustrated in Exhibit 11.17).

The locations and possible remedies presented in Exhibit 11.18 indicate some design treatments to accommodate large vehicles. Ultimately, the combination of grade, geometry, and sight distance can still be challenging.

Commercially available software packages include a feature to model the underside of a low-clearance truck to determine whether it would intersect the digital terrain model design surface of the roundabout and truck apron. This can be modeled and addressed by adjusting the grading surface or reducing the truck apron from 4 in. (100 mm) to 3 in. (75 mm). Alternatively, the vertical clearance

Exhibit 11.18. Ground clearance locations, issues, and possible remedies.

Location	Issue	Possible Remedies
1	Truck rollover incidents on entry and exit	• Flatten the circulatory roadway crown. • Avoid break-over grades over 3% within 200 ft (60 m) of the roundabout. • Limit the cross-slope rate of change, preferably between 0.02%/ft and 0.04%/ft (0.07%/m and 0.13%/m).
2	Trucks strike the truck apron (bottom out)	• Consider a maximum truck apron slope of 1%. • Locate the crest away from areas of concern. • Accommodate design vehicles within the circulatory roadway. • Keep the circulatory roadway profile as flat as possible while maintaining drainage requirements.

SOURCE: Adapted from Wisconsin Department of Transportation (*11*).

can be reviewed by drawing a chord across the apron in the position where the trailer would sweep across. In some cases, the warping of the profile along the circulatory roadway can create high spots that could cause trailers to drag or scrape along the truck apron.

11.7 References

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PART V

Final Design and Implementation

PROJECT DEVELOPMENT PROCESS

	Part I: Introduction to Roundabouts	Chapter 1: Introduction Chapter 2: Roundabout Characteristics and Applications
Planning	*Part II: Planning and Stakeholder Considerations*	Chapter 3: A Performance-Based Planning and Design Approach Chapter 4: User Considerations Chapter 5: Stakeholder Considerations Chapter 6: Intersection Control Evaluation
Identify and Evaluate Alternatives	*Part III: Roundabout Evaluation and Conceptual Design*	Chapter 7: Safety Performance Analysis Chapter 8: Operational Performance Analysis Chapter 9: Geometric Design Process and Performance Checks
Preliminary Design	*Part IV: Horizontal, Vertical, and Cross-Section Design*	Chapter 10: Horizontal Alignment and Design Chapter 11: Vertical Alignment and Cross-Section Design
Final Design Construction, Operations, and Maintenance	*Part V: Final Design and Implementation*	Chapter 12: Traffic Control Devices and Applications Chapter 13: Curb and Pavement Details Chapter 14: Illumination, Landscaping, and Artwork Chapter 15: Construction and Maintenance
Supplemental Appendix		Appendix: Design Performance Check Techniques

CHAPTER 12

Traffic Control Devices and Applications

Contents

This chapter discusses permanent traffic control devices at roundabouts. In the United States, traffic control devices are governed by the latest edition of the MUTCD (*1*). FHWA periodically issues interim approvals and updates to the MUTCD, and the latest version takes precedence over the content of this Guide.

Neither this Guide nor the MUTCD can present all possible combinations of traffic control devices applicable to a given roundabout. This chapter begins by presenting the principles of traffic control devices as they apply to roundabouts. The following sections discuss common traffic control devices used within and in the vicinity of roundabouts.

This chapter focuses on traffic control devices and applications, but practitioners can consider the content in this chapter concurrently with other chapters, specifically Chapter 8: Operational Performance Analysis and Chapter 10: Horizontal Alignment and Design. This chapter discusses permanent traffic control devices; refer to Chapter 15: Construction and Maintenance for information about temporary traffic control.

12.1 Principles of Traffic Control Devices

Traffic control devices—signs, pavement markings, signals, and beacons—work together to create a comprehensive system that regulates, warns, and guides road users through roundabouts. Practitioners can consider the following general principles for using traffic control devices:

- Per the MUTCD, traffic control devices should
  - Fulfill a need;
  - Command attention;
  - Convey a clear, simple meaning;
  - Command respect from road users; and
  - Give adequate time for proper response (*1*).
- Traffic control devices work as a system and need to be compatible with each other to present road users with consistent messaging.
- Traffic control devices complement a roundabout's geometric design. They clarify the rules of the road. **However, traffic control devices are not as effective on their own at providing desired performance as proper geometric design and may not fully correct the effects of faulty geometric design.**
- Traffic control devices are integral to the design process. During the conceptual and preliminary design stages, practitioners are advised to consider markings and, if needed, signal or beacon placement, especially for multilane roundabouts. Further details, such as sign size, width, and placement, typically come later in the design process, although it is helpful to plan horizontal and cross-section features and details (e.g., buffer strip widths for sign and signal or beacon placement) as needed.
- Traffic control devices need to be compatible with the context of the roundabout. For example, urban environments may need fewer signs than rural environments while having a greater need for bicyclist and pedestrian traffic control devices. Roundabouts with more legs or more lanes and roundabouts near freeway interchanges may need more robust guide signing.
- Traffic control devices for bicyclists and pedestrians are integral to roundabout design and are to be considered concurrently with those for motor vehicles.
- Practitioners need to consider traffic control devices in conjunction with the surrounding roadway system and land-use needs. Origins and destinations in the roadway system in the vicinity of the roundabout may dictate lane use and corresponding traffic control devices. Chapter 10: Horizontal Alignment and Design discusses this in more detail.

Traffic control devices at roundabouts can be grouped into four general areas, each with different goals:

- Transition area,
- Entry area,

- Circulating area, and
- Exit area.

The following sections detail many of the traffic control devices commonly used at roundabouts in each of these four general areas. Not all devices that may be used at roundabouts are covered. Practitioners are advised to consult the latest edition of the MUTCD and other documents for specific standards, guidance, options, and support for each device presented in these sections (and others not covered).

12.2 Transition Area

Traffic control devices in the transition area between the roadway segment and the roundabout support reducing speed, conveying changes in horizontal alignment, determining the intended exit from the roundabout, and getting into the correct lane to support the exiting decision. The type and configuration of signs and pavement markings depend on the roundabout's context, with more signs, more pavement markings, or both commonly needed in the following cases:

- Transitions from high-speed roadway approaches to the low-speed roundabout entry.
- Approaches where drivers need advance notice of destination information to make correct lane selections before entering the roundabout.
- Approaches where the roundabout is less visible from a distance because the central island is fully traversable.
- Approaches where the roundabout is offset to one side of the existing alignment and may be less visible as a result.
- Approaches where horizontal curvature, vertical curvature, or a combination of the two reduce the visibility of a roundabout from a distance.
- A roundabout where lighting is not used or lighting coverage is limited (see Chapter 14: Illumination, Landscaping, and Artwork). In these cases, signs and pavement markings provide primary visibility for the roundabout at night.

12.2.1 Advance Warning Signs and Markings

If advance warning of the roundabout is desired, practitioners have several options, including warning signs such as the following:

- **"Circular intersection" symbol sign (W2-6).** This sign warns road users they are approaching a roundabout. The "circular intersection" symbol sign is sometimes supplemented by a plaque with the legend "roundabout" (W16-17P), an advance street name plaque, flashing yellow beacons, flashing yellow LEDs embedded within the border of the sign, or a combination. Exhibit 12.1 shows an example. Some agencies use advisory speed plaques to supplement the "circular intersection" symbol sign.
- **"Yield ahead" sign (W3-2).** This sign is sometimes used to provide advance notice of the yield sign (R1-2) at the roundabout entrance. This sign is typically used where the roundabout and its yield signs are obscured by horizontal curvature, vertical curvature, or other visibility obstructions. The sign is sometimes used at isolated roundabouts or roundabouts on high-speed roadways. If used, the "yield ahead" sign most commonly supplements the "circular intersection" symbol sign.

Although not commonly used in practice, pavement word or symbol markings are sometimes used to supplement signing. Examples include the "yield ahead" triangle symbol marking or "yield ahead" word pavement markings.

Exhibit 12.1. Example of "circular intersection" symbol sign with supplemental street name plaque and flashing LED border.

LOCATION: Powell Butte Highway/Neff Road/Alfalfa Market Road, Deschutes County, Oregon. SOURCE: Lee Rodegerdts.

12.2.2 Advance Guide Signs

Guide signs provide drivers with proper navigational information. Guide signs can serve three purposes at roundabouts:

- **Advance information regarding intended destinations.** This enables roundabout users to prepare to make turning movements. This function is common to many intersection forms.
- **Confirmation signing regarding the appropriate exit.**
- **Supplemental warning that the user is approaching a roundabout.** The guide signs may take the place of similar warning signs.

Guide signs need to match the context of the location:

- Roundabouts at interchanges have the greatest need for guide signs to direct drivers between the crossroad and freeway ramps.
- Roundabouts on rural roadways with posted speeds of 40 mph or greater may benefit from guide signs to provide supplemental warning of the upcoming roundabout.
- Roundabouts where the primary route turns at the intersection may benefit from guide signs. Roundabouts located on state highways, for example, may have a more compelling need for guide signs than those on city streets.
- Roundabouts in urban areas may not need any guide signs aside from street name signs.

Several types of advance guide signs are available:

- **Diagrammatic exit destination signs.** Diagrammatic exit destination signs may be used on roundabout approaches to indicate destinations for each roundabout exit. The arrows representing the legs of the roundabout can be designed to represent the approximate angle of the exit legs. Diagrammatic signs can be especially useful where the geometry of the roundabout is non-typical, such as where more than four legs are present or where the legs are irregularly spaced. Diagrammatic signs are most common on state highways where numbered routes are shown. However, diagrammatic signs can be large when words (e.g., street names) are used instead of or in addition to route numbers to provide adequate legibility and separation of messages between legs. This makes such signs less desirable in many urban environments. Exhibit 12.2, Exhibit 12.3, Exhibit 12.4, and Exhibit 12.5 illustrate progressively larger diagrammatic sign assemblies.

Exhibit 12.2. Example of advance diagrammatic sign with route numbers.

LOCATION: STH 13/CR 2, Scott County, Minnesota. SOURCE: Lee Rodegerdts.

Exhibit 12.3. Example of advance diagrammatic sign with route numbers and destinations.

LOCATION: US 202–Route 4/Route 112, Gorham, Maine. SOURCE: Lee Rodegerdts.

Exhibit 12.4. Example of advance diagrammatic sign with street names.

LOCATION: Riverfront Drive/Broadway Street/Rockwater Boulevard, North Little Rock, Arkansas. SOURCE: Lee Rodegerdts.

Exhibit 12.5. Example of advance route assembly and advance text destination sign.

LOCATION: US 2/US 89, Browning, Montana. SOURCE: Lee Rodegerdts.

- **Text exit destination signs.** Exit destination signs with only text and arrows may be used on roundabout approaches to indicate destinations for each exit. Curved stem arrows can represent left-turn movements. Exhibit 12.4 illustrates an example.
- **Advance route number assemblies.** Advance route number assemblies can designate route destinations without text, and curved stem arrows may represent left-turn movements. Exhibit 12.5 illustrates an example.
- **Advance street name signs.** These guide signs are sometimes installed in advance of roundabouts to provide road users with the name of the next intersecting street. These are comparable to the "next signal" sign that is sometimes used in advance of signalized intersections.

12.2.3 Splitter Island Signs and Pavement Markings

Signs and pavement markings are commonly used to shift travel lanes, create space for the splitter island, and mark its leading edge. As noted in Chapter 10: Horizontal Alignment and Design, when an undivided roadway is divided to create space for a splitter island, pavement markings provide an initial shifting taper in advance of the splitter island. For the advance nose of non-traversable splitter islands, "keep right" signs (R4-7 or text variations R4-7a and R4-7b) with or without object markers, raised pavement markers on top of the splitter island curb, or a combination thereof are commonly used. Some agencies use internally illuminated bollards to highlight the end of the splitter island.

12.2.4 Lane Designations for Multilane Roundabouts

Lane designations—the combination of lane lines, lane-control signs, and lane-control pavement markings—are needed wherever drivers can use more than one lane. While lane designations are most obviously needed for multilane roundabouts with more than one circulating lane, they are also helpful at single-lane roundabouts where a right-turn-only lane is used on one or more approaches.

Lane designations that are consistent and compatible with the roundabout's geometric design and intended lane use are critical to achieving desired safety performance. Multilane roundabouts with exclusive left-turn lanes can lead to erratic maneuvers, conflicts, near-crashes, or property damage crashes, especially if not marked as such before entry (*2*, *3*). Research provides evidence that the safety performance of multilane roundabouts depends, in part, on effectively communicating lane-use assignments to drivers **before** they enter the roundabout (*2*). In turn, the lane-use assignments within the roundabout and on each exit must be compatible with entry lane-use assignments and the geometric configuration.

Lane-control signs and markings increase in importance with the complexity of the roundabout. These include the following conditions:

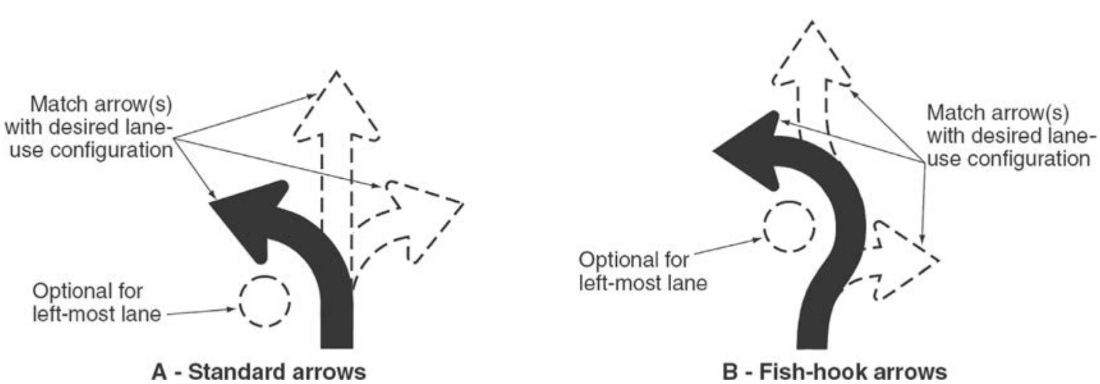
- The lane configuration is different from that specified by the default rules of the road, whereby left turns are allowed only from the leftmost lane, right turns are allowed only from the rightmost lane, and through movements are allowed from any lane.
- An approaching through lane becomes a left-turn-only lane or a right-turn-only lane.
- The lane configuration includes double left-turn movements, double right-turn movements, or both.
- The roadway system has destinations in the vicinity that would benefit from advance lane-use guidance for a given destination, such as establishing correct lane positioning for downstream freeway on-ramps.

On a typical two-lane entry, the left entry lane is for left turns and through movements, and the right entry lane is for right turns and through movements. Even in this common case, approach lane-use arrows are beneficial. Lane-use arrows become increasingly important for roundabout approaches with double left-turn or double right-turn lanes. Lane-use arrows can also improve lane utilization or provide consistent messaging to drivers across all roundabouts. Lane-use arrows are not typically necessary on single-lane roundabouts or a single-lane entry to a multilane roundabout; however, they are optional and have been used in some cases.

The MUTCD includes several options for arrow symbols on intersection lane-control signs and pavement markings, as shown in Exhibit 12.6. Both standard arrows and fishhook arrows are common, but agency requirements or preferences tend to dictate arrow selection. For roundabouts where a left-turn movement is intended, a left-turn arrow is used in advance of the roundabout. Field evidence has demonstrated that a lack of left-turn arrows for left-turn-only lanes can result in increased erratic maneuvers (*3*).

There is no clear research indicating that the fishhook arrow is superior to the standard arrow. Standard arrows are well established in practice and are easier to maintain because of their smaller size. In some states, the fishhook may be beneficial where left-turn arrows on a roundabout approach would otherwise be prohibited. Some agencies place a dot on the left side of the arrow in the inside lane. Exhibit 12.7 shows an example of this application. The style of arrow used for signs and pavement markings needs to be consistent.

Exhibit 12.6. Lane-use (*a*) standard and (*b*) fishhook arrow types used at roundabouts.



SOURCE: MUTCD (*1*).

Exhibit 12.7. Example of lane-control signs and markings with channelization island between lanes.

LOCATION: US 17–US 92/W Haven Road, DeLand, Florida.
SOURCE: Lee Rodegerdts.

Lane-control signs and pavement markings should allow time for drivers to select the appropriate lane for their maneuver before entering the roundabout. Some agencies locate the closest set of lane-control signs and markings approximately 50 ft to 100 ft (15 m to 30 m) in advance of the crosswalk. No lane-control signs or pavement marking arrows are recommended between the crosswalk and roundabout entry, where lane changes are typically discouraged or prohibited. Practitioners need to balance the MUTCD and the AASHTO decision sight distance criteria with local conditions to determine the most appropriate sign and marking placement and spacing. Oversize signs, overhead placement of signs, use of standard arrows to improve driver recognition, redundant sets of signs, or some combination may be needed in constrained environments to improve sign legibility that meets driver perception and reaction time needs. The MUTCD provides further guidance in this area (*1*).

In some cases, overhead lane-control signs may be beneficial at roundabouts. Exhibit 12.8 provides an example. Whereas roadside lane-control signs may get lost in background clutter and can be obscured by other vehicles, overhead lane-control signs are located directly above each

Exhibit 12.8. Example of overhead lane-control signs.

LOCATION: N Riverside Drive/Northern Cross Boulevard, Fort Worth, Texas.
SOURCE: Lee Rodegerdts.

lane for maximum visibility. Overhead signs are more expensive than ground-mounted signs because of the increased cost of sign supports and are to be factored into preliminary costs during ICE activities (see Chapter 6: Intersection Control Evaluation). As with ground-mounted signs, overhead lane-control signs are most effective if placed far enough in advance of the roundabout to allow drivers to select the proper lane before entering. Overhead lane-control signs may help with retrofitting an existing roundabout to improve lane use where existing ground-mounted signs and markings appear to be insufficient. Guide signs may also help convey lane use and destinations for each lane; however, guide signs cannot replace regulatory signs that legally define lane use.

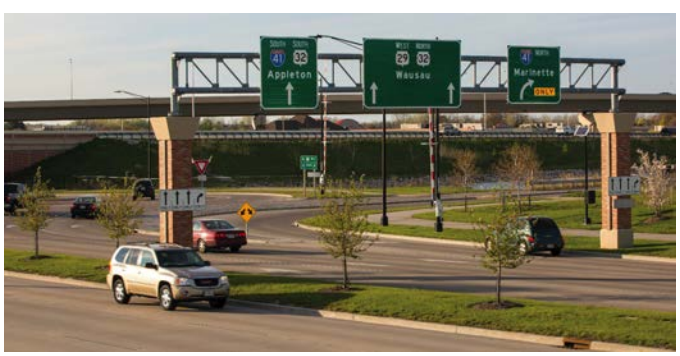
Overhead guide signs are another option for communicating destinations and lane-use requirements on the roundabout approach to supplement regulatory lane-control signs. Overhead signing has been implemented at various locations throughout North America and may be particularly beneficial on three-lane roundabouts. Overhead signing reduces the chances for trucks or other large vehicles to obscure the view of a roadside-mounted guide sign. Overhead signs are common at freeway interchanges where bridge structures provide natural mounting locations. Selecting roadside mounting versus overhead mounting of guide signs depends on the roundabout's environment, the complexity of the information being presented, and the approach geometry. Exhibit 12.9 shows an example of overhead guide signs providing lane-use information at a freeway interchange, supplementing side-mounted regulatory lane-control signs.

As noted in Chapter 4: User Considerations, some states have amended their vehicle codes to address specific roundabout uses, including driving next to trucks within a roundabout. To support this legal requirement specific to Oregon, the Oregon Department of Transportation's *Sign Policy and Guidelines* includes a regulatory sign, "Do Not Drive Beside Trucks," that is used at each entrance to a multilane roundabout (*4*).

Pavement markings showing route numbers, destinations, street names, or cardinal directions (i.e., north, south, east, or west) can help drivers select the appropriate entry lane on roundabout approaches. These markings typically supplement lane-use arrows, lane-control signs, and guide signs at roundabouts. At complex roundabouts with many legs, these markings can make it easier to adequately communicate appropriate lane use.

Route numbers may be shown using numerals and letters (e.g., I-275, US 97, or Hwy 22) or by using pavement markings that simulate Interstate, US, state, and other official highway route shield signs—but they need to be elongated for proper proportioning when viewed as a marking (refer to the MUTCD and FHWA's *Standard Highway Signs and Markings* for further detail) (*1*, *5*). Word

Exhibit 12.9. Overhead guide signs at a freeway interchange.



LOCATION: Shawano Avenue/I-41 Northbound Ramps, Green Bay, Wisconsin.
SOURCE: Lee Rodegerdts.

Exhibit 12.10. Example of route number guide marking.

LOCATION: E 10th Street/I-265 Westbound Ramps, Jeffersonville, Indiana.
SOURCE: Lee Rodegerdts.

pavement markings can also spell out destinations, street names, or cardinal directions using elongated letters or numerals. Exhibit 12.10 shows an example of route number guide markings.

At roundabouts with more than four legs, drivers can find it difficult to select the appropriate lane-use arrows—left, through, or right—to use on each approach. Practitioners are advised to use their engineering judgment to choose the appropriate lane-use arrows for each lane. Where there is a clear major route and three or more minor legs, the major route is likely best served if designated as a through movement to provide route continuity (e.g., using a through arrow to connect roadways with the same street name or route number). At some complex roundabouts with many legs, it can be desirable to use other traffic control devices to supplement lane-use arrows and designate the appropriate approach lanes. These can include pavement word and symbol markings as well as advance guide signs that indicate destinations for each lane.

12.3 Entry Area

The entry area is the area where conflicts with other modes begin. Traffic control devices in this area focus on drivers yielding to other users—bicyclists, pedestrians, and other vehicles within the roundabout—including stopping if necessary or required by state law. This section presents traffic control devices for the entry area.

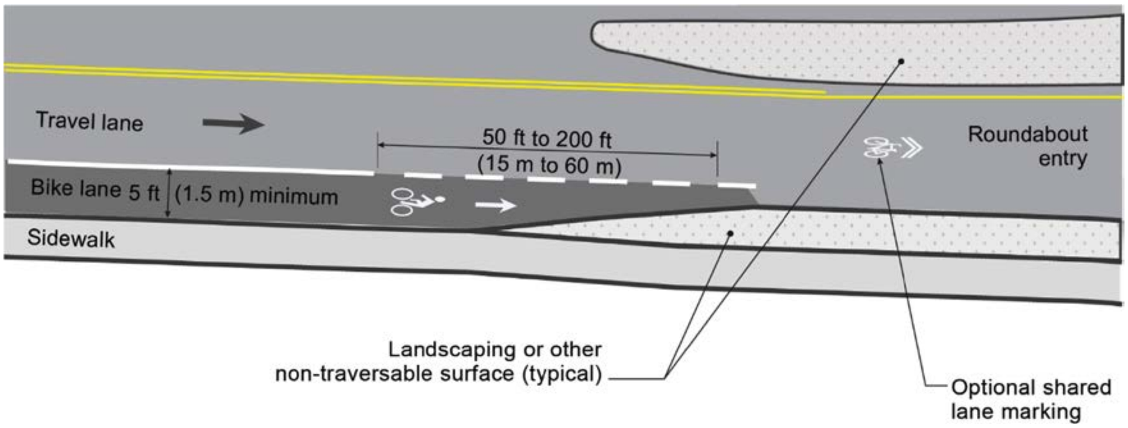
12.3.1 Signs and Pavement Markings for Bicyclists

As discussed in Chapter 10: Horizontal Alignment and Design, some roundabouts provide transitions from one type of bicycle facility approaching the roundabout to another type within the roundabout. On roundabout approaches where bicycles use on-street lanes or shoulders, the bicycle lane line or roadway edge line next to the shoulder is terminated as soon as the taper begins (commonly 8:1), at least 100 ft (30 m) in advance of the edge of the circulatory roadway and at least 50 ft (15 m) in advance of the crosswalk. The bicycle lane lines are to be dotted for the last 50 ft to 200 ft (15 m to 60 m), notifying cyclists in advance that they need to merge and providing enough room to achieve this maneuver and find an appropriate gap in traffic. A "Bike Lane Ends" sign sometimes marks the beginning of the taper. Exhibit 12.11 illustrates this concept.

Where bicycle lanes or shoulders are used on approach roadways and separated bike lanes or a shared-use path are not planned around the roundabout, the bicycle lanes are to end before the roundabout begins (see Exhibit 12.11).

When starting a bicycle lane on a roundabout exit, a dotted line is used to mark the start of the bicycle lane at the beginning of the taper. The solid bicycle lane line is to resume as soon as the normal bicycle lane width is available. Exhibit 12.12 illustrates this concept.

Exhibit 12.11. Markings for transition from on-street bicycle lane to shared lane at roundabout entry.



For approaches with separated bicycle facilities, signing and marking follows the examples provided in Chapter 10: Horizontal Alignment and Design. In some cases, it may be desirable to allow bicyclists to use the adjacent travel lane in addition to the separated facility. Exhibit 12.13 illustrates the transition from a buffered bicycle lane to a separated facility at the roundabout entry; similar markings can be provided at the roundabout exit. If the separated bicycle lane is raised at the roundabout, an additional speed hump marking showing the location of elevation increase at the transition is suggested.

12.3.2 Pedestrian and Bicycle Crossing Signs and Pavement Markings

"Pedestrian Crossing" signs (W11-2) are sometimes used at roundabout pedestrian crossings that are not controlled by regulatory devices (e.g., traffic control signals or pedestrian hybrid beacons). They are also sometimes paired with warning beacons, such as RRFBs. Where installed, these signs should not obstruct the view of the yield sign or signs at the roundabout entry.

At roundabouts, high-visibility crosswalk markings that are longitudinal to the flow of traffic (sometimes referred to as *zebra* or *continental* crosswalk markings) are advised for pedestrian-only crossings or crossings that bicyclists and pedestrians share. Details on the dimensions of

Exhibit 12.12. Markings for transition from shared lane to on-street bicycle lane at roundabout exit.

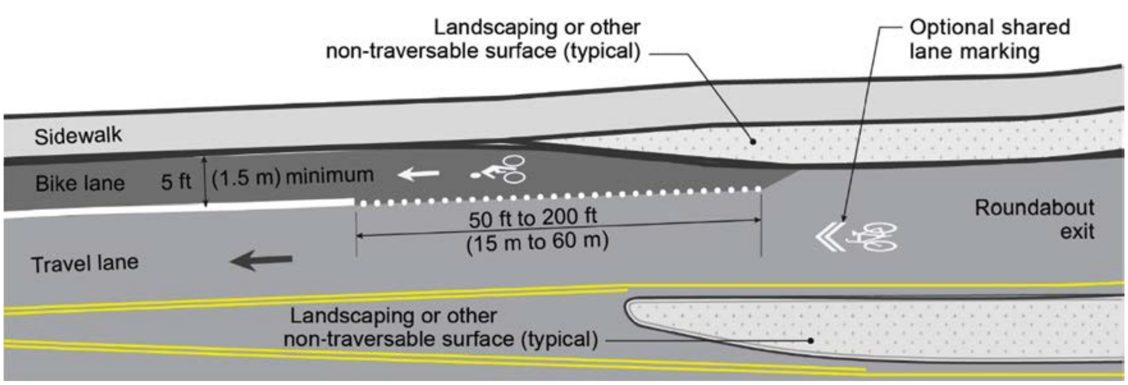
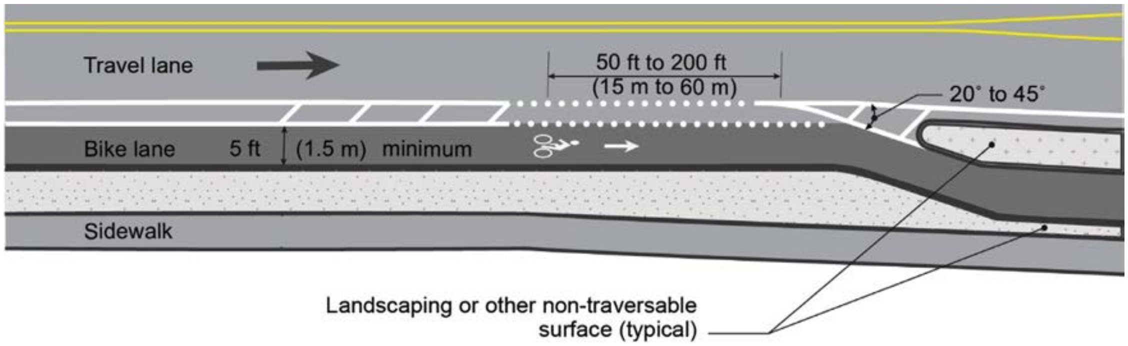


Exhibit 12.13. Markings for transition from buffered bicycle lane to separated bicycle facility at roundabout entry.



these markings can be found in the MUTCD. Longitudinal crosswalk markings have advantages over transverse crosswalk marking in roundabout applications:

- High-visibility longitudinal markings provide a higher degree of visibility, highlighting the location of the crossing away from the roundabout for drivers and crossing users. High-visibility crosswalks are detectable from about twice the distance upstream during daytime conditions as crosswalks with transverse marking elements only (*6*). Pedestrians with low vision especially benefit from the high-visibility markings because of their contrast with the underlying pavement surface.
- Drivers are less likely to confuse longitudinal crosswalk lines with the entrance line or the yield line.
- Although the initial cost is somewhat higher, longitudinal markings require less maintenance if properly spaced to avoid the wheelpaths of vehicles.

Aesthetic treatments at crosswalks can provide contrast with the surrounding roadway and are sometimes implemented for that reason, but the specific pedestrian crossing area should be smooth, with the markings providing the primary contrasting elements. Crossing surface inconsistencies (e.g., pavers or other features) can increase difficulty for people who use wheelchairs or have other special walking needs.

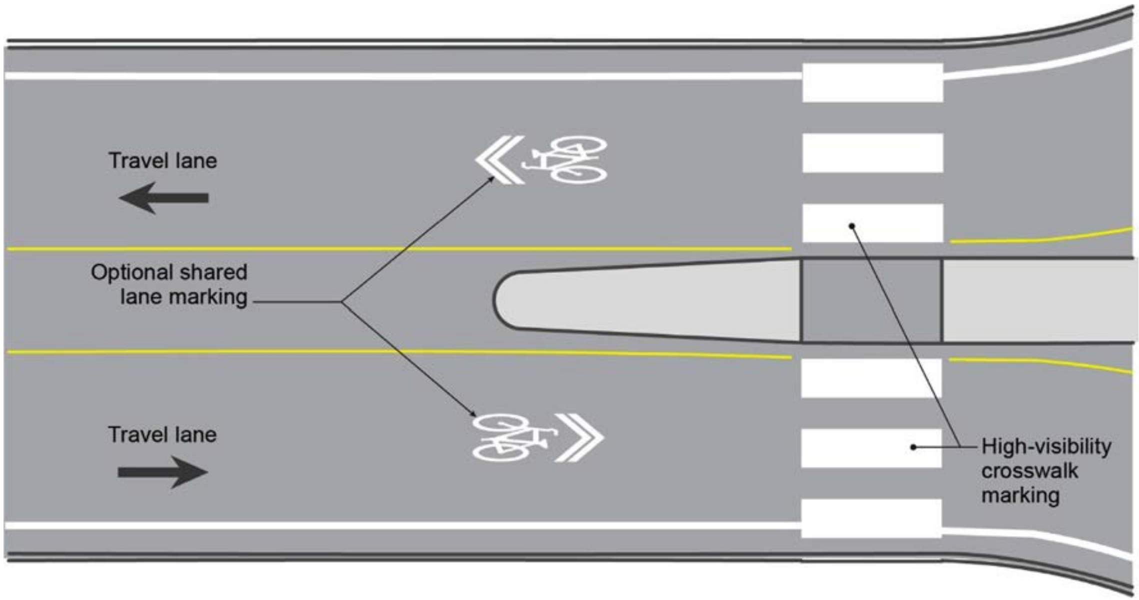
Exhibit 12.14 illustrates typical crosswalk markings for crosswalks at roadway level for a single-lane entry and exit. Where a raised crossing is used, the raised crossing should also be marked as illustrated in Exhibit 12.15.

Exhibit 12.16 illustrates separated bicycle and pedestrian crossing markings for raised crossings at a single-lane entry with a right-turn bypass lane.

12.3.3 Pedestrian and Bicycle Crossing Beacons and Signals

In some cases, additional treatments beyond signs and markings may be needed to provide pedestrian safety and accessibility, especially if the crossing is multilane. Research for *NCHRP Research Report 834: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities: A Guidebook*, developed a method for estimating performance measures for a crossing that can inform geometric and traffic control device design decisions (*7*). Chapter 9: Geometric Design Process and Performance Checks and Appendix: Design Performance Check Techniques present suggested quantitative methods to support design decisions on the most appropriate application for a given crossing.

Exhibit 12.14. Typical markings for at-grade pedestrian crossing at single-lane entry and exit.



The proposed Public Rights-of-Way Accessibility Guidelines, as amended for shared-use paths, require pedestrian-activated signals with accessible pedestrian signals at multilane roundabout crossings and multilane channelized turn lanes (*8*, *9*). This is chiefly because of the multiple threat at multilane crossings, in which a driver's view of pedestrians in a crosswalk may be blocked by a yielding vehicle in another lane, and pedestrians crossing in front of a yielding vehicle may not see or hear a vehicle approaching in the next lane. As discussed in Chapter 10: Horizontal Alignment and Design, FHWA has recommended the proposed PROWAG as best practice (*10*).

The proposed Public Rights-of-Way Accessibility Guidelines also indicate that when pedestrian-activated signals are used on a splitter island, they are to be located and separated to avoid

Exhibit 12.15. Typical markings for raised pedestrian crossing.

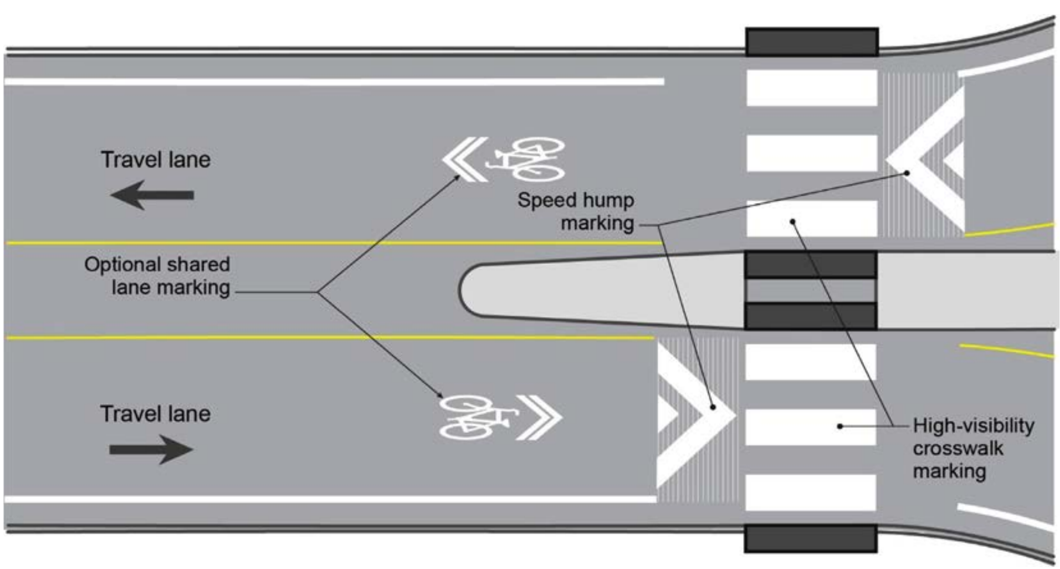
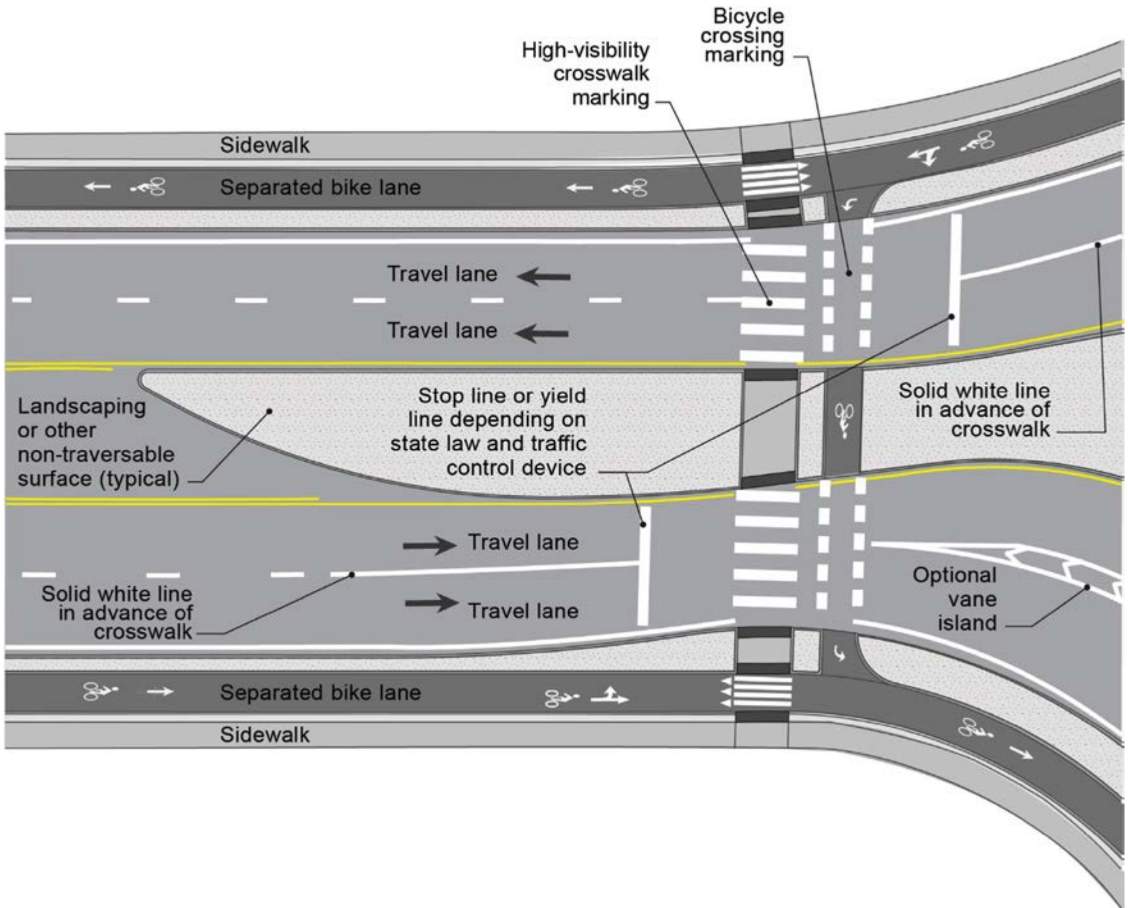


Exhibit 12.16. Typical markings for separated bicycle and pedestrian crossings.



communicating conflicting information about which pedestrian crossing has a walk indication displayed. Accessible pedestrian signals are optimally located on the downstream side of each crossing so that the pedestrian can better listen for oncoming vehicles. The MUTCD and associated interim approvals have standards, guidance, and options for applying these traffic control devices (*1, 11*).

Common active traffic control devices at roundabout crossings include:

- **Rectangular rapid-flashing beacons.** As an active warning device, the RRFB rests in dark when not used and flashes for a predetermined time upon activation by the crossing user (*11*). These devices can be mounted along the roadside, overhead, or both. Exhibit 12.17 shows an example of roadside installation in Springfield, Oregon. RRFBs are not mentioned in the proposed PROWAG but may be suitable through the process of *equivalent facilitation* if they provide substantially equivalent or greater accessibility and usability than the minimum requirements provided within PROWAG (*8*, *9*).
- **Pedestrian hybrid beacons.** This device also rests in dark when not used and follows MUTCD guidelines for signal placement. A PHB was first implemented for research purposes in a temporary installation in Golden, Colorado (see Exhibit 12.18), as part of the research for *NCHRP Report 674: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities* (*12*). The first permanent installation is in Oakland County, Michigan (see Exhibit 12.19). The proposed PROWAG indicates that PHBs with accessible pedestrian signals can be used at roundabouts (*8*, *9*).

Exhibit 12.17. Example of rectangular rapid-flashing beacon.

LOCATION: Pioneer Parkway E/Harlow Road/Hayden Bridge Way, Springfield, Oregon. SOURCE: Lee Rodegerdts.

Exhibit 12.18. Example of pedestrian hybrid beacon (temporary installation).

LOCATION: S Golden Road/Johnson Road, Golden, Colorado. SOURCE: Lee Rodegerdts.

Exhibit 12.19. Example of pedestrian hybrid beacon (permanent installation).

LOCATION: West Maple Road/Drake Road, Oakland County, Michigan. SOURCE: Lee Rodegerdts.

- **Traffic control signal.** This device displays a red–yellow–green indication to drivers and rests in green. Placement on the entry side has similar issues as a metering signal with respect to potential driver misinterpretation of the green indication as overriding the yield sign.

Exhibit 12.20 compares these three active traffic control devices and raised crossings. Further details for raised crossings can be found in Chapter 10: Horizontal Alignment and Design and *NCHRP Research Report 834* (*7*).

Practitioners are advised to consider the type, location, and design details of these treatments holistically during the planning and design process. For instance, if a PHB or traffic control signal is used on a roundabout exit, the crossing may need to be placed farther from the circulating roadway than if a raised crosswalk or RRFB is used. In addition, pushbuttons can be challenging for pedestrians to locate for effective use, particularly with separated bicycle facilities between roundabout approaches. In these locations, sufficient buffer space along the outside curb line must accommodate signs and pushbuttons along with design vehicle movements. The splitter island requires similar considerations. To meet pedestrian and driver expectations, the same crossing treatment is to be used on the entry and exit of a roundabout leg.

12.3.4 Lane Lines at Entry and Exit

Solid white lane lines are typically used at roundabout entries and exits to discourage lane changes. Solid lane lines provide the following benefits:

- Solid lane lines can discourage lane changes immediately before crosswalks to reduce the likelihood of multiple threat crashes between vehicles and pedestrians.
- Solid lane lines at entries may discourage late lane changes and reduce the potential for sideswipe crashes.
- Solid lane lines at entries and exits can discourage drivers from cutting across multiple lanes to attain a faster path through the roundabout. Using solid lane lines throughout the area of entry curvature provides this benefit. However, under lower-volume conditions, drivers frequently cross or straddle solid lane lines if they do not perceive a conflict.

On flared approaches, entry lane utilization may improve if the lane lines in the flared section extend back as far from the circulatory roadway as possible. For example, when flaring from one to two lanes, as soon as there is 20 ft (6 m) of paved entry width available, the lane line can begin, creating two 10-ft (3-m) approach lanes that will typically continue to widen as they approach the circulatory roadway.

White channelizing lines are recommended on the approach to and departure from right-turn bypass islands, where traffic passes on both sides of the islands. Some agencies have used channelizing lines to create painted islands between adjacent entry lanes, sometimes called *vane islands*. These islands, an example of which is shown in Exhibit 12.21, are intended to guide entering drivers to the appropriate lane within the circulatory roadway. These islands also provide an over-tracking area for larger vehicles. Evidence from research conducted for this Guide is mixed on whether truck drivers understand that trucks are intended to drive within the vane island (*14*). This may be because vane islands have a similar visual appearance to freeway gore striping, where driving in the gore is discouraged.

12.3.5 Entry Signs and Markings

The MUTCD requires a yield sign on the right side of each entry into the roundabout and recommends a second yield sign on the left side of the approach (mounted on the splitter island) for additional visibility and approaches with more than one lane. Practitioners need to locate yield signs on the left side to avoid obscuring the line of sight for some drivers (e.g., truck drivers).

Exhibit 12.20. Comparison of passive and active crossing traffic control device applications at roundabouts.

Attribute or Characterization	Raised Pedestrian Crossing	RRFB	PHB	Traffic Control Signal
• Active display to drivers	• Not applicable	• Two rectangular yellow indications that flash alternately in a prescribed pattern	• Flashing yellow ball, solid yellow ball, two simultaneous solid red balls, alternating flashing red balls	• Green ball, yellow ball, red ball
• Display to pedestrians	• Not applicable	• None	• Walk, flashing Don't Walk, and (in some cases) a pedestrian change interval countdown display	• Walk, flashing Don't Walk, and (in some cases) a pedestrian change interval countdown display
• Audible message to crossing users (if used)	• Not applicable	• Locator tone in rest; "yellow lights are flashing" when activated	• Locator tone in rest; "wait" when activated; percussive tone when Walk sign is displayed	• Locator tone in rest; "wait" when activated; percussive tone when Walk sign is displayed
• Advantages	• Provides geometric speed control • May be combined with active traffic control devices listed in this exhibit	• May provide sufficient accessibility for two-lane crossings under lower volume and speed conditions • Lower cost than PHB or traffic control signal	• Provides good accessibility because of red indication to drivers • Device rests in dark to prevent potential misinterpretation of green indication • Can be coordinated with other traffic control signals and PHBs	• Provides good accessibility because of red indication to drivers • Standard indication in common use, although not common at roundabouts in the United States • Alternating flashing red allows drivers to proceed after stopping if there is no conflicting pedestrian present • Device rests in green rather than dark • May also be used for metering applications (see Section 12.6) • Can be coordinated with other traffic control signals and PHBs
• Disadvantages	• May be more difficult to retrofit because of effects on drainage • May be more difficult to maintain in winter environments	• Does not provide sufficient accessibility for three-lane crossings • May not provide sufficient accessibility for two-lane crossings under higher vehicular volume and speed conditions • Driver education may be needed in some regions and areas	• Less common use than traffic control signal • Driver and crossing user compliance with device may not be as good as with a traffic control signal (e.g., *13*) • Higher cost than RRFB and raised crossing • Device rests in dark and may conflict with state laws requiring drivers to stop at a dark indication • Should not be used for metering applications (see Section 12.6) • Driver education may be needed in some regions and areas	• Higher cost than RRFB and raised crossing • Green indication to drivers may be misinterpreted as a green indication to enter the roundabout if located too close to the roundabout entry

Exhibit 12.21. Example of painted channelization lines between entry lanes.

LOCATION: US 17–US 92/W Haven Road, DeLand, Florida. SOURCE: Google Earth.

Despite having yield signs on both sides of a multilane entry, some roundabouts have exhibited crash patterns attributed to failure to yield on entry (*2*). To address this, some agencies have added supplemental word plaques below the yield signs on each side of the entry. These plaques have included language such as "To Both Lanes," "To Traffic in Circle," or other variations. The effectiveness of these supplemental plaques has not been assessed in isolation, as they have commonly been installed as part of a package of signing and pavement marking treatments.

At roundabouts with fully traversable central islands, signs cannot be placed within the central island. In these situations, the MUTCD provides a Roundabout Circulation (R6-5P) plaque, as shown in Exhibit 12.22. This sign is placed below each yield sign on each roundabout approach to define the direction of circulation within the roundabout.

The MUTCD prohibits the "No Left Turn" (R3-2) sign, the "No U-Turn" (R3-4) sign, and the combination "No U-Turn/No Left Turn" (R3-18) sign at roundabout entries. These signs conflict with roundabout operations as a single intersection where left-turn and U-turn movements circulate the central island within the intersection. These signs may be necessary at larger rotaries or traffic circles that could be interpreted as a ring of T-intersections.

Exhibit 12.22. Example of roundabout circulation plaque under yield sign.

LOCATION: W Crescent Rim Drive/W Eastover Terrace, Boise, Idaho.
SOURCE: Lee Rodegerdts.

A roundabout directional arrow sign, an example of which is shown in Exhibit 12.23, indicates the direction of travel within the circulatory roadway at roundabouts with non-traversable central islands. The black-on-white chevron design provides a regulatory message, legally establishing the direction of circulation at roundabouts. These signs are placed on the central island opposite the roundabout entrances to direct traffic counterclockwise around the central island. On multi-lane approaches, high-speed approaches, approaches with limited visibility, or in other circumstances in which increased sign visibility is desirable, larger versions of the sign or multiple copies of the same sign are sometimes used.

Although "One Way" signs (R6-1R) have been used instead of or in addition to the roundabout directional arrow signs, these are more commonly used for one-way roadways connecting to the roundabout, such as freeway entrance and exit ramps. "One Way" signs may also be useful at rotaries and other circular intersections where the circulatory roadway of the roundabout is legally defined as a separate one-way roadway rather than being part of a single intersection.

Most roundabouts have been installed with a dotted circulatory roadway edge-line extension across the entry lane or lanes. These edge lines act as *entrance lines*, marking the boundary between entering and circulating vehicles. These entrance lines have been commonly installed with widths greater than a typical wide line: 12 in. to 24 in. (300 mm to 600 mm) is common. Many agencies have also used a marking pattern unique to this application, with patterns of 2-ft to 3-ft (0.6-m to 0.9-m) lines with 2-ft to 3-ft (0.6-m to 0.9-m) gaps being common.

Yield lines are sometimes used in addition to entrance lines to further indicate the point behind which vehicles are required to yield in response to the yield signs at roundabouts. As described in the MUTCD, yield lines consist of a row of solid white isosceles triangles pointing toward approaching vehicles. Like other applications of yield lines and stop lines, the yield lines should normally be placed at right angles to the entry roadway. Exhibit 12.24 illustrates an example.

Debate continues about best practices for entrance markings. The MUTCD defines different purposes for edge-line extensions and yield lines, but in practice edge-line extensions often function as yield lines when paired with the required yield signs. There is little documented evidence that the supplemental yield line improves yielding behavior enough to justify the increased

Exhibit 12.23. Example of roundabout directional arrow sign.

LOCATION: NW 13th Street/W Fletcher Avenue, Lincoln, Nebraska.
SOURCE: Lee Rodegerdts.

Exhibit 12.24. Example of yield line at single-lane roundabout entry.

LOCATION: US 2/US 89, Browning, Montana. SOURCE: Lee Rodegerdts.

installation and maintenance costs. Some agencies have instead used a yield word pavement marking at a roundabout entrance to supplement the yield sign and edge-line extension.

If yield lines or yield word markings are used at multilane roundabouts, they should be staggered on a lane-by-lane basis to help drivers waiting at the yield line in the outer lane(s) see in front of vehicles waiting in the inner lane(s), as illustrated in Exhibit 12.25.

12.3.6 Full Signalization of Entry-Circulating Junction Points

Rotaries and other large, multilane circular intersections may benefit from full signalization at each entry-circulating point if there is adequate storage space in the circulatory roadway. In these cases, the circular intersection operates as a ring of coordinated signalized intersections with queue storage between them. The resulting combination of coordinated signalized intersections has operational, safety, and accessibility characteristics that can be different from roundabouts as defined in US practice. A detailed discussion of full signalization is outside the scope of

Exhibit 12.25. Example of yield word marking at multilane roundabout entry.

LOCATION: W Mason Street/I-41 Southbound Ramps, Green Bay, Wisconsin.
SOURCE: Lee Rodegerdts.

this document, but references from countries where this is more common (particularly the United Kingdom) are available to provide insight into possible practices, for example, *Signal Controlled Roundabouts* (*15*).

12.4 Circulating Area

Traffic control devices for drivers in the circulating area focus on maintaining the correct lane while circulating. They are most critical for multilane roundabouts where maintaining lane position is desired.

12.4.1 Markings Adjacent to the Central Island

In general, roundabout central islands do not need supplemental markings. Some agencies use a solid yellow line to delineate the edge of the central island. This practice is not specifically required by the MUTCD, which allows edge lines to be excluded on the basis of engineering judgment (e.g., if the traveled way is delineated by a curb). Given that most central islands have truck aprons or are fully traversable and intended for regular use by large vehicles, a yellow edge line next to the truck apron is routinely traversed by trucks and becomes more difficult to maintain over time.

Some agencies have used yellow edge lines to spiral traffic away from the central island toward a specific circulating lane. Research has found that yellow edge lines are ineffective at channelizing vehicles, with drivers commonly following the circular truck apron curb line rather than the yellow markings. This has resulted in documented late lane changes near the exits that can lead to increased vehicle conflicts and property damage crashes (*2, 3*). An extended raised central island truck apron is suggested instead of yellow striping for the purposes of spiraling circulating lanes; this is discussed further in Chapter 10: Horizontal Alignment and Design.

12.4.2 Circulating Lane Lines and Lane-Use Arrows

Lane lines within the circulatory roadway provide guidance, and many countries around the world use them. The practice recommended in the United States is to include lane lines within the circulatory roadway, so drivers are guided to the intended exit without needing to change lanes. As discussed in Chapter 10: Horizontal Alignment and Design, this practice requires the horizontal geometry of the roundabout to be compatible with the intended lane use. This is distinct from the practice used in some countries where concentric lane lines within the circulatory roadway require drivers in the interior circulating lane(s) to change lanes to exit. The MUTCD prohibits continuous concentric lane lines within the circulatory roadway of the roundabout because of the exit-circulating conflicts the concentric lane lines introduce.

The type of lane line within the circulatory roadway varies considerably in practice, often following agency preference. Exhibit 12.26 shows an example of a combination of solid lines and dotted lines.

The dilemma with circulatory roadway lane line marking patterns stems from the following observations:

- From the perspective of circulating traffic, a continuous solid line would best discourage lane changing within the circulatory roadway. This would appropriately support the principle of allowing a driver to choose the appropriate lane on the approach and not change lanes to get to the desired exit.

Exhibit 12.26. Example of circulatory roadway lane line pattern using solid–dotted combination.

LOCATION: 40th Street/East Yukon Street, Tampa, Florida. SOURCE: Google Earth.

- From the perspective of traffic entering a roundabout in any lane but the rightmost entry lane, a solid lane line across the roundabout entrance on the circulatory roadway may discourage drivers in the left entry lane from crossing the lane line to enter the left circulating lane. The dotted line facilitates this entry movement.
- From the perspective of truck drivers, a continuous solid line suggests they will not need to cross the line to circulate, but this is only true if the roundabout was designed with a true stay-in-lane configuration. Most multilane roundabouts with solid lane lines built in the United States have been implicitly designed for trucks to straddle lanes within the circulatory roadway. However, research conducted for this Guide indicates truck drivers were unable to distinguish the design intent for trucks (i.e., straddling lanes versus staying in lane).

If a solid line transitions to a dotted line, some circulating drivers might think they are allowed to change lanes at the dotted line before exiting the roundabout, contributing to exit-circulating crashes. Exhibit 12.27 illustrates an alternative marking pattern that some agencies within the United States have used. This strategy uses a consistent pattern of stripes and gaps throughout the circulatory roadway and exits. The rationale for this pattern is that it may be less likely to concentrate lane changes at the vulnerable entry-exit conflict area, and it is a line marking pattern that has been successfully employed in other countries, as shown in *Design of Road Markings at Roundabouts* (*16*).

Research to identify a preferred circulatory marking pattern is inconclusive. All documented modifications of existing roundabouts where a consistent broken or dotted line type was retrofitted also have other signing and pavement marking changes as part of a package of modifications, making it impossible to isolate circulatory roadway markings as a factor (*13*). Practitioners need to confirm that any selected marking pattern complies with the MUTCD and seek request for experimentation from FHWA for non-compliant marking patterns.

Research on property damage crash patterns at multilane roundabouts included a combination of sites with uniform dotted patterns and sites with a combination of dotted and solid lane lines (*2*). The biggest factors influencing lane changes within the roundabout did not appear to be caused by the lane marking pattern but rather by the base geometry, as well as factors such as approach signing and markings (ability to get drivers in the correct lane before entry), lane

Exhibit 12.27. Example of consistent circulatory roadway lane line pattern.

LOCATION: Shawano Street/South Taylor Street, Green Bay, Wisconsin.
SOURCE: Google Earth.

utilization, and network origin–destination patterns. In some cases, the uniform broken or dotted line type was shifted laterally to make the inside lane narrower and the outside lane wider. This may have improved crash performance because of better alignment with entry lanes and a smoother alignment into the exits.

Some agencies have used double solid lines that change to dotted lines, where entering traffic must cross the lane line. In some cases, the double solid lines have been supplemented with raised pavement markers or other traversable devices as needed for the passage of large trucks unable to stay in-lane (e.g., OSOW trucks). Exhibit 12.28 shows an example of this type of installation. **In all cases, any proposed variations from what is provided in the MUTCD may require approval of experimentation from FHWA (*1*).**

It is most common in the United States to use standard lane-use arrows within the circulatory roadway. Arrow placement varies, with some roundabouts having the arrows closer to the exit (at the beginning of the segment in front of the splitter island) and some having them closer to the entry. Research suggests that there may be advantages to placing the arrows in the circulating lane closer to the entry side (*2*):

- A through arrow in the outside circulating lane next to the entry is at the point where a circulating driver may be deciding whether to attempt to continue circulating from the outside lane (an improper left turn). The through arrow may emphasize the need to exit.
- Circulating arrows next to the entry may reinforce the correct direction of circulation for entering drivers.
- Arrows in each circulating lane may inform entering drivers that there are two circulating lanes and that both lanes may exit. This may improve driver yielding to other drivers in both circulating lanes.

Exhibit 12.28. Example of circulatory roadway double solid lane line pattern.

LOCATION: N Tamiami Trail/Fruitville Road, Sarasota, Florida. SOURCE: Ken Sides.

In some cases where splitter islands are wider, two sets of circulating arrows—one set close to the exit side and a second set close to the entry side—may be beneficial.

12.4.3 Signs and Pavement Markings in Circulatory Roadway for Bicyclists

Bicycle lanes are not advised within the circulatory roadway. Continuing a bicycle lane along the circulatory roadway can create two different conflicts:

- A conflict between through bicyclists and exiting drivers, increasing the potential for *right-hook* crashes with exiting drivers who cut off circulating bicyclists.
- A conflict with entering drivers who fail to yield to circulating bicyclists.

For many roundabouts, no specific signs or markings for bicyclists are needed. Some agencies have used sharrow markings to encourage bicyclists to ride in the middle of the circulatory roadway and communicate to drivers that people biking are expected to circulate with traffic. These markings are sometimes accompanied by "Bikes May Use Full Lane" or "Do Not Pass Bikes" signs.

12.5 Exit Area

As with the entry area, traffic control devices for drivers in the exit area focus on yielding to other users—bicyclists and pedestrians—as discussed in Section 12.3. The exit area also provides guidance and confirmation to drivers that they have selected the correct exit. At single-lane roundabouts, the destination decision can be made in the exit area. At multilane roundabouts, the destination decision must be made in the transition area before entry, discussed in Section 12.2.

Several types of confirmation guide signs may be applicable at roundabouts:

- **Exit guide signs and directional assemblies.** These signs designate the destinations, street names, or route designations of each exit from the roundabout and are commonly placed on the splitter island. Examples are shown in Exhibit 12.29 and Exhibit 12.30.
- **Route confirmation assemblies.** For roundabouts involving the intersection of one or more numbered routes, confirmation guide signs can be used on the right side of the exiting roadway beyond the crosswalk.

Exhibit 12.29. Example of street name exit guide sign and directional assembly.

LOCATION: W Tapp Road/I-69 Southbound Ramps, Bloomington, Indiana.
SOURCE: Lee Rodegerdts.

Exhibit 12.30. Example of combination route number and destination exit guide sign.

LOCATION: SR 16/CR 89, Madison, California. SOURCE: Lee Rodegerdts.

12.6 Entry Metering Signals

During peak periods, the flow from one entry can dominate downstream entries to the point that insufficient gaps are available, causing excessive delays and queues at the downstream entry. In these cases, entrance metering can provide significant operational benefits during peak periods. In some applications, entry metering signals may be a more economical solution than geometric improvements and may improve the overall safety performance of the roundabout because of the reduced number of lanes. This could include locations where the traffic condition requiring metering is of short duration and the geometric improvements would require adding lanes. In some cases, it may be advantageous to meter more than one entry during the same peak period or to change which entries are metered by time of day.

A basic metering system consists of two components:

- **Queue detector.** This can be placed on the downstream entry exhibiting excessive delays and queues. When a long queue is detected, the signal controller activates the metering signal.

- **Metering signal.** This is provided on the dominant approach, preferably set far enough back from the entry to minimize confusion with the yield sign but not so far as to require excessive red time to clear the queue in front of the metering signal. Experience in the United States is too limited to specify a standard minimum or maximum distance, but metering applications to date have been 100 ft to 200 ft (30 m to 60 m) in advance of the roundabout entry. If the metering signal cannot be set back sufficiently, some countries (e.g., Australia) use a special changeable message sign that shows a yield sign but can be changed to read "Stop on Red Signal."

  An example of a simple metering system is shown in Exhibit 12.31.

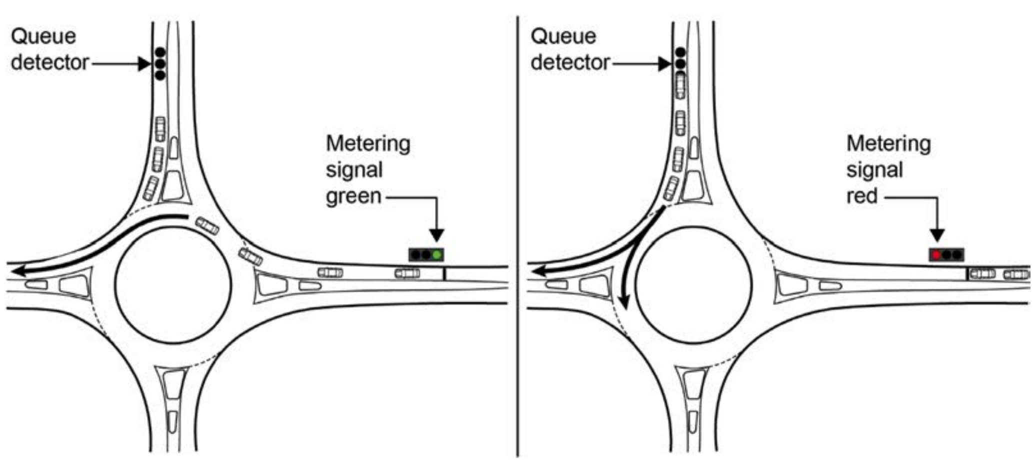
Four installations in the United States with permanent roundabout metering, one temporary installation, and one using freeway ramp metering on a roundabout approach yielded the following observations:

- Roundabout meters have successfully created gaps in circulating traffic so that vehicles can enter the roundabout from approaches other than the high-volume approach.
- Roundabout meters are operated only when queues on one or more legs create an operational or safety issue (sometimes both).
- Roundabout meter installations have most often been used where one of the legs is a freeway exit ramp and queues from the roundabout extend back onto the freeway. The roundabout metering signals have successfully limited the encroachment of the exit ramp queues onto the freeway.
- The distance between the signal and the roundabout entry varies between locations. Data and experience are insufficient to judge a minimum separation distance for use in guidelines.

Metering may also be possible by controlling the timing of an upstream signalized intersection to limit flows toward the roundabout. Practitioners need to evaluate expected queue lengths on the roundabout exits between the signalized intersection used for metering and the circulatory roadway for the most appropriate operation. Metering by upstream signalized intersections is generally not as effective as direct entrance metering because of vehicles turning into the roadway at or downstream of the signalized intersection.

If used at a roundabout, PHBs (discussed in more detail in Section 12.3.3) are best reserved for pedestrian crossing applications and not used for entry metering, although they may have a secondary entry metering effect. The activation of PHBs by queue detection in metering applications without the presence of pedestrians may dilute the effectiveness of the devices for crossing users.

Exhibit 12.31. Metering signal operation.



12.7 At-Grade Rail Crossings

At-grade rail crossings present a challenge near any intersection; this is not unique to roundabouts. Having an intersection near an at-grade rail crossing is sometimes unavoidable, and a roundabout may be the preferred intersection form (e.g., for safety reasons) even with the at-grade rail crossing present. This section discusses techniques to manage the interaction between a roundabout and an at-grade rail crossing. Considering these issues early during ICE stages is highly advised to help with decision making.

For any intersections near at-grade rail crossings, including roundabouts, two concerns are common:

- Queuing at the intersection may extend back to and through the at-grade rail crossing. The queue may be caused by conflicting traffic in front of the subject entry, pedestrian activity, parking activity that blocks the intersection, or other factors. Rail operators usually raise this concern.
- Queuing at the at-grade rail crossing during train passage may extend to the intersection and disrupt intersection operations. The relevant road authority usually raises this concern.

Unlike signalized intersections, roundabouts or other unsignalized intersections do not have an option for clearing the queue on an approach before a train arrives. Without the ability to flush or clear the queue on a roundabout approach, traffic can be occupying a grade crossing when a train arrives. However, queues at unsignalized intersections can often be shorter than at signalized intersections because of lower roadway volumes, thus reducing the likelihood of traffic occupying the grade crossing in the first place.

Where roundabouts include or are near a highway–rail grade crossing, practitioners have to carefully consider whether vehicles will queue across the tracks and, if so, how the queues can be cleared in advance of an oncoming train. The MUTCD requires conducting an engineering study for any roundabout near a highway–rail grade crossing to determine whether queuing could impact the rail crossing and develop provisions to clear the highway traffic from the highway–rail grade crossing before the train's arrival (*1*). The FHWA and Federal Railroad Administration *Highway-Rail Crossing Handbook,* 3rd edition, discusses the use of a diagnostic team to assess the rail crossing and suggests that traffic control signals or queue-cutter signals may be needed (*17*).

A limited range of experiences in the United States precludes definitive guidance in this important topic area. Each at-grade rail crossing at or near a roundabout often has unique conditions. Railroad-operated gates, road authority–operated highway traffic signals, or some combination thereof may be appropriate. In some cases, no special treatments between the at-grade rail crossing and roundabout are needed; an example is provided in Exhibit 12.32. The following sections discuss factors to consider and some of the common cases experienced to date.

12.7.1 Factors to Consider

Many factors can influence traffic operations, safety, and traffic control near a roundabout when there is an at-grade rail crossing in its vicinity. Key influencing factors include:

- Rail operators are often concerned about the likelihood of queuing extending into the rail crossing. The potential for a queue extending from a roundabout to a rail crossing is highly dependent on local conditions, with the level of treatment needed scalable to those conditions. Treatments may range from doing nothing more than existing conditions to a variety of active treatments. Many factors can influence the likelihood of queuing:
  - **Traffic volumes and the proximity of the crossing to the intersection.** These two factors are interrelated. A grade crossing located on a major leg of the roundabout with higher

Exhibit 12.32. Example of at-grade rail crossing near roundabout.

LOCATION: D Street/I-5 Southbound Ramps/Marine Drive, Blaine, Washington.
SOURCE: Lee Rodegerdts.

vehicle volumes may have a peak period queue from the roundabout that extends 0.25 miles (0.4 km) or more. Conversely, if a grade crossing is located on a leg of a roundabout with lower overall vehicular volumes, a queue will not likely extend to the rail crossing, even if the rail crossing is within 100 ft (30 m) of the roundabout.

- **The control of the crossing itself.** Rail crossings that are currently passively controlled (i.e., controlled by stop or yield signs) are often on low-volume roadways. In some cases, these passively controlled crossings are supplemented with a "Do Not Stop on Tracks" sign. Queuing in these cases may change little with the installation of a roundabout. Crossings requiring active control (i.e., signals or signals and gates) can be paired with more active treatments of a nearby roundabout or other intersection. These treatment approaches are discussed in Section 12.7.2.
- **The nature of train traffic at the rail crossing.** Rail crossings along railroad mainlines or light rail lines with higher train speeds and frequencies have a higher likelihood of interaction with queues than, for example, industrial sidings that operate infrequently and at low train speeds. The associated traffic control at the crossing can be scaled accordingly.

- An agency concern regarding grade crossings near roundabouts is the queue from the rail crossing extending back into the roundabout and blocking the roundabout. Many factors can influence the queue length that results from a train at a grade crossing:
  - **Length of the train.** Some freight trains can exceed 10,000 ft (3,048 m) in length, and such lengths are likely to become more commonplace.
  - **Speed of the train.** Communities that have established lower train speeds create longer queues at grade crossings. High-speed trains create the need for long advance warning times.
  - **Frequency of train arrivals.** Where crossings serve light rail or other transit vehicles, frequent train arrivals may perpetuate queues.
  - **Conflicting highway traffic volume.** Where conflicting highway traffic is highly peaked or serves comparatively high volumes (e.g., related to special events or freeway off-ramps), queues may be highly variable.
- The complications of an at-grade rail crossing in or near a roundabout lessen when roundabout traffic volumes are low, train frequency is low, or both.
- Double-rail lines have a higher potential for a queuing condition over the tracks when traffic is clearing after a first train with a second train arriving shortly after.
- Railroad signals and gates operate differently than highway signals during power outages. Railroad gates drop with a loss of power; highway signals flash or go dark.

12.7.2 General Treatment Approaches

A variety of generalized treatment approaches can address queuing when a grade crossing is in or near a roundabout and the queuing is deemed to warrant treatment.

- **Railroad gate arms.** Most at-grade rail crossings at or near roundabouts in the United States have railroad gate arms at the rail crossing. Some roundabouts have used railroad gate arms on other approaches to essentially close the roundabout to traffic when a train is nearing or present at the crossing. Closing the roundabout to all traffic during train passage is more practical for shorter light rail crossings. This technique is less common for at-grade crossings involving heavy rail, as railroad gate arms are typically owned and operated by the railroad but would be located outside the railroad right-of-way.
- **Traffic control signals or beacons.** Some existing roundabouts have used some form of traffic control signal or beacon to create a stop condition when a train approaches a grade crossing on the roundabout entries that do not cross the tracks. By stopping the traffic on the approaches not crossing the tracks, vehicles on the approach crossing the tracks can enter the roundabout and clear the crossing. The MUTCD would determine the form and function of these signals, which would be operated by the road authority. This approach is similar in concept to using traffic control signals for roundabout metering, as described in Section 12.6.
- **Intersection configuration changes.** A right-turn bypass lane for the approach crossing the tracks can reduce the queuing potential over the railroad tracks.
- **Signs at the grade crossing.** The MUTCD provides a regulatory sign, "Do Not Stop on Tracks" (R8-8), which may be sufficient for some grade crossings at roundabouts. This is especially true for crossings with a low frequency of train use and low roadway volumes.

As noted previously, the context of the roundabout installation affects what, if any, treatments are needed at the grade crossing. In some cases, a roundabout replacing another intersection form or control will either maintain or reduce the queuing on the subject leg with the grade crossing. An example is a proposed roundabout replacing an existing two-way stop-controlled intersection where the leg with the grade crossing is stop controlled. If the distance for queuing between the proposed roundabout and rail crossing is the same as between the existing stop-controlled intersection and rail crossing, and if the roadway volumes are the same in both cases, queuing from the roundabout to the grade crossing is likely to be the same or shorter. This is because yield control is generally more efficient than stop control. For this example, the existing passive or active traffic control systems at the grade crossing itself may be sufficient without additional treatments. An engineering study can confirm the recommended approach for the specific site conditions.

The following sections discuss issues associated with two generalized cases found in the United States. Other guidance is provided in state-level documents, such as that from the Georgia Department of Transportation (*18*).

12.7.3 Rail Crossing on One or More Legs

When rails cross only one roundabout leg, the simplest and most common treatment is to provide gates only on the leg where the rails cross. These gates would commonly be in the railroad right-of-way and operated by the railroad. An example of this application in Richland, Washington, is shown in Exhibit 12.33.

In another example, additional flashing red beacons were installed on the legs of the roundabout not crossing the railroad. This application in Reedley, California, is shown in Exhibit 12.34.

12.7.4 Rail Crossing through Central Island

Where rails pass through the roundabout's central island, either diagonally or along the median of one of the intersecting roadways, the simplest and most common treatment is to provide gates

Exhibit 12.33. Aerial perspective of at-grade rail crossing on one leg.

NOTE: Railroad gates located only at the at-grade rail crossing. No gates are provided across the sidewalk at the at-grade railroad crossing. LOCATION: W Clearwater Avenue/E Badger Road/Ridgeline Drive/Leslie Road, Richland, Washington. SOURCE: Google Earth.

Exhibit 12.34. Example of aerial perspective of railroad crossing near roundabout.

NOTE: Railroad gates are located only at the at-grade railroad crossing. Supplemental horizontal flashing red beacons are located on the roundabout leg in the lower right corner of the image. LOCATION: N Reed Avenue/W North Avenue, Reedley, California. SOURCE: Google Earth.

only on the circulatory roadway where the rails cross. These gates are commonly in the railroad right-of-way and operated by the railroad. An example of this application in Daingerfield, Texas, is shown in Exhibit 12.35 (aerial perspective) and Exhibit 12.36 (ground-level view of one of the at-grade crossings).

A similar case occurs where rails pass along the median of one of the intersecting roadways and then through the central island. An example of this occurs in a light rail application in Salt Lake City, Utah, as shown in Exhibit 12.37 and Exhibit 12.38.

12.8 Pavement Marking Materials

The types of pavement marking materials used at roundabouts vary widely across the United States. These types typically mirror the applications used elsewhere on the roadway system, often reflecting agency preference for installation and maintenance. Materials range from paint to more

Exhibit 12.35. Example of railroad diagonally through roundabout.

NOTE: Gates are located only at the at-grade railroad crossing. LOCATION: Webb Street/Myrtle Street/Jefferson Street/Coffey Street, Daingerfield, Texas. SOURCE: Google Earth.

Exhibit 12.36. Example of gate arm and signal on circulatory roadway.

LOCATION: Webb Street/Myrtle Street/Jefferson Street/Coffey Street, Daingerfield, Texas. SOURCE: Lee Rodegerdts.

Exhibit 12.37. Example of rail crossing along median through central island.

NOTE: Railroad gates are located at the at-grade light rail crossing and on each of the two entries parallel to the light rail tracks. LOCATION: E South Campus Drive/Campus Center Drive, Salt Lake City, Utah. SOURCE: Google Earth.

Exhibit 12.38. Example of rail crossing along median through central island.

LOCATION: E South Campus Drive/Campus Center Drive, Salt Lake City, Utah.
SOURCE: Lee Rodegerdts.

durable materials, such as thermoplastic. Pavement markings are sometimes inlaid to improve durability. Sometimes, pavement markings are supplemented or replaced by raised or depressed pavement markers. Further discussion on this topic can be found in other documents, such as the FHWA *Synthesis of Pavement Marking Research* (*19*).

12.9 Other Devices

Other devices, including traffic control devices governed by the MUTCD, have been used in some cases to address specific site conditions. These devices include

- Flexible, internally illuminated bollards;
- Transverse rumble strips placed in advance of the roundabout;
- Warning beacons supplementing approach warning signs;
- Speed reduction markings placed transversely across travel lanes; and
- Vehicle-activated speed warning signs commonly triggered by speeds exceeding an acceptable threshold.

12.10 References

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CHAPTER 13

Curb and Pavement Details

Contents

This chapter provides guidance on design, surface, and material details that bridge a roundabout's design from the horizontal and vertical layouts described in Chapter 10: Horizontal Alignment and Design and Chapter 11: Vertical Alignment and Cross-Section Design to the construction process described in Chapter 15: Construction and Maintenance. This chapter discusses

- Pavement and surface treatments,
- Curb types, and
- Median and splitter island features that facilitate maintenance.

This chapter is not an exhaustive discussion of all relevant design details. Many geometric design considerations related to these topics are fundamental to all intersection types, including those presented in Chapters 10 and 11.

13.1 Roadway Pavement Type

Pavement type and surface material treatment preference vary by agency and are based on climate and established local practice. Two material types are common for the top surface of approach, departure, and circulatory roadways at roundabouts: asphalt concrete (AC) and portland cement concrete (PCC). Whether to use AC or PCC depends on local preferences and the pavement type on the approach roadways. Some trade-offs for each are described in Exhibit 13.1.

Project context often dictates the choice between AC and PCC. For example, a complex staging and traffic management scenario may be more readily executed using PCC. Conversely, AC may be beneficial for a multilane roundabout with complex lane configurations that need a spiral marking pattern.

Exhibit 13.1. Considerations for pavement type at roundabouts.

	Asphalt Concrete	Portland Cement Concrete
Maintenance	• Mill and overlay of the existing roundabout are easier with traffic present. • Easier to surface repair.	• Joint repair is not possible with traffic present, so more detailed traffic control plans are necessary for maintenance.
Pavement marking	• Best contrast with any type of marking material.	• Requires using contrast tape, which is more costly to maintain.
Staging	• May be able to take advantage of temporary pavement as a base below the leveling course. • No joint lines to address. • Temporary pavement and other surfaces may be covered if the top asphalt layer is placed all at once in a later stage. • If joint lines are not perpendicular, longitudinal cracking will occur over time. • Adding curb in later stages requires a sawcut and backfilling with specified compaction.	• Joint lines provide a clean break for stages. • Temporary AC adjacent to PCC can be easily removed without a sawcut. • Staging requires stage cuts at joint lines, which may be more difficult with traffic present. • Overall construction time may be longer because of curing time.
Durability	• Shorter design life. • More prone to rutting, which affects drainage characteristics. • Requires substantial base material and depth and surface mix design for optimal durability and skid resistance. • Rehabilitation is feasible, cost-effective, and practical.	• Longer design life; more likely to retain initial drainage characteristics. • Near the end of the design life, complete reconstruction is required—pavement rehabilitation is not possible.
Color contrast	• If splitter islands are AC, there will be minimal contrast as color lightens over time. • Provides good contrast with pavement markings and with PCC truck aprons. • Colored AC is possible but less common than colored PCC.	• Mixes can be colored to provide contrast and textured for aesthetics. • More difficult to establish contrast with pavement markings and truck apron. • Requires using contrast tape (more costly to maintain).
Other	• AC placement will be more rounded through cross-slope transitions, which may help oversized vehicles and lowboy trailers traverse through the roundabout. • Easier to construct a smooth crown line.	• Skid resistance declines more rapidly. • Joint lines may resemble lane lines in the multilane design.
Expandability or staged design expansion	• Adjustability of grades is easier, and drainage is less impacted.	• The PCC joint pattern may not be compatible with an expanded layout. • Dowels may be required for expansion areas.

SOURCE: Adapted from American Concrete Pavement Association *(1)*.

13.2 Truck Apron Material

Agencies use a range of aesthetic treatments, including simple broomed PCC, stamped/patterned PCC (broomed finish), and various types of paver materials—there is no preferred texture for the truck apron. However, it is beneficial for the truck apron to be a different color and texture from the circulatory roadway and non-traversable surfaces (e.g., sidewalks) to improve its visibility to drivers and distinguish it from other elements. There are multiple ways to accomplish this, three of which are discussed below.

- **PCC and AC.** Some agencies use PCC for truck aprons (for durability) and AC for the circulatory roadway. This way, the truck apron is less prone to rutting. The visual distinction also helps communicate the difference in the intended uses.
- **PCC only.** For roundabouts constructed entirely of PCC, mixtures can be colored to provide visual distinction. The apron may also be textured or patterned. With this approach, an agency preferably will not select a color that may be mistaken for one that the MUTCD designates for a specific use (*2*). For example, red and green coloring denotes travel lanes for transit and bicycle use. Therefore, some agencies have adopted designated colors for associated roundabout design elements.
- **AC and pavers.** Some agencies use pavers (or other stone material) in the truck apron (see Exhibit 13.2 and Exhibit 13.3), with the uneven driving surface dissuading drivers from

Exhibit 13.2. Example of raised truck apron using pavers.

LOCATION: US 5/Route 9, Brattleboro, Vermont. SOURCE: Lee Rodegerdts.

Exhibit 13.3. Example of flush truck apron using pavers.

LOCATION: Broad Street/Coburn Avenue/Chuck Druding Drive, Nashua, New Hampshire. SOURCE: Lee Rodegerdts.

Exhibit 13.4. Example of placing truck apron curb.

LOCATION: Route 9–Route 126/I-95 Northbound Ramps/Service Plaza Drive, West Gardiner, Maine. SOURCE: Jonathan French.

traversing the area. Pavers can be an effective design element that provides an aesthetic quality, but they require more time, money, and expertise—paver installation is labor intensive and can result in water ponding or erosion if pavers are improperly installed.

Exhibit 13.4 and Exhibit 13.5 demonstrate the means and methods for constructing a PCC truck apron. In this example, the truck apron curb was located and constructed before the remainder of the truck apron. Steel reinforcing in the truck apron adds durability for anticipated design vehicle loads.

The shape of the truck apron curb more effectively discourages passenger cars from using the apron than the material it is made from. The curb helps reinforce the use of the circulatory roadway while allowing the intended vehicles to track upon the truck apron; this practice permits the use of smooth truck aprons that are easier to construct and maintain. Section 13.4 further discusses curb types.

Pedestrians should not access the roundabout's central island. Truck apron material and color alone are not appropriate ways to reinforce this because these differences are not adequate for people who are blind or have low vision. Instead, landscaping and buffer strips or

Exhibit 13.5. Example of steel reinforcing being placed for truck apron.

LOCATION: Route 9–Route 126/I-95 Northbound Ramps/Service Plaza Drive, West Gardiner, Maine. SOURCE: Jonathan French.

other detectable edges between the sidewalk and circulatory roadway, discussed in Chapter 10: Horizontal Alignment and Design, more effectively discourage pedestrians of all abilities from accessing the central island.

13.3 Pavement Jointing

If PCC is used for the circulatory roadway of a multilane roundabout, expansion joint design and location are key considerations. Practitioners must carefully develop a jointing plan to avoid joint lines being mistaken for lane lines.

In general, the best joint patterns are those that are concentric and radial to the circulatory roadway within the roundabout.

- On single-lane roundabouts, jointing must not split the circulatory roadway into equal parts, as this can give the illusion of a two-lane roundabout. This can be particularly problematic at night and in wet conditions when vehicles may drive along the joints. This introduces the potential for side-by-side movements. Alternatively, the jointing may split the roadway into larger and smaller segments that are unlikely to be confused for distinct travel lanes (see Exhibit 13.6).
- On multilane roundabouts, circumferential joints within the circulatory roadway need to follow pavement markings to the extent practical (see Exhibit 13.7).

Cracking in PCC has been a problem at some roundabouts, particularly around the outside of the circulatory roadway near outside curbs or splitter islands. Practitioners can solve this issue by isolating the circulatory roadway portion with an expansion joint and constructing special monolithic sections in key areas on the approaches and around splitter islands. When the joints are laid out independently of each other, the joint spacing adjacent to the truck apron and the outside of the circulatory roadway can be more uniform, rather than closer together near the truck apron and farther apart on the outside of the circulatory roadway.

Practitioners need to prepare a jointing plan and associated detail sheets as part of the final design plan set and submit them to the review authority. Exhibit 13.6 provides an example concrete jointing plan and the resulting roundabout that illustrates the radial pattern. Exhibit 13.7 shows an example of jointing alignment with pavement markings.

Exhibit 13.6. Example jointing plan for a single-lane roundabout.

LOCATION: US 75/K-31/K-268, Osage County, Kansas. SOURCE: Kansas Department of Transportation.

Exhibit 13.7. Example of pavement markings aligned with concrete jointing at a single-lane roundabout.

LOCATION: Rice Road/I-70 Eastbound Ramps/Cyprus Drive, Topeka, Kansas.
SOURCE: Lee Rodegerdts.

A jointing plan is needed so the joint layout will be constructed properly; the plan is the key by which the joints will be correctly located. The American Concrete Pavement Association (ACPA) identifies a six-step process for developing a jointing plan (*1*):

1. Draw all pavement edge and back-of-curb lines in plan view. Draw locations of all manholes, drainage inlets, and valve covers so that joints can intersect them.
2. Draw all lane lines on approach legs and in the circulatory roadway. Confirm that joint spacing does not exceed the maximum recommended width of 15 ft (4.5 m).
3. In the circulatory roadway, add transverse joints radiating out from the center of the circle. Extend these joints through the back of the curb and gutter.
4. On the approaches, add transverse joints at all locations where a width change occurs in the pavement (at bullnose of splitter islands; beginning and ending of curves, tapers, tangents, curb returns; etc.). Extend these joints through the back of the curb and gutter.
5. Add transverse joints beyond and between those added in Step 4. Space joints evenly between other joints, making sure to not violate maximum joint spacing.
6. Adjust for in-pavement objects and fixtures and to eliminate L-shapes, small triangular slabs, and so on.

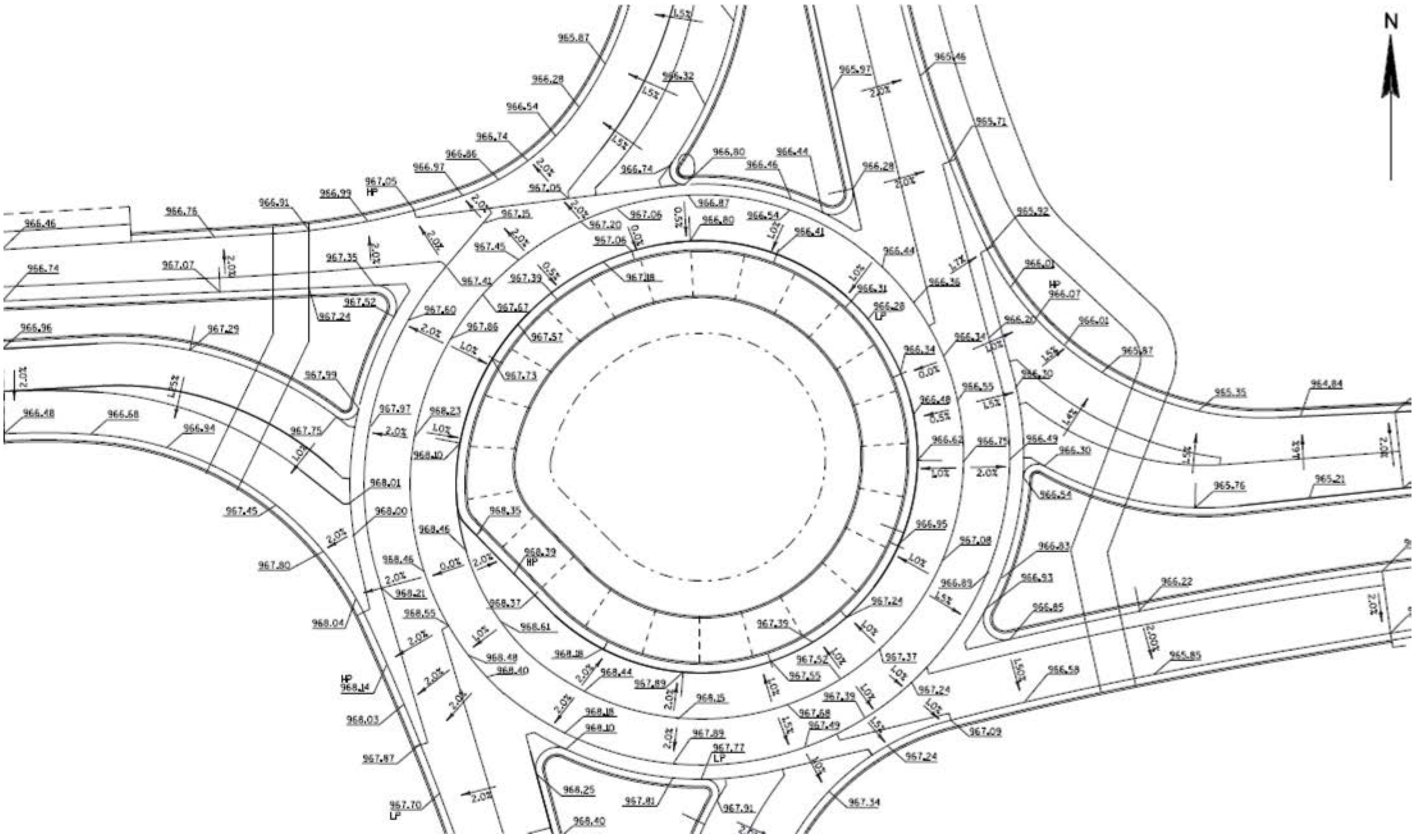
The ACPA recommends considering the following when preparing a jointing plan for a roundabout (*1*):

- Match existing joints and cracks wherever possible.
- Place joints to meet in-pavement structures.
- Set maximum joint spacing as follows:
  - 24 times concrete thickness (on unstabilized base)
  - 21 times concrete thickness (on stabilized base)
  - Maximum of 15 ft (4.5 m) for streets and highways
- Understand that practical adjustments can be made to joint locations.

Similarly, the ACPA recommends avoiding the following (*1*):

- Slabs less than 1 ft (300 mm) wide
- Slabs greater than 15 ft (4.5 m) wide
- Angles less than 60 degrees created by dog-legging joints through curve radius points (approximately 90 degrees is best)

Exhibit 13.8. Example of multilane roundabout jointing plan.



LOCATION: Radio Road/Paulson Road, Saint Croix County, Wisconsin. SOURCE: Wisconsin Department of Transportation.

- Creating interior corners (L-shaped slabs)
- Creating odd shapes (keep slabs square or pie-shaped)

As noted in Section 10.8, a roundabout may be built as a single-lane roundabout with plans for expansion in the future based on projected traffic volumes. However, because concrete jointing can be mistaken for striping, the jointing plans established for the opening-year roundabout should be reasonably compatible with plans for the ultimate roundabout configuration.

Exhibit 13.8 illustrates an example of a jointing plan for a multilane roundabout with a spiral design. Exhibit 13.9 shows how the painted lane lines are aligned with the longitudinal jointing.

13.4 Curb Type

Two general curb (or curb and gutter) types are used at roundabouts. One group of curb types is traversable and accommodates vehicles driving onto and over them if necessary. Other curb types are non-traversable, typically with more vertical rise, and are expressly designed to discourage any driver from mounting or driving over them. Exhibit 13.10 shows a wide array of concrete curb types, demonstrating that curbs and local design standards dictate the details but that various designs can support the traversable or non-traversable intent. Variations using granite curbs are possible.

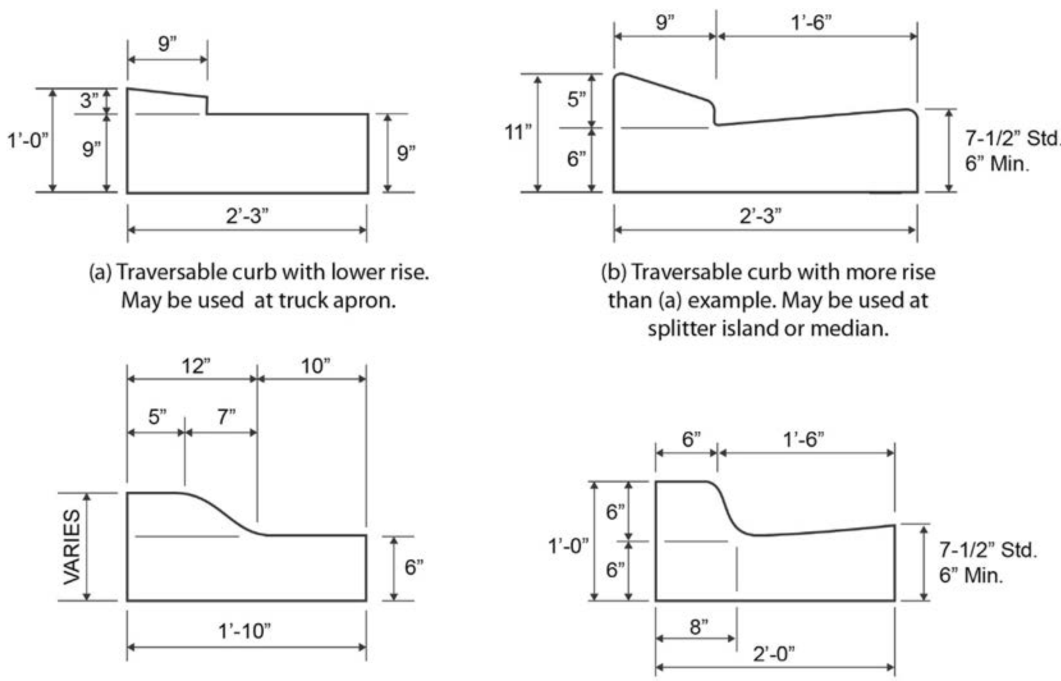
- **Traversable curbs.** These are sometimes called *rolled* or *mountable* curbs. These are most common for the leading edges of truck aprons but are sometimes used throughout a roundabout

Exhibit 13.9. Example of multilane roundabout jointing along pavement markings.

LOCATION: Mason Street / I-41 Southbound Ramps, Green Bay, Wisconsin.
SOURCE: Lee Rodegerdts.

in higher-speed environments. In the higher-speed context, mountable curbs may be used at splitter islands or medians with a taller height and different profile from those at truck aprons. Traversable curbs generally have a low vertical component of 1 in. to 2 in. (25 mm to 50 mm), a low overall rise of 3 in. to 4 in. (75 mm to 100 mm), and a broad slope in a vertical-to-horizontal ratio of 1:4. Curb types can vary, but general practice favors keeping the vertical component and the overall rise lower to minimize the adverse effects on truck dynamics or damage to truck tires while still discouraging passenger car use. There is considerable variation from agency to agency. Exhibit 13.10 provides a few examples of curb type variations.

Exhibit 13.10. Concrete curb type variations.



(a) Traversable curb with lower rise. May be used at truck apron.

(b) Traversable curb with more rise than (a) example. May be used at splitter island or median.

(c) Rolled, mountable curb. May be used at truck apron.

(d) Non-traversable curb with sloped face. May be used at splitter island or median.

NOTE: Variations using granite curbs are possible but not shown. SOURCE: Adapted from Florida Department of Transportation and Washington State Department of Transportation details (*4, 5*).

- **Non-traversable curbs.** These are sometimes called *vertical* or *slope-faced* curbs. They are most common in the vicinity of pedestrian crossings but are sometimes used throughout a roundabout in lower-speed environments (except for the front edge of truck aprons). Non-traversable portions of central islands can also be separated from truck aprons with vertical curbs. Agency preferences vary widely, but these are often 6-in. (150 mm) vertical curbs that provide protection and detectable edging for pedestrians, typical of what is provided in most urban areas. These curb types may also have a sloped face but remain unmountable (see Exhibit 13.10, *d*).

Curb strikes are one of the leading causes of motorcyclist fatalities, which are overrepresented at roundabouts compared with other intersection forms (*3*). Mountable curb types around the perimeter and along the inside of the truck apron may improve recovery for these vehicle types. Curb types need to be consistent with the intersection plan to accommodate oversize or overweight vehicles.

13.5 Splitter Islands with Sloped Noses

As discussed in Chapter 10: Horizontal Alignment and Design, channelization of splitter islands includes the fundamental principles of offsetting and matching the radius to the intended driver-funneling effect (*6*). For roundabouts in locations with snowfall that needs to be cleared, plowable end treatments (depicted in Exhibit 13.11 and Exhibit 13.12) can allow snowplows to push

Exhibit 13.11. Example of plowable end treatment at splitter island.

LOCATION: CR 17/52nd Avenue S, West Fargo, North Dakota.
SOURCE: Lee Rodegerdts.

Exhibit 13.12. Example of plowable end treatment at bypass island.

LOCATION: US 50/California State Route 89, El Dorado County, California.
SOURCE: Michael Alston.

snow up to and on the splitter island. Some agencies also use sloped edges at pedestrian ramps and pedestrian routes through splitter islands to reduce damage from plowing operations. This is a viable treatment where winter weather is a serious consideration.

13.6 References

1. *Research & Technology Update No. 6.03: Concrete Roundabouts*. American Concrete Pavement Association, Washington, DC, 2005.
2. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed., Including Revision 1, Dated May 2012; Revision 2, Dated May 2012; and Revision 3, Dated August 2022. FHWA, US Department of Transportation, 2022. http://mutcd.fhwa.dot.gov/.
3. Steyn, H. J., A. Griffin, and L. Rodegerdts. *A Review of Fatal and Severe Injury Crashes at Roundabouts*. Vol. IV of VII, *Accelerating Roundabout Implementation in the United States.* Publication FHWA-SA-15-072. FHWA, US Department of Transportation, 2015.
4. *FY 2022–23 Standard Plans: Curb and Gutter*. Index 520-001. Florida Department of Transportation, Tallahassee, 2021. https://www.fdot.gov/design/standardplans/current/default.shtm. (Accessed June 9, 2022.)
5. *Roundabout Cement Concrete Curbs: Standard Plan F-10.18-02.* Washington State Department of Transportation, Olympia, 2020. https://wsdot.wa.gov/engineering-standards/all-manuals-and-standards/standard-plans. (Accessed June 9, 2022.)
6. *A Policy on Geometric Design of Highways and Streets*, 7th ed. AASHTO, Washington, DC, 2018.

CHAPTER 14

Illumination, Landscaping, and Artwork

Contents

This chapter discusses illumination, landscaping, and artwork at roundabouts. Illumination information encompasses general considerations, lighting levels, and illumination equipment type and location, including suggested lighting levels for various applications, transition lighting recommendations, and equipment and pole location suggestions. This chapter also addresses horizontal and vertical illuminance needs and uses illumination terms and concepts defined and described in the Illuminating Engineering Society's (IES) *Recommended Practice for Design and Maintenance of Roadway and Parking Facility Lighting*, ANSI/IES RP-8-18 (*1*).

Landscaping information includes general objectives and guidance for landscaping within the central island, in medians and approaches, and associated with sidewalks and path buffers. Additional guidance and considerations for artwork and other objects at the roundabout are also included.

14.1 General Illumination Considerations

As with any intersection lighting, roundabout lighting makes the roundabout visible from a distance and makes vehicular and non-motorized traffic more visible in conflict areas. Motor vehicles have headlights and taillights to improve their visibility at night. However, pedestrians and bicyclists may not have lights or be as visible, and unexpected objects (e.g., a boulder that has fallen into the roadway) or animals may be in the travel lanes. The view a driver needs for stopping sight distance within the circulatory roadway is often beyond the range covered by typical fixed headlight configurations, unless the headlights can steer to the left to match the vehicle trajectory. As a result, the IES recommends providing roundabout lighting (*1*).

Delineation—retroreflective signs, pavement markings, pavement markers, and other devices—can also help a driver understand the changing conditions from the roadway segment to the roundabout. Delineation can mimic the presence of curbing and the splitter island to provide positive guidance to and through the roundabout. In some cases, delineation without supplemental lighting may be desired, especially if providing lighting is impractical. However, delineation does not provide supplemental lighting to illuminate conflict areas with other drivers or with bicyclists or pedestrians, nor does it help identify unexpected objects or wildlife in the roadway.

14.1.1 Lighting Policies

Requiring or recommending roundabout lighting is a policy-level decision. In general, agencies that have published their own roundabout design or lighting standards have specified that lighting is required (*2, 3, 4*). Agency practices vary widely with respect to providing lighting for any type of isolated rural intersections (*5*).

As an example of a specific lighting policy for roundabouts, the Pennsylvania Department of Transportation (PennDOT) requires roundabout lighting if the roundabout meets one or more of the following factors based on the design year (*6*):

- The roundabout is part of an interchange that has full or partial lighting.
- Any of the intersecting roads have an AADT exceeding 1,500 vehicles per day.
- Nighttime pedestrian activity exceeds 10 pedestrians per hour during the highest average annual nighttime hour.
- One or more of the roundabout legs has or is expected to have lighting.
- The roundabout is in an urban or urban core environment.

PennDOT requires approving an exception to the lighting policy if one or more of the above warranting factors is not met. If lighting is not provided, retroreflective signs and pavement markings to identify fixed-object hazards are required. This includes delineating the central island, the splitter island noses, and the beginning of any curb sections.

Internationally, roundabout lighting recommendations are mixed. One study found that of 22 European countries, 12 Asian countries, 2 African countries, and 9 countries in the Americas outside the United States, 16 percent of the surveyed countries attempt to light all roundabouts (*7*). The researchers also examined crash data from Minnesota and concluded that partial illumination achieves significant benefits compared with leaving the roundabout unlit. The researchers concluded with a "qualified yes" that it may be feasible to use a reduced illumination roundabout as a safety treatment for either uncontrolled or stop-controlled rural intersections (*7*). The French lighting guide reports that two-thirds of all roundabouts in rural areas are not illuminated and that nighttime injury crashes are divided equally between illuminated and unlit roundabouts. The French guide also notes that almost all nighttime crashes involve the loss of control of single vehicles and result in property-damage-only crashes, many of which may not be reported. As a result, the crash history is not as readily quantifiable (*8*).

14.1.2 Dark Sky Principles

The International Dark-Sky Association and IES have jointly published five principles for responsible outdoor lighting (*9*):

1. **Useful.** All light should have a clear purpose.
2. **Targeted.** Light should be directed only to where it is needed.
3. **Low light levels.** Light should be no brighter than necessary.
4. **Controlled.** Light should be used only when it is useful.
5. **Color.** Warmer-color lights should be used where possible.

These principles can be applied through a variety of means:

- Lighting only the parts of the roundabout that require it. This includes the key conflict areas where drivers with headlights may encounter bicyclists and pedestrians or where headlights are less effective because of horizontal curvature.
- Using only the minimum necessary lighting level. The following sections provide lighting-level recommendations consistent with IES principles and are more flexible to meet site-specific needs.
- Selecting lighting fixtures that provide the most targeted coverage and use lighting sources that are warmer where possible.
- Using and maintaining photocells so lighting is on only when needed.
- Balancing landscaping uplighting with dark sky principles.

14.2 Lighting Levels

AASHTO and IES provide lighting-level guidance, with IES guidance offering more detail (*10, 1*). IES RP-8-18 presents three classifications of intersection lighting:

- **Full intersection lighting** is used for intersections on one or more streets with continuous lighting.
- **Partial intersection lighting** is used for areas within interchanges and for isolated intersections where no continuous lighting is provided on the intersecting streets.
- **Intersection delineation lighting** is used to identify the location of an intersection.

Lighting-level metrics for roundabouts include a combination of horizontal and vertical illuminance. In general terms, horizontal illuminance is a measure of how much light is projected onto a horizontal plane, and vertical illuminance is a measure of how much light is projected onto a vertical plane. Horizontal illuminance is, therefore, used to evaluate the lighting levels for the roadway surface, and vertical illuminance is used to evaluate how much light is projected onto pedestrians in crosswalks. More detail, including recommended grid patterns for evaluations, can be found in IES RP-8-18 (*1*).

The following sections were adapted from IES RP-8-18 for PennDOT and are suggested for general use in the United States (*11*). These suggested lighting levels vary on the basis of whether the roundabout is isolated or within a system of continuous lighting, and they consider the roundabout pavement material, AADT levels, and nighttime pedestrian activity.

14.2.1 Roundabouts on Streets with Continuous Lighting

If two or more of the intersecting roadways have continuous lighting, the following practice is suggested:

- If the roundabout is paved with asphalt concrete (excluding any truck aprons, if provided), Exhibit 14.1 can help determine the appropriate horizontal illuminance level for the roundabout.

Exhibit 14.1. Pavement illuminance criteria for roundabouts with asphalt concrete paving.

Major Street AADT (veh/day)	Minor Street AADT (veh/day)	Pedestrian Activity Level During Highest Average Annual Nighttime Hour			Uniformity Ratio E_{avg}/E_{min}
		>100 p/hr	10–100 p/hr	<10 p/hr	
>3,500	>3,500	3.2 fc (34 lx)	2.4 fc (26 lx)	1.7 fc (18 lx)	3.0
>3,500	1,500–3,500	2.7 fc (29 lx)	2.0 fc (22 lx)	1.4 fc (15 lx)	3.0
>3,500	<1,500	2.4 fc (26 lx)	1.9 fc (20 lx)	1.2 fc (13 lx)	3.0
1,500–3,500	1,500–3,500	2.2 fc (24 lx)	1.7 fc (18 lx)	1.1 fc (12 lx)	4.0
1,500–3,500	<1,500	2.0 fc (21 lx)	1.5 fc (16 lx)	0.9 fc (10 lx)	4.0
<1,500	<1,500	1.7 fc (18 lx)	1.3 fc (14 lx)	0.7 fc (8 lx)	6.0

NOTE: AADT = average annual daily traffic; fc = foot-candle; lx = lux; p/hr = pedestrians per hour; veh/day = vehicles per day.
SOURCE: Adapted from IES RP-8-18, Table 12-4, Section 12.1.2, and Section 12.1.3 (*1*), as presented in PennDOT Lighting Policy for Roundabouts (*11*).

- If the roundabout is paved with PCC, Exhibit 14.2 can help determine the appropriate horizontal illuminance level for the roundabout.

If an approach has a higher lighting level than IES recommends for that type of facility, the roundabout illuminance level should be equal to the sum of the intersecting roadways.

14.2.2 Isolated Roundabouts (No Continuous Lighting on Any Approach)

If none of the intersecting roadways have continuous lighting, practitioners can use Exhibit 14.3 to determine the appropriate roundabout illuminance level.

The number of luminaires needed for an isolated roundabout depends in part on the target uniformity ratio. For roundabouts on a major street with 3,500 vehicles per day or greater, the uniformity ratio of 3.0 may require luminaires in each quadrant (four for a typical four-leg roundabout). Conversely, it may be possible to use fewer luminaires to adequately light a roundabout on a major street with less than 1,500 vehicles per day depending on the size of the roundabout

Exhibit 14.2. Pavement illuminance criteria for roundabouts with portland cement concrete paving.

Major Street AADT (veh/day)	Minor Street AADT (veh/day)	Pedestrian Activity Level During Highest Average Annual Nighttime Hour			Uniformity Ratio E_{avg}/E_{min}
		>100 p/hr	10–100 p/hr	<10 p/hr	
>3,500	>3,500	2.2 fc (24 lx)	1.7 fc (18 lx)	1.1 fc (12 lx)	3.0
>3,500	1,500–3,500	1.9 fc (20 lx)	1.4 fc (15 lx)	0.9 fc (10 lx)	3.0
>3,500	<1,500	1.5 fc (16 lx)	1.3 fc (14 lx)	0.8 fc (9 lx)	3.0
1,500–3,500	1,500–3,500	1.5 fc (16 lx)	1.1 fc (12 lx)	0.7 fc (8 lx)	4.0
1,500–3,500	<1,500	1.3 fc (14 lx)	1.0 fc (11 lx)	0.7 fc (7 lx)	4.0
<1,500	<1,500	1.1 fc (12 lx)	0.9 fc (10 lx)	0.6 fc (6 lx)	6.0

NOTE: AADT = average annual daily traffic; fc = foot-candle; lx = lux; p/hr = pedestrians per hour; veh/day = vehicles per day.
SOURCE: Adapted from IES RP-8-18, Table 12-4, Section 12.1.2, and Section 12.1.3 (*1*), and illuminance criteria for R1 roadways as published in IES RP-8-00 (*12*), as presented in PennDOT Lighting Policy for Roundabouts (*11*).

Exhibit 14.3. Pavement illuminance criteria for isolated roundabouts.

Major Street AADT (veh/day)	Road Surface		Uniformity Ratio E_{avg}/E_{min}
	Portland Cement Concrete	Asphalt Concrete	
>3,500	0.6 fc (6 lx)	0.8 fc (9 lx)	3.0
1,500–3,500	0.4 fc (4 lx)	0.6 fc (6 lx)	4.0
<1,500	0.3 fc (3 lx)	0.4 fc (4 lx)	6.0

NOTE: AADT = average annual daily traffic; fc = foot-candle; lx = lux; veh/day = vehicles per day. SOURCE: Adapted from IES RP-8-18, Table 12-2 and Section 12.1.2 (*1*), as presented in PennDOT Lighting Policy for Roundabouts (*11*).

and the mounting height, lumen level, and distribution type of the selected luminaires. A case-specific design will be necessary to determine the applicable lighting configuration.

14.2.3 Crosswalk Lighting

In addition to roundabout horizontal illuminance, practitioners need to evaluate vertical illuminance at each crosswalk. This consists of evaluating points above the crosswalk (commonly 5 ft [1.5 m]) and achieving a vertical illuminance that matches the design horizontal illuminance. Crosswalk vertical illuminance is to be measured as viewed by drivers approaching each crosswalk (i.e., toward the roundabout on entry, away from the roundabout on exit). Other references on crosswalk lighting include the FHWA *Street Lighting for Pedestrian Safety* and the FHWA *Informational Report on Lighting Design for Midblock Crosswalks* (*13*, *14*).

14.2.4 Transition Lighting

When a roadway transitions to no lighting from an illuminance level that exceeds the values in Exhibit 14.3, roundabouts need transition lighting as appropriate for the pavement type to allow time for driver eyes to adjust to the change in lighting level. This may happen, for example, if the roundabout was designed to fit into an existing or future continuous lighting system on one or more legs, even if the subject leg is not part of a continuous lighting system. AASHTO and IES provide inflexible values on the length of transition lighting needed: 400 ft (121 m) for AASHTO and 262 ft (80 m) for IES (*1*, *10*).

A flexible transition lighting method based on human factor principles allows for lighting that is sensitive to the roundabout design, its context, and other factors. Useful parallels in IES RP-8-18 can be found for tunnels. IES provides a transition adaptation curve showing the percentage of threshold luminance declining exponentially as a function of time in seconds, reflecting the human eye's adaptation from light areas to darkness.

Lighting levels at or below those in Exhibit 14.3 for isolated roundabouts do not require transition lighting. If transition lighting is not provided on a given leg, the start of curbing within the median or outside edges of the approaching roadway needs to be highlighted. This includes using retroreflective signs, pavement markings, pavement markers on top of curbs, or other techniques to mark the leading edge of the splitter island as well as the start of any curbing on the outside edge of the approach roadway.

For lighting levels above those in Exhibit 14.3 for isolated roundabouts, Exhibit 14.4 presents the extent of necessary transition lighting. The exhibit identifies a series of zones that step away from the roundabout. Depending on the lighting level of the roundabout itself, the number of transition zones needed may range from zero to three. The first zone, Zone 1, represents 70 percent of the main intersection illuminance level; the illuminance level in each subsequent zone decreases

Exhibit 14.4. Transition zones based on roundabout illuminance levels.

Roundabout Illuminance	Transition Lighting Needed?	Transition Zone Illuminance		
		Zone 1 (70%)	Zone 2 (40%)	Zone 3 (16%)
3.2 fc (34 lx)	Yes	2.2 fc (24 lx)	1.3 fc (14 lx)	0.5 fc (5 lx)
2.7 fc (29 lx)	Yes	1.9 fc (20 lx)	1.1 fc (12 lx)	0.5 fc (5 lx)
2.4 fc (26 lx)	Yes	1.7 fc (18 lx)	0.9 fc (10 lx)	0.4 fc (4 lx)
2.2 fc (24 lx)	Yes	1.6 fc (17 lx)	0.9 fc (10 lx)	0.4 fc (4 lx)
2.0 fc (22 lx)	Yes	1.4 fc (15 lx)	0.8 fc (9 lx)	None
2.0 fc (21 lx)	Yes	1.4 fc (15 lx)	0.7 fc (8 lx)	None
1.9 fc (20 lx)	Yes	1.3 fc (14 lx)	0.7 fc (8 lx)	None
1.7 fc (18 lx)	Yes	1.2 fc (13 lx)	0.7 fc (7 lx)	None
1.5 fc (16 lx)	Yes	1.0 fc (11 lx)	0.6 fc (6 lx)	None
1.4 fc (15 lx)	Yes	1.0 fc (11 lx)	0.6 fc (6 lx)	None
1.3 fc (14 lx)	Yes	0.9 fc (10 lx)	0.6 fc (6 lx)	None
1.2 fc (13 lx)	Yes	0.8 fc (9 lx)	None	None
1.1 fc (12 lx)	Yes	0.7 fc (8 lx)	None	None
1.0 fc (11 lx)	Yes	0.7 fc (8 lx)	None	None
0.9 fc (10 lx)	Yes	0.7 fc (7 lx)	None	None
0.8 fc (9 lx) or less	No	None	None	None

NOTE: fc = foot-candle; lx = lux. SOURCE: Adapted from PennDOT Lighting Policy for Roundabouts (*11*).

with increased distance from the roundabout. Values in the exhibit may be interpolated as needed or rounded up to the next highest value.

The length of each zone is a function of the roundabout's exiting speed and the posted speed of the leg downstream from the roundabout. As exiting speed and posted speed increase, each zone length also increases. Exhibit 14.5 provides design values for the length of each zone based on the design exit speed from the roundabout (and the posted speed downstream of the roundabout). Values in between the values in the exhibit may either be interpolated or rounded up to the next higher value. All zones are to be measured along the centerline of the roadway.

Exhibit 14.6 summarizes the results of these recommendations for transition lighting. The need for transition lighting is primarily dictated by the roundabout lighting level (shown in the exhibit as Zone 0) and the amount of time it takes for the human eye to adapt from a bright condition to a dark condition. If transition lighting is needed, the extent of necessary transition is a function of the roundabout lighting level, the exit speed, and the posted speed downstream of the roundabout.

14.3 Illumination Equipment Type and Location

A photometric analysis is required to determine the appropriate lighting fixture and pole location. Practitioners should consider the number of fixed objects in the public right-of-way adjacent to a roundabout when identifying optimal locations for lighting poles; fewer poles with higher-intensity light fixtures minimize the number of fixed objects. The type of area should also

Exhibit 14.5. Transition zone lengths based on roundabout exit speed and downstream speed limit.

Transition Zone Length (ft)			
Downstream Posted Speed	**Zone 1 (70%)**	**Zone 2 (40%)**	**Zone 3 (16%)**
Exit Speed = 20 mph (30 km/h)			
30 mph (50 km/h)	30 ft (9 m)	90 ft (27 m)	140 ft (43 m)
35 mph (55 km/h)	30 ft (9 m)	100 ft (30 m)	160 ft (49 m)
40 mph (65 km/h)	30 ft (9 m)	100 ft (30 m)	180 ft (55 m)
45 mph (70 km/h)	30 ft (9 m)	100 ft (30 m)	190 ft (58 m)
50 mph (80 km/h)	30 ft (9 m)	100 ft (30 m)	190 ft (58 m)
55+ mph (90+ km/h)	30 ft (9 m)	100 ft (30 m)	190 ft (58 m)
Exit Speed = 25 mph (40 km/h)			
30 mph (50 km/h)	40 ft (12 m)	90 ft (27 m)	140 ft (43 m)
35 mph (55 km/h)	40 ft (12 m)	90 ft (27 m)	140 ft (43 m)
40 mph (65 km/h)	40 ft (12 m)	120 ft (37 m)	180 ft (55 m)
45 mph (70 km/h)	40 ft (12 m)	120 ft (37 m)	200 ft (61 m)
50 mph (80 km/h)	40 ft (12 m)	120 ft (37 m)	220 ft (67 m)
55+ mph (90+ km/h)	40 ft (12 m)	120 ft (37 m)	220 ft (67 m)
Exit Speed = 30 mph (50 km/h)			
30 mph (50 km/h)	50 ft (15 m)	90 ft (27 m)	140 ft (43 m)
35 mph (55 km/h)	50 ft (15 m)	110 ft (34 m)	160 ft (49 m)
40 mph (65 km/h)	50 ft (15 m)	120 ft (37 m)	180 ft (55 m)
45 mph (70 km/h)	50 ft (15 m)	140 ft (43 m)	200 ft (61 m)
50 mph (80 km/h)	50 ft (15 m)	140 ft (43 m)	230 ft (70 m)
55+ mph (90+ km/h)	50 ft (15 m)	140 ft (43 m)	250 ft (76 m)

NOTE: Zone 1 begins 50 ft (15 m) from the edge of the circulatory roadway or 20 ft (6 m) beyond the farthest edge of the crosswalk, whichever is longer. SOURCE: Adapted from PennDOT Lighting Policy for Roundabouts (*11*); metric values rounded to nearest 5 km/h and 1 m.

be considered when determining the equipment type and location. In an urban area with a high level of pedestrian activity, it may be more appropriate to install illumination at lower mounting heights. In these cases, the illumination at lower mounting heights may need to be supplemented with taller, cobra-style assemblies to provide adequate lighting.

A wide variety of illumination equipment types have been used at roundabouts and typically reflect the local practices of the road authority or power company providing the illumination. Three common types of fixtures are used:

- Cobra style,
- Pedestal, and
- High mast.

Of these, cobra-style fixtures commonly use a lighting distribution to focus the lighting in a specific area below the lighting fixture. Other fixtures tend to have an omnidirectional distribution to light areas in all directions of the fixture.

Exhibit 14.6. Summary of transition lighting recommendations.

Roundabout Illuminance	Transition Lighting Needed Beyond the Roundabout (Zone 0)?	Length of Transition Lighting				
		Roundabout (Zone 0) (100% Illuminance)	Zone 1 (70%)	Zone 2 (40%)	Zone 3 (16%)	Total
>2.0 fc (>22 lx)	Yes	50 ft (15 m), or 20 ft (6 m) beyond farthest edge of crosswalk	30 ft to 50 ft (9 m to 15 m)	90 ft to 140 ft (27 m to 43 m)	140 ft to 250 ft (43 m to 76 m)	310 ft to 490 ft (94 m to 149 m)
>1.2 fc to 2.0 fc (>13 lx to 22 lx)	Yes	50 ft (15 m), or 20 ft (6 m) beyond farthest edge of crosswalk	30 ft to 50 ft (9 m to 15 m)	90 ft to 140 ft (27 m to 43 m)	None	170 ft to 240 ft (52 m to 73 m)
>0.8 fc to 1.2 fc (>9 lx to 13 lx)	Yes	50 ft (15 m), or 20 ft (6 m) beyond farthest edge of crosswalk	30 ft to 50 ft (9 m to 15 m)	None	None	80 ft to 100 ft (24 m to 30 m)
≤0.8 fc (≤9 lx)	No	50 ft (15 m), or 20 ft (6 m) beyond farthest edge of crosswalk	None	None	None	50 ft (15 m)

NOTE: Zone 0 includes the circulatory roadway and extends 50 ft (15 m) from the edge of the circulatory roadway, or 20 ft (6 m) beyond farthest edge of crosswalk, whichever is longer. fc = foot-candle; lx = lux. SOURCE: Adapted from PennDOT Lighting Policy for Roundabouts (*11*); metric values rounded to nearest 1 m.

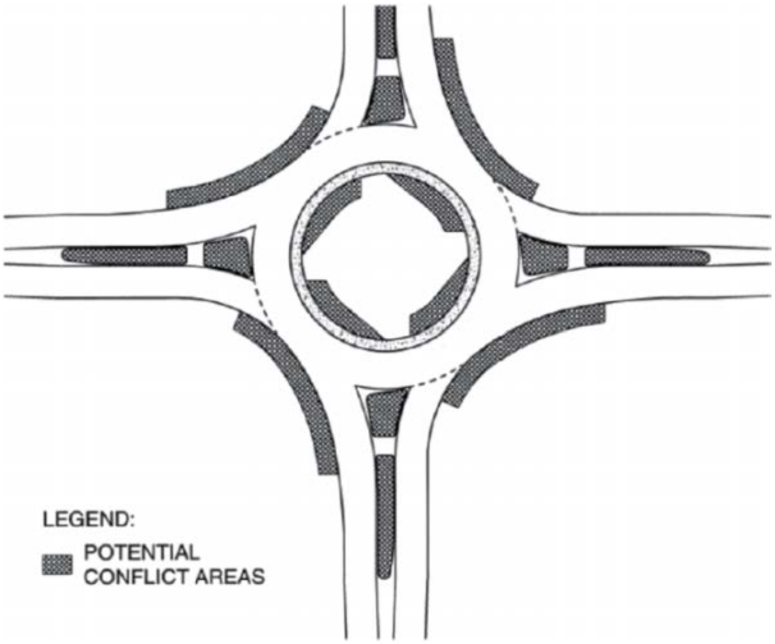
The ability to provide adequate visibility at a roundabout depends largely on the illumination pole locations. Roundabout lighting can be achieved by installing lighting within the central island or around the perimeter of the intersection. IES recommends placing lighting around the perimeter of the roundabout and at locations on the approach side of the crosswalks (*1*). Perimeter illumination provides the most optimal visibility within the key conflict areas and allows vehicles approaching the roundabout to see circulating vehicles. In addition, the vertical lighting level in the crosswalks cannot be achieved without approach lighting. Therefore, roundabouts with central island illumination may require additional approach lighting or may be combined with perimeter illumination to achieve vertical lighting levels. Further discussion and illustrations can be found in IES RP-8-18 (*1*).

Some agencies provide guidance on critical conflict areas where errant vehicles may be more likely to hit poles. For example, Exhibit 14.7 provides guidance from the Kansas Department of Transportation (KDOT). KDOT recommends placing light poles as far back from the curb face as practical; in rural areas where pedestrian activity is low, KDOT requires breakaway pole bases for poles located in these critical areas (*15*).

14.4 Landscaping

At all intersection types, landscaping can improve aesthetics, decrease impervious surfaces, indicate a change of context, and promote context sensitivity. All intersections have landscaping opportunities along their outer edges and median islands. At roundabouts, however, the central island provides a unique additional location for landscaping that most other intersections do not have.

Exhibit 14.7. Critical conflict areas affecting pole placement.



SOURCE: *Kansas Roundabout Guide*, 2nd ed. (*15*).

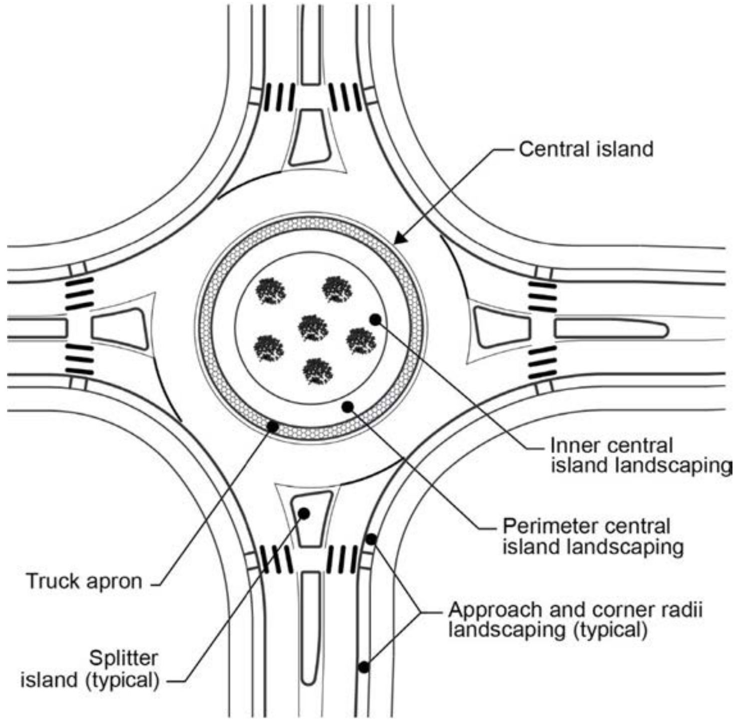
Discussions about the type and quantity of landscaping or other material to incorporate into a roundabout design, maintenance considerations, and the available planting zones best occur early in planning and design. Choosing between soft landscaping and hardscaping may affect funding and maintenance agreements, and discussions about the type or extent of possible treatments are appropriate during ICE activities. Intersection sight distance requirements affect landscaping details, and landscaping plans must coordinate with design performance checks. As described in Chapter 9: Geometric Design Process and Performance Checks, sight distance requirements at the roundabout dictate the size and types of landscaping materials appropriate for each of these areas. Sight distance needs are also dictated by vehicle speeds and project context. The following sections describe landscaping considerations specific to roundabouts and locations in the roundabout, as illustrated in Exhibit 14.8.

14.4.1 Landscaping Objectives

A landscaping plan consistent with the project context and type can help provide several benefits without sacrificing other design outcomes. Fundamentally, landscaping at a roundabout has several objectives:

- **Support intersection visibility on approach and maintain adequate sight distance.** Landscaping should allow drivers to observe the signing and shape of the roundabout as they approach, and it should provide adequate visibility for making decisions within the roundabout. While sight distance is often thought to be influenced only by static features, landscape and vegetation growth and maintenance can also temporarily affect sight distance.
- **Prevent excessive sight distance.** Excessive intersection sight distance can lead to higher vehicle speeds that increase crash risk and severity for all road users. Landscaping features indicate to approaching drivers that they cannot pass straight through the intersection. International evidence suggests it is advantageous to provide no more than the minimum required intersection sight distance on each approach (*16*). Practitioners should also note that mounding the central island can reduce headlights shining across the circle to opposing directions of travel.

Exhibit 14.8. Landscaping zones at a roundabout.



- **Help pedestrians who are blind or have low vision locate sidewalks and crosswalks.** The buffer strip beside a sidewalk or walking path is an essential wayfinding component for pedestrians who are blind or have low vision. Traversable walking surfaces versus non-traversable surfaces, such as soft landscaping or hardscaping, are effective components that support wayfinding (*17*).

If achieved, these landscaping objectives provide considerable benefit over a roundabout without such landscaping.

14.4.2 Central Island Landscaping

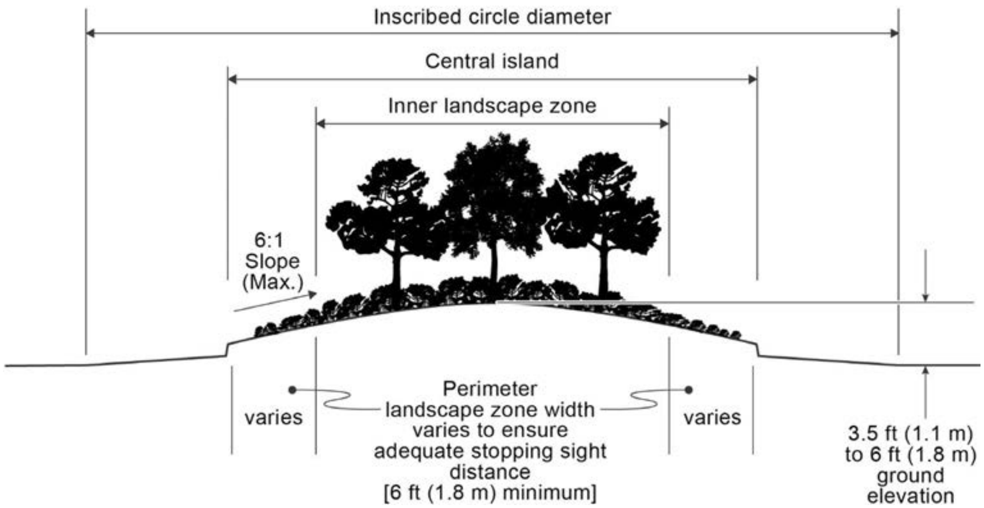
Within non-traversable central islands, landscaping can

- Improve intersection conspicuity,
- Promote lower speeds,
- Break the headlight glare of oncoming vehicles, and
- Focus driver attention to the left at the entry to look for conflicting vehicles.

Typically, different types of landscaping are selected for the inner and outer portions of the central island, as described in the following and depicted in Exhibit 14.9. They can be classified into the *inner landscape zone* and the *perimeter landscape zone*.

Within the inner landscape zone, landscaping can be strategically located and managed to limit the amount of excess intersection sight distance, help encourage slow speeds, and provide a *terminal vista* for supporting approach visibility and stopping sight distance. The perimeter portion of the central island can be landscaped with low-level shrubs, grass, or groundcover, which can help maintain stopping sight distance requirements for vehicles within the circulatory roadway as well as improve intersection sight distance for vehicles entering the roundabout. The planting zone width around the perimeter of the central island will vary depending on the size of the

Exhibit 14.9. Landscaping profile for non-traversable central island.



SOURCE: Adapted from Wisconsin Department of Transportation (*18*).

roundabout and the required sight triangles, as described in Chapter 9: Geometric Design Process and Performance Checks. Exhibit 14.10 illustrates an example of central island landscaping.

A roundabout with a larger diameter provides more opportunity for prominent placemaking or landscaping that can serve as a gateway feature. However, an agency may not be able to provide ongoing maintenance because of cost or other resource limitations. Practitioners need to consider maintenance when developing the landscape plan to inform the types and quantity of landscaping that might be needed. This includes needs for irrigation, drought tolerance, and frequency of required maintenance. As trees grow, they can affect sight distance triangles if not properly maintained. In northern climates, practitioners need to consider the salt tolerance of any plant material along with snow storage and removal practices. In addition, landscaping requiring watering may increase the likelihood of wet and potentially slippery pavement.

A domed or mounded central island can provide the same conspicuity and terminal vista benefits as landscaping but should not exceed a horizontal-to-vertical ratio of 6:1 (adapted from

Exhibit 14.10. Example of central island landscaping.

LOCATION: NE Lombard Street/Airport Way Frontage Road/PDX Economy Parking Lots, Portland, Oregon. SOURCE: Lee Rodegerdts.

the guidance for transverse slopes in the AASHTO *Roadside Design Guide*) (*19*). Exhibit 14.9 provides elevations and sloping for a mounded central island. Mounding can deflect errant drivers to the right and reduce the likelihood of a head-on collision while absorbing some of the energy of entry. However, a mounded central island without landscaping does not adequately deter drivers from occasionally driving onto or over the central island.

Illuminating features on the central island can also provide positive visual evidence of the roundabout. Lighting aimed at plantings and signs provides the necessary contrast for non-traversable areas of the roundabout. Eco-luminance is a concept that integrates lighting with vegetation by using lower mounting heights and reflected light from plants and retroreflective elements. The potential benefits of this approach include illuminating a roundabout using less energy and with improved aesthetics and positive contrast for all users (*20*).

For roundabouts with traversable central islands, central island landscaping is not an option. Exhibit 14.11 illustrates a retrofitted mini-roundabout that retained median landscaping even though the fully traversable central island does not provide landscaping opportunities.

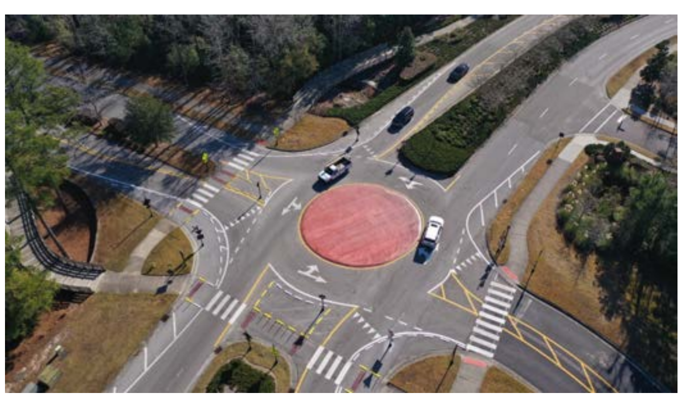
14.4.3 Median and Approach Landscaping

Landscaping on a roundabout's approaches can enhance safety by making the intersection a focal point (i.e., enhancing its visibility) and narrowing the visual field for approaching drivers. This creates a funneling effect that induces drivers to slow down on approach.

Landscaping at splitter islands is subject to different considerations than landscaping on the central island. Landscaping at splitter islands must avoid obstructing stopping sight distance to the crosswalk, yield signs, and the roundabout entrance, particularly if reverse curvature is present on an approach. However, median and splitter island landscaping can be used to help remove excess sight distance. As discussed in Chapter 9: Geometric Design Process and Performance Checks, splitter islands are within intersection sight distance triangles between entering and conflicting vehicles, and they frequently serve as part of bicyclist and pedestrian crossings. Exhibit 14.12 and Exhibit 14.13 provide examples where the vegetation in the splitter island is beginning to undesirably encroach on stopping sight distance and intersection sight distance, respectively.

Exhibit 14.14 provides an example of low-lying vegetation in the splitter island with no risk of obstructing sight distance. The size of the splitter islands and the location of the roundabout

Exhibit 14.11. Example of roundabout with traversable central island and exterior landscaping.



LOCATION: Brunswick Forest Parkway/Low Country Boulevard, Leland, North Carolina. SOURCE: Kittelson & Associates, Inc.

Exhibit 14.12. Example of undesirable blockage of stopping sight distance on roundabout approaches.

SOURCE: Larimer County, Colorado.

Exhibit 14.13. Example of undesirable blockage of intersection sight distance at roundabout entry.

LOCATION: La Jolla Boulevard/Midway Street, San Diego, California.
SOURCE: Mark Lenters.

Exhibit 14.14. Example of low vegetation in splitter island.

LOCATION: Old Meridian Street/N Pennsylvania Street, Carmel, Indiana.
SOURCE: Lee Rodegerdts.

Exhibit 14.15. Example of low-lying vegetation providing a detectable buffer.

LOCATION: Monterey Avenue/Causey Avenue, Clackamas, Oregon.
SOURCE: Lee Rodegerdts.

are determining factors when assessing whether to provide landscaping within the splitter islands. Generally, low-growing landscaping is recommended within sight triangles on either side of the pedestrian crossing and between the crossing and the circulatory roadway.

14.4.4 Sidewalk or Path Buffers

Section 10.4 presented key design considerations for pedestrians traversing a roundabout, including the need for a detectable edge treatment that buffers sidewalks wherever crossings are not intended. Low shrubs, grass, and other tactile material distinct from normal walking surfaces, such as river rock or stone, are likely detectable underfoot and make for suitable buffers. Along with the benefits discussed in Chapter 10: Horizontal Alignment and Design, a sidewalk buffer also further indicates to pedestrians that a walking path to the central island is not available. Exhibit 14.15 provides examples of suitable sidewalk buffers at roundabouts. Chapter 9: Geometric Design Process and Performance Checks and Appendix: Design Performance Check Techniques describe a wayfinding assessment for providing accessible walking paths and crossings.

A primary technique to encourage pedestrians to remain on the perimeter of the roundabout is an ADA-compliant pedestrian access route, including detectable buffers between the sidewalk and circulatory roadway curb. Exhibits 14.15 and 14.16 provide examples. Per proposed Public Rights-of-Way Accessibility Guidelines, the detectable buffer must be at least 2 ft (600 mm) wide (wider is better) or have a continuous vertical feature, like a fence, that a person can detect by hand, cane, or foot (*21*). If the same material is used for both the truck apron and the sidewalk, practitioners are encouraged to include a separate, distinguishing factor to differentiate the two, such as a color or stamped texture.

14.5 Art and Other Fixed Objects

In addition to landscaping, some agencies use the roundabout's central island as an opportunity to display local art or other gateway features. Communities often desire public art or other large aesthetic objects within the central island, including statues, fountains, monuments, and other gateway features for community enhancement. In some areas, a roundabout design can help define a community, township, or region by displaying a piece of art that represents local

Exhibit 14.16. Example of embedded river rock being placed in the buffer.

SOURCE: Fred Wismer.

heritage. Art can also aid placemaking, giving each roundabout in a community a distinct look. While the choice of art can sometimes spark debate due to differences in aesthetic tastes, it can also bring critically needed support to the project. Examples of artwork and other objects on the central island are shown in Exhibit 14.17 through Exhibit 14.22.

Including art and other fixed objects at roundabouts depends largely on the context of the roundabout. Any central island art or other objects need to be of a size and scale to be readily appreciated and observable from the outer perimeter of the intersection. The central island is not to include any inviting elements, such as benches or plaques, that might encourage a person to walk onto the central island for closer inspection. In addition, the central island features cannot

Exhibit 14.17. Example of central island art.

LOCATION: 14th Street/Galveston Avenue, Bend, Oregon. SOURCE: Lee Rodegerdts.

Exhibit 14.18. Example of central island art.

LOCATION: Gannett Avenue/Rittenhouse Street, Des Moines, Iowa.
SOURCE: Lee Rodegerdts.

Exhibit 14.19. Example of central island art.

LOCATION: Monterey Avenue/Stevens Road, Clackamas, Oregon.
SOURCE: Lee Rodegerdts.

Exhibit 14.20. Example of central island art.

NOTE: Boulders should be constructed of frangible materials.
LOCATION: Carlsbad Boulevard/State Street, Carlsbad, California.
SOURCE: Lee Rodegerdts.

Exhibit 14.21. Example of central island art.

LOCATION: Portage Road/Aspen Boulevard/Birch Street, Pemberton, British Columbia, Canada. SOURCE: Lee Rodegerdts.

affect the drivers circulating the roundabout. For example, fountains on the central island of a roundabout may be feasible, but maintenance, the potential for leaks, and the range of spray under windy conditions must be considered.

Fixed objects present a potential hazard to vehicles that depart from the roadway, and they become more critical as approach speeds increase. **If fixed objects are placed on the central island, they need to be designed and located to minimize crash risk and severity.** This is especially important in environments with higher approach speeds, where fixed objects may improve visibility from a distance but introduce the risk of a crash with the fixed object. Roundabouts may have different levels of entry channelization depending on site context and intersection geometry. For example, if speed control relies on the central island (rather than entry curvature and splitter island channelization), the likelihood of errant vehicles striking the central island may be greater. If used, fixed objects are to be placed within the inner landscape zone at a location where the roundabout's geometry deflects approaching vehicles away from the object, as discussed in Section 14.4. To the extent possible, frangible materials are to be used in the perimeter landscape zone.

Exhibit 14.22. Example of central island art.

LOCATION: Rehoboth Avenue/Grove Street/Columbia Avenue, Rehoboth Beach, Delaware. SOURCE: Lee Rodegerdts.

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CHAPTER 15

Construction and Maintenance

Contents

This chapter focuses on issues related to constructing and maintaining roundabouts. As with any roadway or intersection construction project, construction can affect adjacent properties and roadway travelers. Continuous and meaningful stakeholder engagement and outreach from design through construction can reduce disruption and promote goodwill and project support.

15.1 Introduction

Roundabouts have been successfully implemented throughout the United States, and many tribal, state, county, and city agencies are becoming efficient at preparing roundabout construction plans. However, not all engineers, contractors, and inspectors have extensive experience with some of the distinctive aspects of preparing roundabout construction documents or constructing the roundabout. Early design and pre-construction coordination between all parties occurs with any intersection or roadway project, but it is beneficial to emphasize design and construction attributes particular to roundabouts.

Each project location is unique, and there is no single best approach to staging construction while maintaining traveler access. Roundabout concept design and ICE benefit from considering constructability and staging needs early in the planning and design process. If practitioners address specific site implementation needs at each planning and design stage, fewer issues will likely arise during construction.

The project type (i.e., new construction versus reconstruction) greatly influences construction staging and sequencing needs. In constrained locations where maintaining traffic during construction is critical, the roundabout design or construction materials, techniques, and durations could be influential. Practitioners establish work zone traffic control for each unique construction staging and phasing, with the basic objective to provide efficient and effective travel opportunities for each user.

Like construction staging, facility maintenance and serviceability need to be part of early roundabout planning and ICE. The types of materials and features provided at an intersection directly affect long-term serviceability and future rehabilitation needs. Maintenance costs need to be included with project life-cycle costs to guide intersection and traffic control selection. In addition to the extent of maintenance any intersection needs, landscaping and other aesthetic features may require special consideration or maintenance partnerships and agreements between cooperating agencies.

15.2 Stakeholder Engagement and Construction

Public engagement and outreach need to begin during the planning phase and carry through final design and project construction. As with other intersection projects, stakeholder and public engagement during project development can guide construction sequencing and staging needs. As projects move from final plan preparation to construction bidding, the construction engineering and contracting team needs to review and understand the stakeholder input received during planning and design. There may be roundabout-specific subjects or needs, such as changes to access or issues associated with a footprint larger than the current intersection. This type of information could be shared in contract bid request packages and at pre-bid information meetings. Upon initiating construction activities, general outreach commonly transitions to the property owner or other affected users.

Stakeholder engagement during design and pre-construction provides the opportunity to consider the benefits and trade-offs of full intersection closures compared with partial closures. Full closures, when possible, may reduce the number of construction days compared with partial closures that maintain traffic during construction. In some cases, there are no options for full closures during construction (e.g., no alternative routes or inability to address emergency response needs). However, agencies and communities may see the benefits of a shorter full closure over a longer, but potentially more disruptive, construction staging and sequencing plan. Community engagement creates the opportunity to discuss and provide input on project construction sequencing plans.

When a traffic pattern is set to change after roundabout implementation, practitioners need to inform stakeholders, property owners, and the public of what to expect. This could include broad information about general traffic pattern changes throughout the construction project as well as project phasing–specific information, such as changes to travel patterns, temporary closures, and temporary alternative access plans. If a roundabout is one of the first in an area, it can be beneficial to educate users about roundabout navigation and reinforce messages beyond the construction information. Practitioners need to customize public involvement techniques to specific community needs. Chapter 5: Stakeholder Considerations provides more information and techniques.

The following suggestions can help alleviate initial driver confusion:

- Conduct meetings with affected property owners and the public before initiating construction.
- Prepare news releases, handouts, or other media detailing what property owners and motorists can expect before, during, and after construction.
- Install temporary fixed signs, changeable message signs, or both before, during, and immediately after construction to communicate traffic pattern changes.
- Use travelers' advisory radio before and during construction to disseminate information on how to drive, etc.
- Use websites or other online social media to broadcast construction progress and use of the roundabout.
- Meet with neighborhood, business, institution, or advocacy groups as applicable for the construction location and influence area.

15.3 Construction Plans

Construction plans, specifications, estimates, permits, and other documentation are established by supporting agencies. These documents present horizontal, vertical, and cross-section design complemented by details and other sheets outlining demolition, drainage, utilities, landscaping, and traffic control. The design and construction methods are evolving, and new approaches to promoting strong connections between computer-aided design and construction activities are conducive to roundabout design and implementation.

Building information modeling (BIM) is a process supported by various tools and technologies to expand on traditional plan, profile, and cross-section design information and provide three-dimensional digital representations of the proposed design. This direct transfer of digital information from designers to contractors can improve construction efficiency and reduce errors and change orders. The increased computing power provided by three-dimensional modeling is especially helpful for roundabout design and construction. For example, the ability to develop and share models with the contractor promotes efficient and effective communication of the complex vertical and cross-section design often present at a roundabout. In addition to BIM information, roundabout final design plan sheets may include

- Staging plan with detour routes (as appropriate),
- Staking plan with curve data (coordinates, radius, elevations),
- Paving plan and jointing plan (concrete pavement),
- Utility plan,
- Lighting plan,
- Signing plan,
- Pavement marking plan, and
- Landscaping plan.

15.4 Construction Coordination

Roundabout construction requires coordination among the engineer, contractor, inspector, utility providers, project owner, and supporting agencies. The following sections provide examples of possible roundabout-specific coordination that may occur during construction.

15.4.1 Contractor and Designer Coordination

The design team needs to address proposed design changes to adapt to project conditions. Roundabout safety and operational performance can be affected by geometric design, signing, and pavement markings. Changes can influence vehicle speeds, vehicle alignments, non-motorized user quality of service, and how trucks are served. For example,

- Multilane roundabout operations require precisely placing pavement markings according to the plan. If the markings stray from the design, the roundabout may not operate as expected, as the entering and receiving lanes need to line up appropriately.
- If provided, spiral markings need to support drivable and flowing alignments that assist driver navigation and promote lane discipline.
- Where PCC is used, the jointing plans must reflect the pavement marking of lane lines and edge continuity lines. Joint lines that contradict lane lines can be mistaken for lane lines, and changes to joint patterns proposed during construction need to be carefully reviewed.
- Contractors are to follow the design details and dimensions for each aspect of the roundabout design, particularly the truck apron. A truck apron too flush to the circulatory roadway could reduce its ability to control vehicular speeds, while too much curb reveal could discourage truck drivers from using the apron and make the apron an impact risk for other vehicles.

15.4.2 Utility Coordination

Utility coordination for roundabouts is the same as that of other intersections. During intersection reconstruction, however, a roundabout approach alignment may deviate from the existing roadway horizontal alignment, vertical alignment, or both. The roundabout may have a larger footprint than the existing intersection, and the power supply for illumination, conduit for future potential beacons, or drainage facilities may require special attention. Lighting may need to be installed before or during roundabout placement to maintain safe traffic management during construction. Utility vaults and access portals within the roundabout may require special consideration for maintenance vehicle parking or safe crew access to the central island. This parking could be outside the roundabout or provided as a specific parking space within the central island.

15.5 Construction Staging

Roundabout construction staging varies by site and project conditions. In general, constructing a roundabout requires the same considerations as other intersection forms. However, because of their unique configuration and associated operations, roundabout planning and design may sometimes be more influenced by construction staging and traffic sequencing needs compared with other intersection forms. Depending on user demands, construction staging considerations could influence the roundabout's size or location. Pavement material selection could also affect construction staging and may influence initial roundabout planning and design.

During construction, the roundabout's vertical design and ability to serve large vehicles could influence how staging might occur. This could lead to temporary roadways through the central island or other practical considerations regarding truck vertical clearance between truck aprons and intermediate paving courses. Splitter islands and non-traversable central island elements may need to be completed during later stages to support each user's needs during each construction stage. In general, roundabouts are often constructed under the following scenarios and traffic conditions:

- No traffic,
- Some traffic diverted, and
- Full traffic.

As with any intersection that must be constructed while maintaining traffic, a common goal is to minimize staging and construct substantial portions of the roundabout during each construction stage. Longer construction stages can improve construction quality and efficiency, reduce user confusion, reduce overall construction duration, and save construction costs. Generally, diverting or detouring as much traffic from the intersection as possible is the most desirable option. However, in many circumstances, full or partial detours are not feasible.

15.5.1 Construction Under No Traffic

Constructing a roundabout without traffic passing through the work zone can significantly reduce the construction duration and cost while also reducing crash risks for the construction personnel. This is possible under two common scenarios:

- The roundabout is on a new roadway.
- All traffic can be diverted away from the roundabout, even for a short time.

In some cases, traffic can be diverted for only a portion of the construction time to build the central island and circulatory roadway. With that substantial work completed, traffic can be maintained while constructing the splitter islands and other areas outside the central island.

Minimizing detour changes during construction helps reduce public confusion. It is easier to communicate one or two different detours to the driving public through the course of a project and establish some consistency than to frequently change routes. Before traffic is detoured, peripheral items (e.g., signing, illumination, and landscaping) outside the traveled way or items with minimal effect on traffic can be completed to reduce road closure durations before the first detour is in place.

15.5.2 Construction with Some Traffic Diverted

Construction under partial traffic commonly includes closing the minor roadway approaches and maintaining all major street movements. The major street alignments generally occur on the existing roadway or temporary roadways during staging. This technique is to eliminate intersection conflicts while still allowing some traffic to use the intersection.

Practitioners might consider reasonable alternative routes for each mode—motor vehicle, truck (if different from passenger cars), bicyclist, and pedestrian. Splitting detours by mode may be feasible and desirable, recognizing that out-of-direction travel is less feasible for pedestrians and bicyclists and that trucks may be restricted to certain routes.

Exhibit 15.1 provides an example of constructing a single-lane roundabout under partial traffic (*1*). The staging plan maintained traffic flow on the major roadway using temporary roadways. Most of the roundabout construction occurred during Stage II, with the minor approaches closed. Stage III completed the west approach and Stage IV addressed the relatively small remaining portions on the south approach.

15.5.3 Construction Under Full Traffic

Detouring as many approaches as possible reduces the intersection traffic volume and the number of turning movements available. However, when a roundabout is under full traffic, some intersection movements must be maintained with a level of traffic control commensurate with the volume. Practitioners need to integrate pedestrian and bicycle traffic needs into the early staging plan effort.

In many cases, the intersection can operate as a roundabout during construction after initial work is completed outside the roundabout limits. Other work can often include utility relocation,

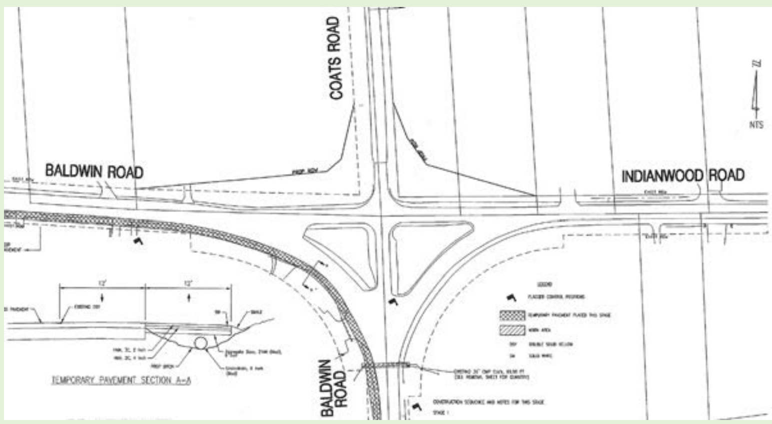
Exhibit 15.1. Example construction with some traffic diverted.

Example Construction Staging: Baldwin Road/Coats Road/Indianwood Road

Baldwin Road is the major roadway, which includes the west and south approaches. Construction was completed in four stages. The shaded portions of the plans represent the permanent pavement under construction, temporary pavement being placed for construction staging, or temporary pavement under traffic.

Stage I: Temporary Roadway Construction

- Construct a 12-ft (3.6-m) temporary roadway adjacent to the existing Baldwin Road for the east and south approaches.
- Construct a replacement culvert over the south approach.
- Maintain two-way traffic on the east, west, and north approaches.
- Maintain traffic on the south approach with partial lane closure controlled by flagging.



Stage II: Primary Roundabout Construction

- Close Coats Road and Indianwood Road to traffic.
- Shift traffic to temporary roadway on the east and west approaches to maintain two-way traffic on Baldwin Road.
- Close the southeast business driveway and restrict the northwest business driveway to right-in/right-out only.
- Construct all roundabout elements on the east and north approaches.
- Construct partial roundabout elements on the west and south approaches.
- Construct temporary pavement at the west and south approaches.

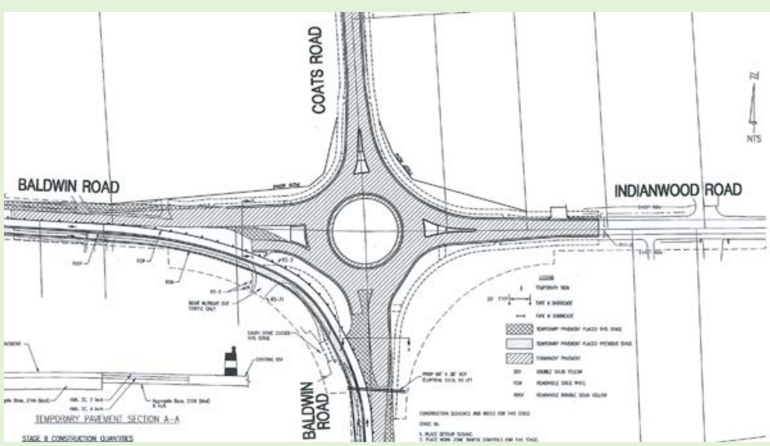
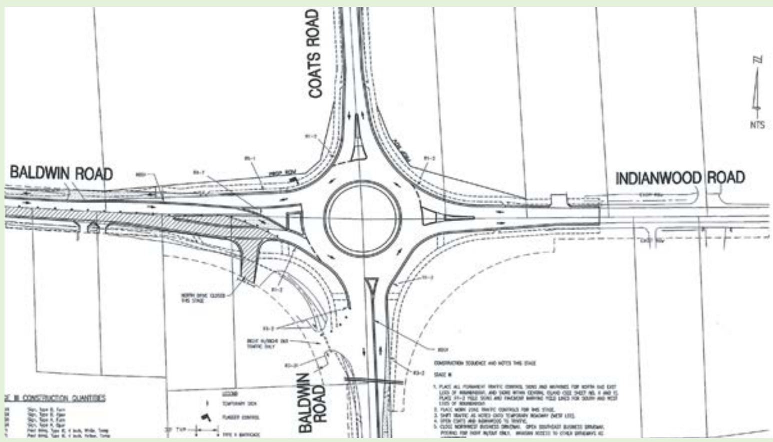


Exhibit 15.1. (Continued).

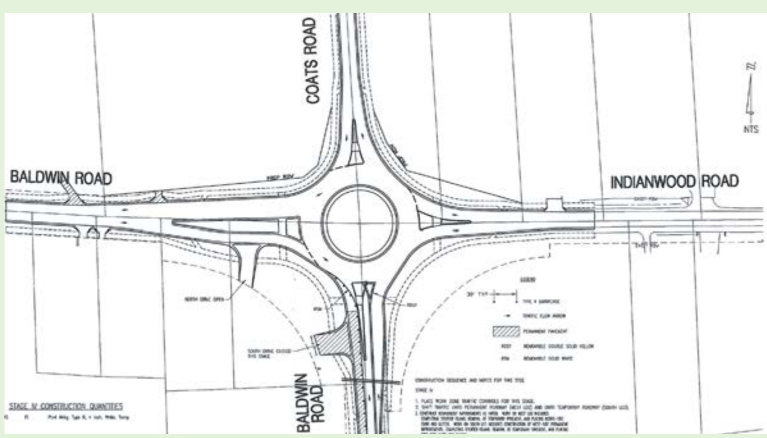
Stage III: West Approach Construction

- Complete the roundabout elements on the west approach.
- Remove temporary pavement on the south and west approaches.
- Shift traffic to temporary roadways on the west approach to maintain two-way traffic on Baldwin Road.
- Close the northwest business driveway and open the southeast business driveway to right-in/right-out only movements.
- Install permanent signing on the north and east approaches and on the central island.
- Install signing and markings on the south and west approaches.
- Open Coats Road and Indianwood Road to traffic on permanent roadways.
- Begin operating the east, north, and south approaches as a roundabout with two-way traffic.



Stage IV: South Approach Construction

- Shift traffic to the permanent roadway on the west approach.
- Shift traffic to the temporary roadway on the south approach.
- Complete the south approach, including the splitter island, and complete the permanent roadway on the west side of the approach and remove temporary pavement.
- Complete the west approach, including the splitter island, and remove temporary pavement.
- Install the remaining permanent signing and striping on all approaches.



SOURCE: *NCHRP Report 672* (*1*).

permanent signing (covered until the roundabout configuration matches the signing), lighting, and some pavement markings. These items, if installed before the central and splitter islands are constructed, expedite completion and introduce roundabout safety performance benefits during construction.

At some previously congested locations, traffic flow may improve during construction because of the roundabout's yield control. Roundabout operation during construction has the benefit of helping drivers establish driving habits that are a similar pattern to the final roundabout configuration. However, during construction, barrels and cones around a central island may limit lane widths during construction and lead to side-by-side vehicle conflicts in multilane configurations. Side-by-side travel during construction is only allowed if there is adequate space to prevent vehicle-to-vehicle conflicts.

Other staging considerations include

- Night or weekend work reduces the impact on peak-period traffic.
- Flagging can be used on the approaches and exits to allow the contractors to work.
- Temporary signals can be used on the approaches under certain stages.
- Temporary roadway construction may be necessary during certain stages.
- Temporary traffic patterns that counter normal roundabout operation (i.e., vehicles circulating clockwise instead of counterclockwise) are undesirable.
- For multilane roundabouts along multilane roadways, side-by-side vehicle travel during various stages of construction (including tractor trailer vehicles) must occur only if adequate space is available to avoid vehicle-to-vehicle conflicts during side-by-side travel. In some situations, it may be beneficial or even required to temporarily reduce to one lane of travel.

Exhibit 15.2 and Exhibit 15.3 provide examples of temporary traffic signals and temporary pavement through a roundabout using PCC. Temporary pavement has been placed where the ultimate splitter island will be located. This allows traffic to use the newly constructed pavement as temporary lanes. The raised curbing of the central island and splitter islands was constructed during a later stage.

One possible sequence for staging construction under full traffic is as follows:

1. Install signing and lighting (roundabout signing should initially be covered).
2. Construct outside widening.
3. Reconstruct or resurface approaches.

Exhibit 15.2. Example construction with temporary signals and pavement.

SOURCE: Ourston.

Exhibit 15.3. Example construction with temporary signals and pavement.

SOURCE: Ourston.

4. Construct splitter islands and delineate the central island. At this point, the signs could potentially be uncovered, and the intersection could operate as a roundabout. A splitter island under construction is shown in Exhibit 15.4.
5. Finish construction of the central island.
6. Prepare the final grade and apply the final paving course for the circulating roadway and entry/exits. Grading of the circulatory roadway is shown in Exhibit 15.5.

A practical, cost-effective alternative to consider for construction staging is to create a large paved area of the intersection by delaying the construction of the splitter islands and central island until the final stage of construction.

The existing intersection can be milled and leveled to the near-finished pavement elevation of base asphalt. When the widening and resurfacing of the intersection are complete, lanes can be moved around as needed to finalize the pavement grade changes. Once the whole intersection area is leveled to near-final grades at base asphalt, the splitter islands can be added to the base

Exhibit 15.4. Constructing the splitter island.

LOCATION: SW Terwilliger Boulevard/SW Palater Road, Portland, Oregon.
SOURCE: Lee Rodegerdts.

Exhibit 15.5. Constructing the central island and circulatory roadway.

LOCATION: SW Terwilliger Boulevard/SW Palater Road, Portland, Oregon.
SOURCE: Lee Rodegerdts.

asphalt as monolithic slabs. The truck apron can also be applied to base asphalt and dowelled in place. The central island is cut out of the paved surface and mounded after curbs are placed. This creates a flexible traffic management scheme with minimal disruption to existing traffic, and it often shortens the overall construction duration.

15.6 Work Zone Traffic Control

During roundabout construction, the intended travel paths need to be clearly identified. This may be accomplished through pavement markings, signing, delineation, channelizing devices, and guidance from police or construction personnel. Pedestrian wayfinding and accessible routes for people with disabilities are to be included during construction planning and integrated into project construction staging. Channelizing devices should give motorists, bicyclists, and pedestrians a clear indication of the required travel path. Overall, MUTCD requirements regarding work zone traffic control are to form the basis for work zone applications (*2*).

Exhibit 15.6 illustrates the use of cones and barrels to delineate the roundabout approaches and circulatory roadway while the splitter island and central island are constructed.

Exhibit 15.6. Temporary traffic control during construction.

LOCATION: Grand Avenue/Broadway/N 1st Street/I-70 Business Loop, Grand Junction, Colorado. SOURCE: Kaitlin Clark, Colorado Department of Transportation.

Exhibit 15.7. Temporary traffic signal during early roundabout construction.

LOCATION: DeLand, Florida. SOURCE: Florida Department of Transportation.

It is common to use flaggers or temporary traffic signals during construction. Exhibit 15.7 presents a temporary signal used during the early stages of roundabout construction.

15.6.1 Pavement Markings

Pavement markings in work zones need to have the same layout and dimensions as those used for the final installation. Because of the potential confusion in a work area and change in traffic patterns, additional pavement markings may be used to clearly show the intended direction of travel. In some cases, when pavement markings cannot be placed, temporary channelizing devices (e.g., cones, tubular markers, drums) should be used to establish the travel path.

15.6.2 Signing

Work zone signing includes user needs in the work area, pre-construction signing advising the public of the planned construction, and regulatory and warning signs addressing traffic needs outside the work area. The permanent roundabout signing needs to be installed where practicable during the first construction stage so it is available when the roundabout is operable. Permanent signing that cannot be installed initially needs to be placed on temporary supports in the proposed location until permanent installation can be completed.

15.6.3 Illumination

Illumination, discussed in Chapter 14: Illumination, Landscaping, and Artwork, is needed in the work area. Lighting needs to be provided specifically in construction areas so pedestrians and bicyclists are visible to motorized users. Exhibit 15.8 depicts temporary lighting on a roundabout approach under construction.

15.7 Maintenance

Facility maintenance includes landscaping, illumination, pavement marking, pavement replacement, and curb replacement. A maintenance operation plan is always necessary and may include tasks such as trimming shrubs; removing snow; or completing routine refurbishing of

Exhibit 15.8. Temporary lighting on roundabout approach.

LOCATION: DeLand, Florida. SOURCE: Florida Department of Transportation.

pavement, signing, and markings. Practitioners need to consider maintenance and potential maintenance agreements for funding early in the planning and design process. Practitioners also need to consider maintenance in life-cycle cost evaluations and ICE activities.

As with any transportation project, a realistic maintenance program is to be considered when designing a roundabout's landscape features. While it is generally necessary for local governments to assume maintenance responsibilities for landscaping, formal maintenance agreements with local civic groups, neighborhood associations, and garden clubs are also possible when complex planting arrangements are planned. Early enthusiasm and consistent activities by volunteer groups may wane, but creating access to areas near active traffic creates risks for all users. Safety plans and equipment are, therefore, important elements of any (public or private) landscaping maintenance plan. If a willing maintenance party is not identified, simple plant materials or hardscape items that require little or no maintenance are preferred.

In addition, maintenance vehicles should be able to properly access the central island and splitter islands if needed. Potential stoppage or pullout areas for maintenance vehicles can be located so that visibility and access for vehicles and pedestrians are preserved. Exhibit 15.9 provides an example of a pullout area for maintenance vehicles.

Exhibit 15.9. Example of maintenance vehicle pullout area in central island.

LOCATION: NW Shevlin Park Road/Newport Avenue/College Way, Bend, Oregon. SOURCE: Lee Rodegerdts.

15.7.1 Landscaping Maintenance

Landscaping maintenance needs can vary by extent and frequency depending on the type of climate and extent of plantings. Proper drainage for any watering system should be provided and should minimize the water runoff onto the circulatory roadway. Watering systems with a mist-type spray should be avoided, as water spray onto windshields could create safety concerns.

Access to landscaped areas is fundamental, and project planning, ICE, and preliminary design need to consider equipment parking and worker access. Maintenance in high-traffic volume locations could require flaggers or short-duration lane closures to allow workers or equipment to access focus areas. In some conditions, parking pullouts may need to be located on the roadway approaches or the central island (see Exhibit 15.9).

Plants and trees within the roundabout cannot interfere with the sight distance approaching and within the roundabout. Therefore, practitioners need to consider the expected growth of specific plant and tree species in a landscape plan and prioritize lower-maintenance species. In addition, grass, trees, and shrubs are to be regularly trimmed or pruned to prevent obstruction of the sight triangles and maintain the intersection's aesthetics.

15.7.2 Pavement Maintenance and Rehabilitation

Pavement maintenance and rehabilitation are generally completed under traffic using the techniques described for work zone traffic control. The American Traffic Safety Services Association and FHWA's *Temporary Traffic Control for Building and Maintaining Single and Multi-lane Roundabouts* provides an example of a flagging operation for conducting maintenance work on one quadrant of an existing roundabout (*3*). It also describes how work might be completed under full traffic with four flaggers (one at each approach) to guide traffic flow. In addition, it may be necessary to include another flagger on the central island to direct traffic through the roundabout.

15.7.3 Curb and Sidewalk

Curb and sidewalk rehabilitation may be associated with vehicle strikes and truck encroachment. Replacing or repairing the curb and sidewalk would be completed under traffic and follow techniques for construction staging during rehabilitation activities. Unlike conventional intersections, curbs at splitter islands, central islands, truck aprons, and other potential encroachment or strike areas are susceptible to more degradation than at other intersection forms. Adding steel reinforcement to PCC curbs and sidewalk areas susceptible to vehicle encroachment could reduce future maintenance needs.

15.7.4 Utilities in the Roundabout Area

Constructing a roundabout at an existing intersection or rehabilitating an existing circular intersection may result in utilities located on the roundabout central island. These issues and needs need to be identified early in roundabout planning and design to minimize difficulty after the roundabout has been implemented.

Beyond the central island, it is desirable to avoid locating utilities and their access within the circulatory roadway. If possible, practitioners will locate utilities in the legs of the roundabout to allow for future maintenance and access at an isolated leg versus affecting the entire roundabout.

15.8 Snow Plowing and Storage

Roundabouts often operate in winter climates that include snow and ice. Practitioners need to consider winter maintenance along with roundabout safety and operational performance benefits on a life-cycle cost basis. It is not necessary to reject a roundabout on the basis of winter maintenance needs alone.

Exhibit 15.10. Example of snow-plowed roundabout.

LOCATION: Chena Hot Springs Road/Steese Highway Northbound Ramps, Fairbanks, Alaska.
SOURCE: Gary Katsion.

Each agency in a cold climate has its own technique and routine for plowing snow. For the first roundabout in a jurisdiction, it may be helpful to develop a plowing sequence plan until the plow operators become familiar with plowing the roundabouts.

Many jurisdictions have standard widths for snowplows within their fleet. In areas where snow removal is anticipated to be a regular occurrence, the roundabout dimensions may be tailored to accommodate the width of the plow blade and the turning radii of anticipated maintenance vehicles. Maintenance crews must be able to identify and locate the splitter island and truck apron locations. Special curb types that support plowing operations and splitter island plowable end treatments may be integrated into the roundabout design. Exhibit 15.10 shows an example of a roundabout at an interchange ramp terminal intersection plowed for snow.

Exhibit 15.11 shows a roundabout with a traversable central island that has been plowed along the circulatory roadway but not within the central island where trucks traverse. Exhibit 15.12

Exhibit 15.11. Example of plowed roundabout with traversable central island.

LOCATION: W Bemis Road/Moon Road, Washtenaw County, Michigan.
SOURCE: Washtenaw County Road Commission.

Exhibit 15.12. Example of plowed roundabout in heavy snow conditions.

LOCATION: SW Bond Street/SW Wilson Street, Bend, Oregon.
SOURCE: Kittelson & Associates, Inc.

presents a roundabout in heavy snow conditions. The roadways had been plowed, but additional snowfall covered the approach roadways and circulatory roadway.

One plowing method is to start on the innermost section of the circulatory roadway, often on the truck apron, and keep circulating while spiraling outward, with each revolution pushing the snow outward from the circulatory roadway. This same operator or a second plow operator may clear the entries and exits once the circulatory roadway is clear. The crown of the circulatory roadway, if present, will also help dictate the roundabout's plowing sequence.

Snow storage is sometimes part of snow management. Snow storage should not create a sight obstruction for drivers approaching or circulating the roundabout, nor should it impact bicyclist and pedestrian access through a roundabout. Knocking down the height of the snow piles or removing snow from the islands may be necessary after prolonged periods of snowfall.

Exhibit 15.13 illustrates snow accumulated on the channelized island of a dedicated right-turn lane. Snow storage areas should not limit sight distance on the roundabout approaches or circulatory roadway. Snow storage can result in thaw and freeze cycles that allow ice buildup on the circulatory roadway. In some cases, drainage inlets in the non-traversable central island or along the truck apron can reduce ice buildup. Practitioners are advised that snow plowed from

Exhibit 15.13. Example of snow accumulation on a channelized island.

LOCATION: Chena Hot Springs Road/Steese Highway Northbound Ramps, Fairbanks, Alaska.
SOURCE: Gary Katsion.

the roadway may contain road salts and other automobile waste that could impact vegetation if placed in sensitive landscaped areas.

15.9 References

1. 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, DC, 2010. http://dx.doi.org/10.17226/22914.
2. *Manual on Uniform Traffic Control Devices for Streets and Highways*, 2009 ed., Including Revision 1, Dated May 2012; Revision 2, Dated May 2012; and Revision 3, Dated August 2022. FHWA, US Department of Transportation, 2022. http://mutcd.fhwa.dot.gov/.
3. *Temporary Traffic Control for Building and Maintaining Single and Multi-lane Roundabouts*. Grant Agreement DTFH61-06-G-00004. American Traffic Safety Services Association, Fredericksburg, Va., and FHWA, US Department of Transportation, 2012.

APPENDIX

Design Performance Check Techniques

Contents

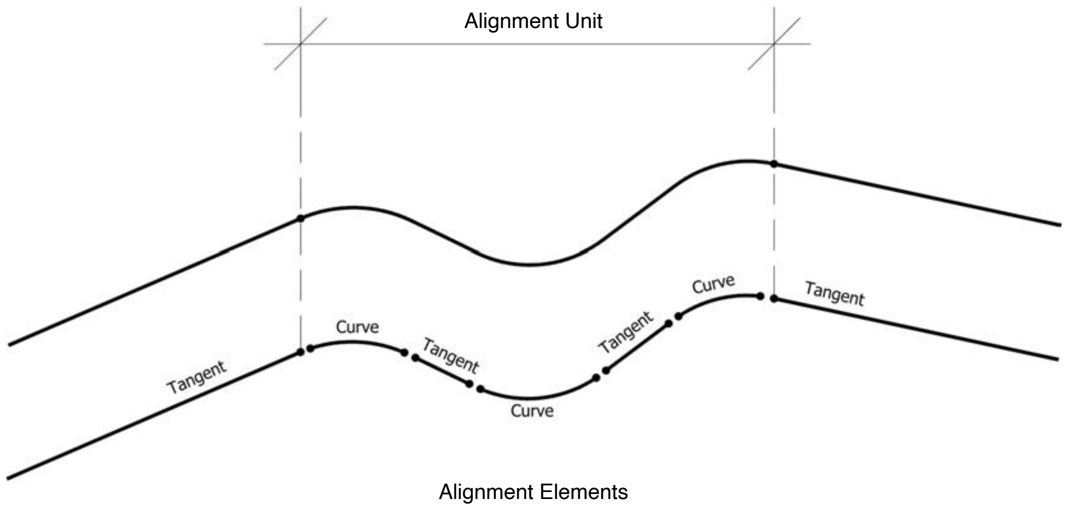
This appendix details a variety of design performance check techniques that can facilitate the check process discussed in Chapter 9: Geometric Design Process and Performance Checks. The techniques in this appendix are representative but not exhaustive of all possible techniques. Practitioners must sometimes modify performance check techniques to meet a specific configuration; any modifications need to be compatible with the design principles in Chapter 9.

A.1 Geometric Speed Check Techniques

This section presents a variety of geometric speed check techniques, including both hand-drawn and CAD-based methods. Each method varies in detail but can produce results that are consistent with the principles presented in Chapter 9: Geometric Design Process and Performance Checks.

The geometric speed check method is an easy, efficient, and effective way to check speeds for hand-sketched concepts or red-lined revision markups of early CAD-based designs. CAD-based methods offer increased precision in computing estimated speeds. The geometric speed model is based on a generalized vehicle dimension and assumed driver behavior. Both geometric speed techniques use the same model assumptions; because of these assumptions, computed speeds should be assessed only to the nearest 1 mph or 1 km/h.

Exhibit A.1. Alignment elements.



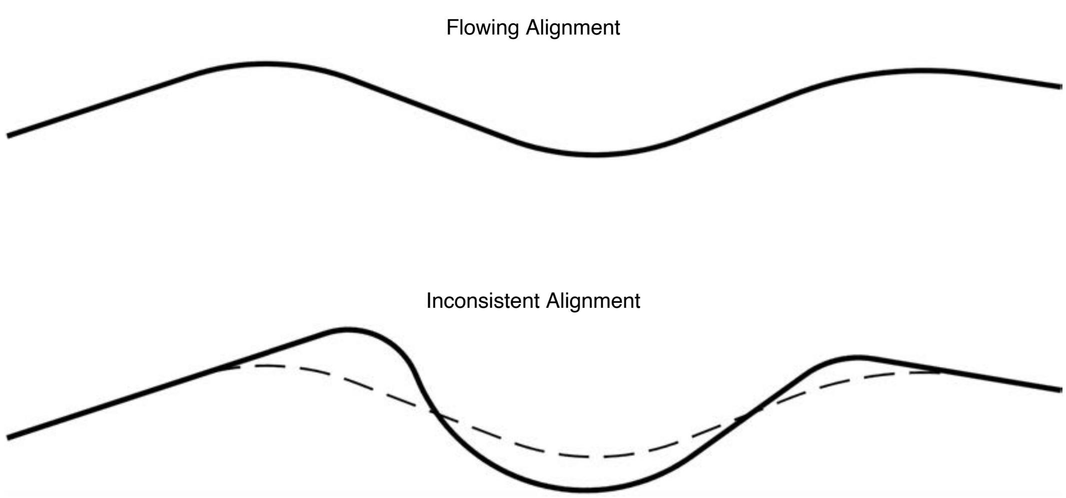
The geometric speed check method combines individual alignment elements: tangents, curves, and spirals. Each curve has an associated speed based on its radii and assumed side friction and superelevation. Drivers navigate a curvilinear horizontal alignment by viewing the roadway ahead and adjusting their speed and position based on the combination of alignment elements, in effect considering an alignment as a unit rather than as its individual components. Drivers naturally follow a spiral path between curves and tangents, which can be captured using hand-drawn and CAD-based techniques.

Exhibit A.1 depicts the concept of alignment elements and an alignment unit.

Exhibit A.2 represents two curvilinear paths: one alignment that can be characterized as a *flowing alignment* and another that can be characterized as an *inconsistent alignment*. The flowing alignment path represents a smooth curvilinear alignment resulting in similar speeds, associated lateral forces, and similar driver comfort between alignment elements. The inconsistent alignment represents a driving path that may be possible to drive but that is not likely to be the fastest or smoothest alignment possible within the given geometry.

Regardless of the method, practitioners need to review each developed fastest path alignment objectively to assess if it represents the model's intent. The desired fastest path alignment

Exhibit A.2. Flowing and inconsistent alignment.



is the smoothest, flattest path possible for a single vehicle in the absence of other traffic and ignoring all lane markings.

A.1.1 Hand-Sketch Method

A possible method for conducting a geometric speed check using hand-sketch techniques includes the following steps:

1. Draw the roundabout or plot a CAD drawing at a scale that allows the roundabout and its approaches to fit onto a common size of paper (typically 11 in. × 17 in./A3 or smaller). For most roundabouts, a scale of 1 in. = 50 ft or 1:500 is most useful.
2. Place a vellum or other trace paper over the roundabout concept and secure it with tape. Place a registration mark on the trace paper.
3. Scale appropriate offsets from curbs and stripes as appropriate using the recommendations in Chapter 9: Geometric Design Process and Performance Checks. Sometimes, it is helpful to place a few small pencil dots along the possible path.
4. Start 125 ft to 200 ft (40 m to 60 m) upstream from the roundabout entrance based on a location on the approach not affected by the roundabout entry. Lightly sketch an entry path.
5. Similarly, work backward from a point approximately 125 ft to 200 ft (40 m to 60 m) downstream of the roundabout exit and lightly sketch upstream toward the circulatory roadway.
6. Using an offset of 5 ft (1.5 m) from the central island, sketch a light line upstream and downstream from the circulatory roadway, aiming toward the entry alignment and the exit alignment. This forms the initial circulating alignment.
7. Lightly sketch the entry alignment toward the circulating alignment and from the circulating alignment toward the entry until the paths meet. Include tangents or gradual transitions between reversing curves.
8. Lightly sketch the exit alignment upstream toward the circulating alignment and from the circulating alignment toward the exit alignment until the paths meet. Include tangents or gradual transitions between reversing curves.
9. Lightly pass over the fastest path alignment to darken the pencil sketch, smoothing the drawn path as needed to create a balanced and flowing alignment. It is common to erase small portions of the sketched path and resketch portions to improve the fastest path.
10. Measure the radius using a template. Look up the speed to the nearest 1 mph or 1 km/h corresponding to the measured radius using the speed–radius graphs (see Section A.1.3) based on positive or negative superelevation for the location of the curve being measured. Record the speeds and compare them to the target performance.
11. Conduct the evaluations for other through and turning movements.
12. If the estimated speeds are adequate for all movements, continue refining the roundabout. If speeds on some movements are too fast, make geometric changes as needed to reduce speeds and repeat the assessment.

A.1.2 CAD-Based Methods

Several states provide guidance for CAD-based methods. Many of these methods apply spline curves that generate smooth spiral curves like those obtained using freehand methods. Strategically placed points along the spline curve result in a path dictated by the roundabout's geometric elements. Best-fit circular curves are then used to measure the controlling curves along the spiral path to identify R_1 through R_5 radii for each approach.

The general approach for each CAD-based method is to create construction lines offset from curbs and edge lines that represent the center of the passenger car. It is common to consider the approaching and departing evaluation distance to be 165 ft (50 m), but the distance may be shorter or longer depending on the roundabout's approach and departure geometry. Practitioners must consider each roundabout movement individually and employ the CAD-based method to best reflect the geometric speed exercise's intent to create a smooth and consistent pathway reflecting likely driver behavior.

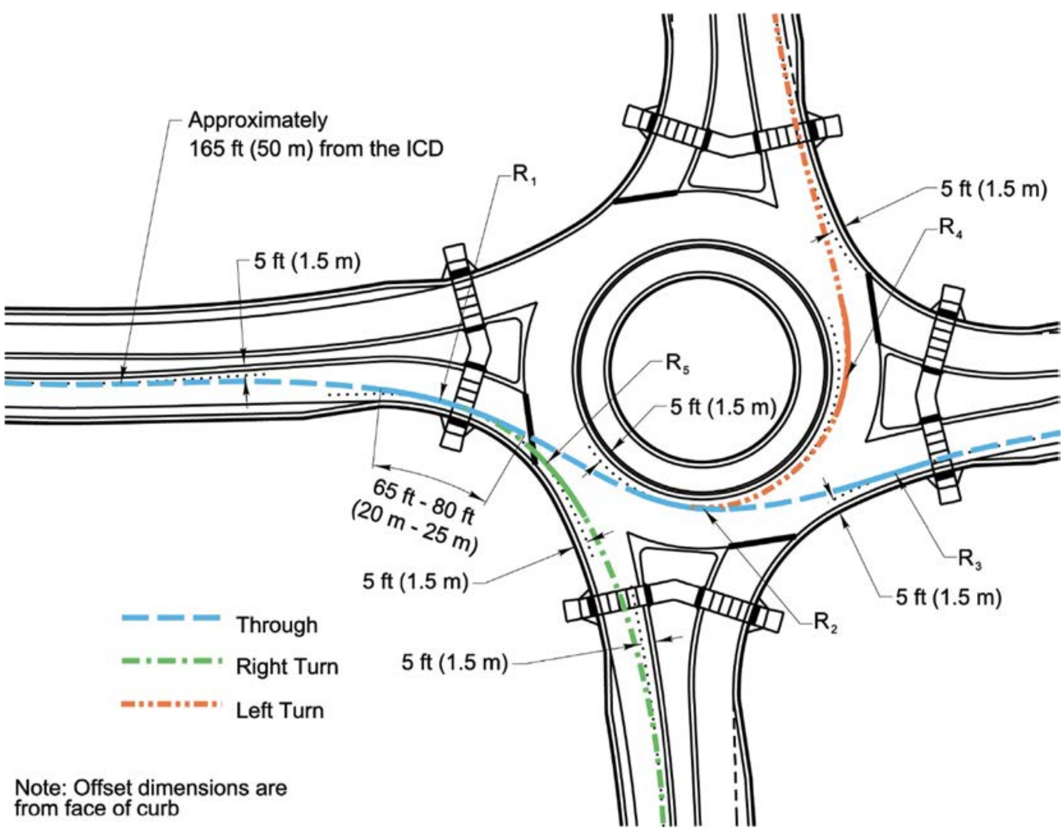
Exhibit A.3 illustrates how to construct the fastest vehicle paths at a single-lane roundabout.

Exhibit A.4a and Exhibit A.4b illustrate how to construct the fastest vehicle paths at a multilane roundabout. Each path should be reviewed to assess if the CAD-drawn path reflects likely driver behavior. The CAD-drawn path may not always represent the probable actual path. Exhibit A.4b shows the potential difference between the "probable actual path" and the "CAD-drawn path." The actual exiting speeds between these two paths might not result in substantive predicted speed performance differences.

There may be differences in CAD commands depending on the platform. However, the process and intent are the same between methods and software applications. CAD-based geometric speed checks usually include the following steps.

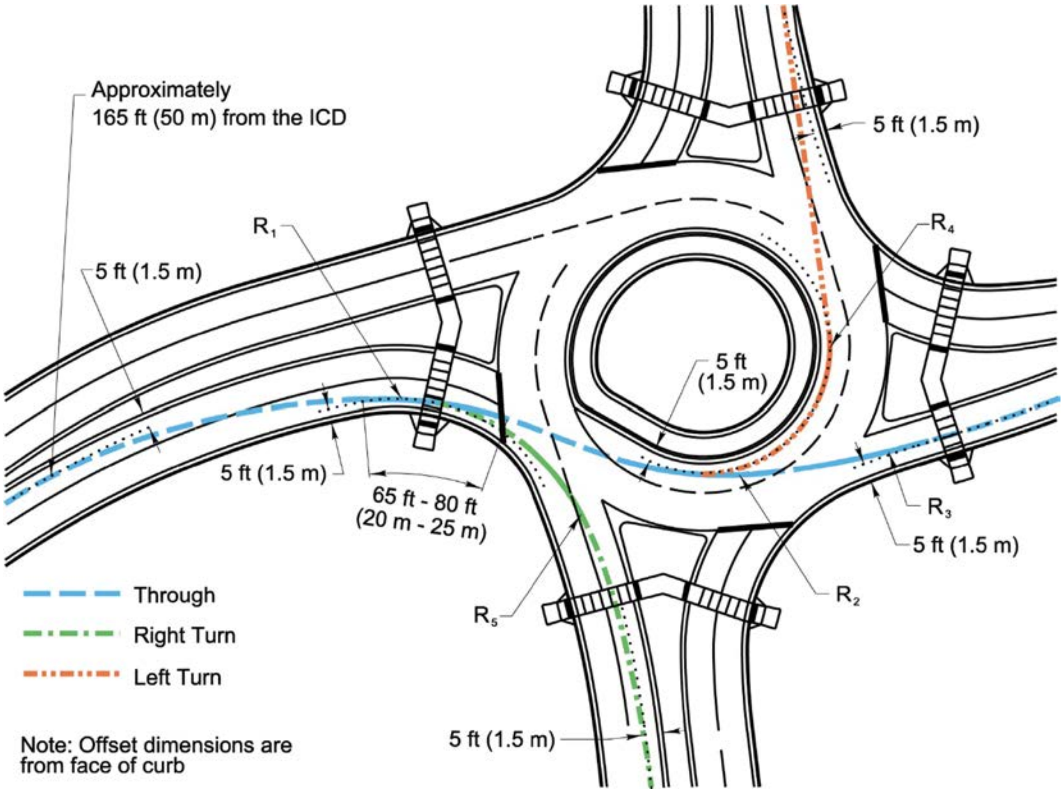
1. Copy curb offsets from the face of the curb or painted lines using values associated with the cross-section feature. See Chapter 9: Geometric Design Process and Performance Checks for additional information about the offset dimensions.
2. Establish the upstream limit line and downstream limit line for each roadway approach and departure. This is commonly 165 ft (50 m). The actual value depends on the roundabout's approach and departure geometry and may be closer to or farther from the roundabout to best represent a smooth and consistent path.

Exhibit A.3. Fastest vehicle paths for a single-lane roundabout.



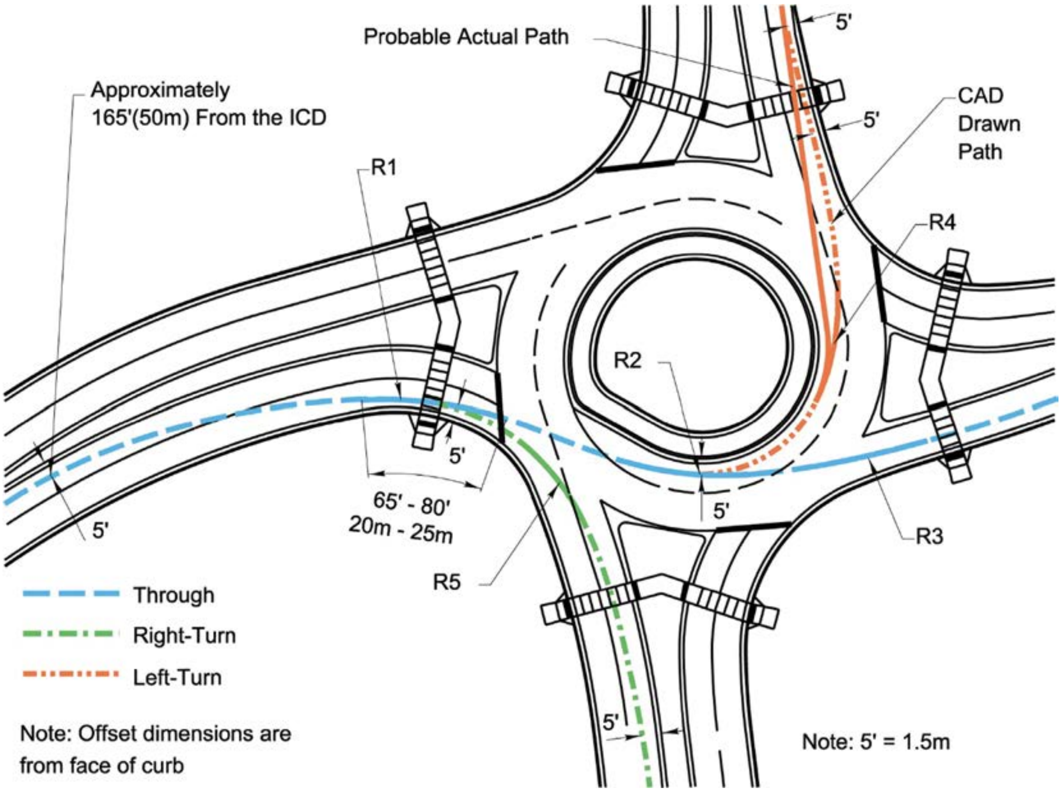
SOURCE: Adapted from Georgia Department of Transportation (*1*).

Exhibit A.4a. Fastest vehicle paths for a multilane roundabout.



SOURCE: Adapted from Georgia Department of Transportation (*1*).

Exhibit A.4b. Fastest vehicle path through a multilane roundabout with CAD-drawn path.



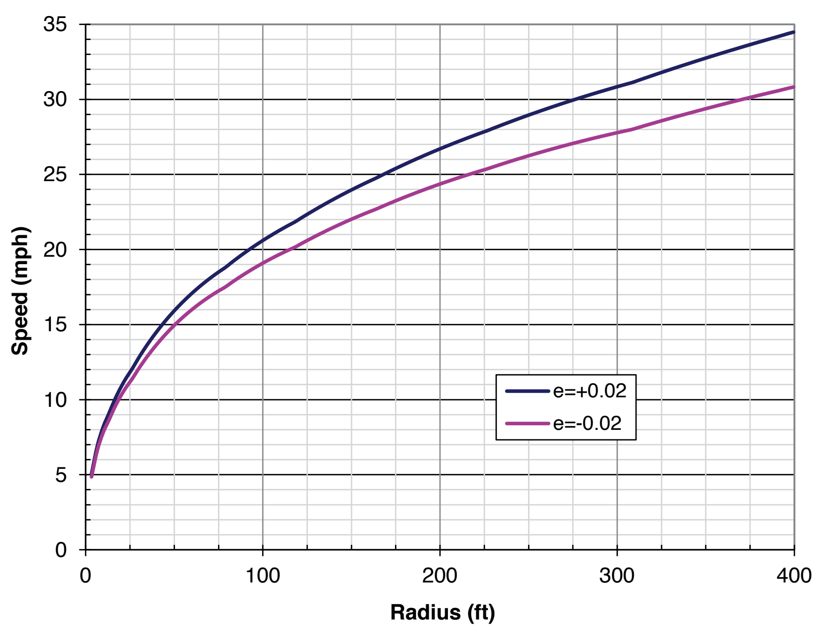
SOURCE: Adapted from Georgia Department of Transportation (*1*).

3. Draw the spline curve between the upstream movement and the offsets. This is typically accomplished by snapping three points that occur outside the upstream limit line, on the upstream limit line, and on the curb offset line.
   a. In some configurations, the left or right curb line could be the control depending on the logical vehicle driving path.
   b. In some configurations, often at exits, the logical vehicle driving path is outside the offset line, and the fastest path may not be affected by the curb offset line.
   c. In some right turns, the fastest paths could be offsets from the right (inside) of the turning radii or from the left (outside) of the turning radii that are controlled by the splitter island, truck apron, and exiting splitter island.
4. Review and revise the spline lines to be sure they are outside required offsets or located as needed to represent a fastest path. The beginning or end of the spline may need to be pulled farther away from the roundabout (up or downstream) to create a realistic fastest path.
5. Measure the radius values. Arc lengths for any circular curve should extend from 65 ft to 80 ft (20 m to 25 m). If they are shorter than that, the path should be modified to achieve these lengths. Achieving these lengths may require adjusting the spline lines to be sure the fastest path reflects driver behavior.
6. Conduct the evaluations for other through and turning movements.
7. If the estimated speeds are adequate for all movements, continue refining the roundabout. If speeds on some movements are too fast, make geometric changes as needed to reduce speeds and repeat the assessment.

A.1.3 Speed–Radius Graphs

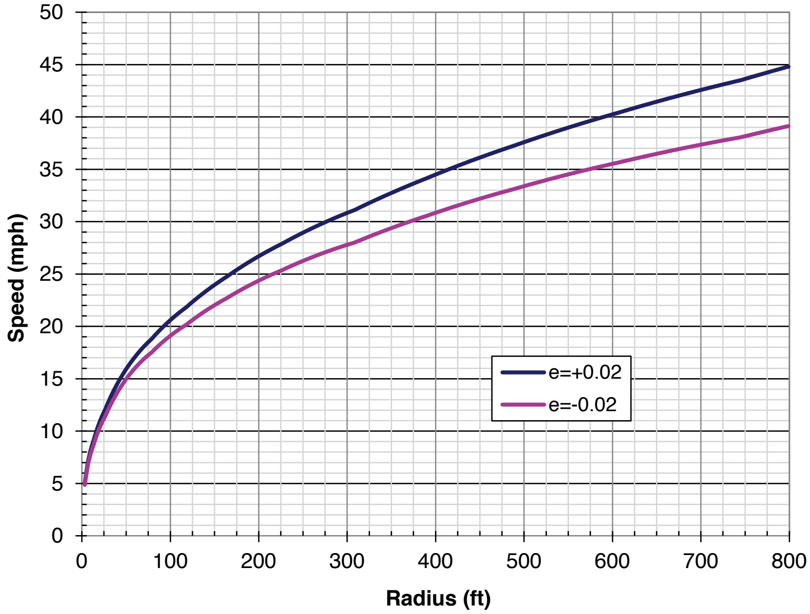
Chapter 9: Geometric Design Process and Performance Checks explains the speed–radius graphs used for estimating speeds when conducting geometric speed checks. Exhibit A.5 through Exhibit A.8 provide larger versions of the graphs in Chapter 9 to allow for easier use when conducting checks.

Exhibit A.5. Speed–radius relationship, US customary up to 400 ft.



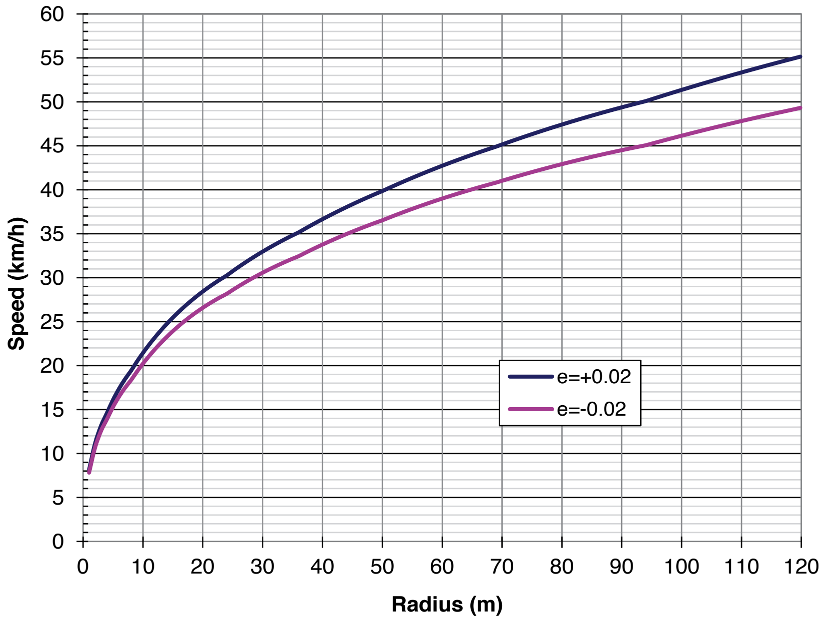
SOURCE: Based on AASHTO *Green Book*, Equation 3-7 and side friction factors assumed for design (AASHTO Figure 3-4) (*2*).

Exhibit A.6. Speed–radius relationship, US customary up to 800 ft.



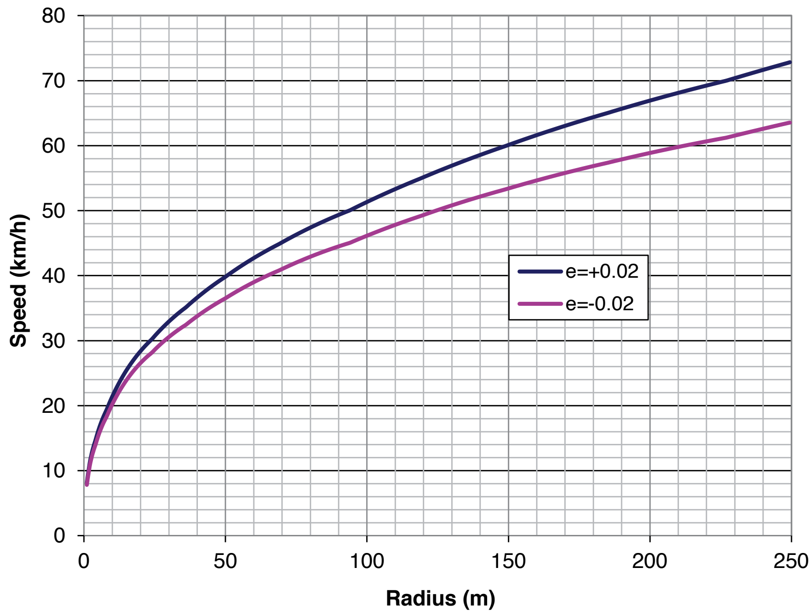
SOURCE: Based on AASHTO *Green Book*, Equation 3-7, and side friction factors assumed for design (AASHTO Figure 3-4) (*2*).

Exhibit A.7. Speed–radius relationship, metric up to 120 m.



SOURCE: Based on AASHTO *Green Book*, Equation 3-7, and side friction factors assumed for design (AASHTO Figure 3-4) (*2*).

Exhibit A.8. Speed–radius relationship, metric up to 250 m.



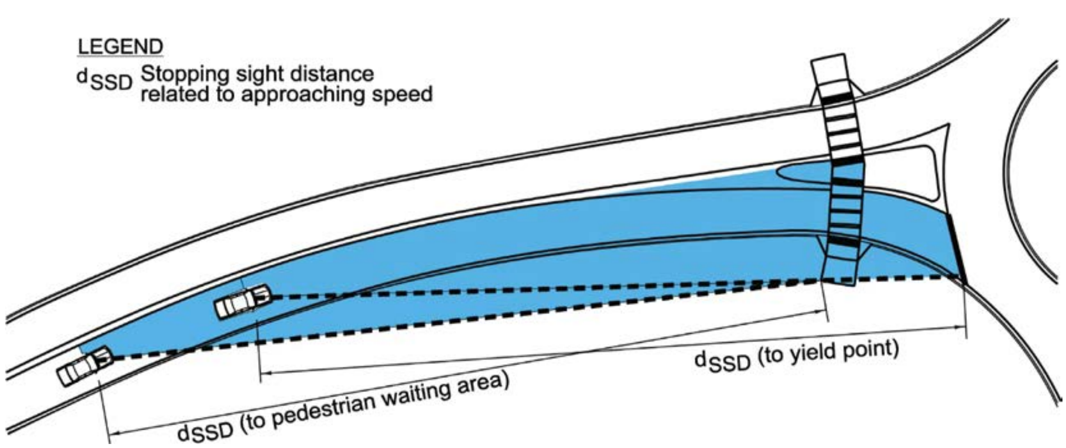
SOURCE: Based on AASHTO *Green Book*, Equation 3-7, and side friction factors assumed for design (AASHTO Figure 3-4) (*2*).

A.2 Sight Distance and Visibility

Chapter 9: Geometric Design Process and Performance Checks discusses stopping and intersection sight distance. Practitioners will use geometric speed check values to establish stopping and intersection sight distance. A possible method for conducting stopping sight distance evaluations, illustrated in Exhibit A.9 through Exhibit A.13, includes the following steps:

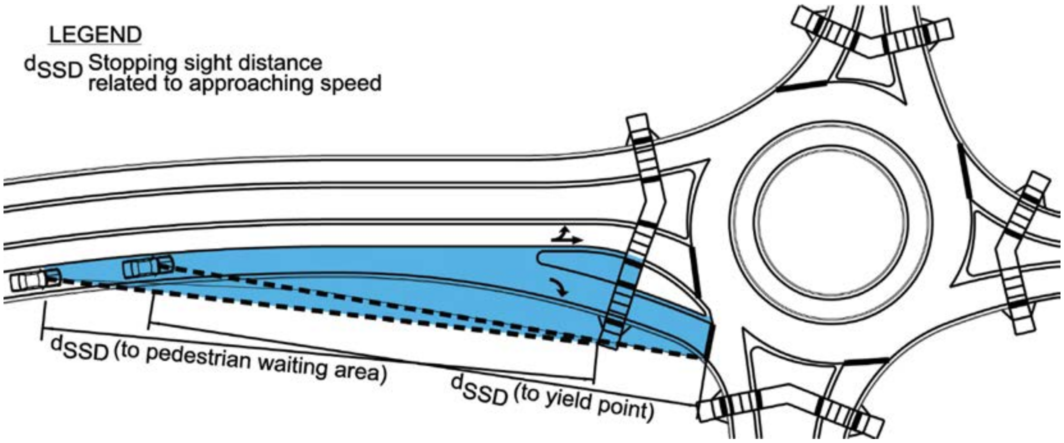
1. Assess the stopping sight distance on the approach by considering the approach speed and establishing the appropriate sight distance corresponding to that speed.
2. Measure the distance along the roadway approach path to the pedestrian waiting area or to the entrance line as appropriate. From the vehicle positioned at the distance along the traveled

Exhibit A.9. Stopping sight distance to the pedestrian crossing and entrance line on the approach.



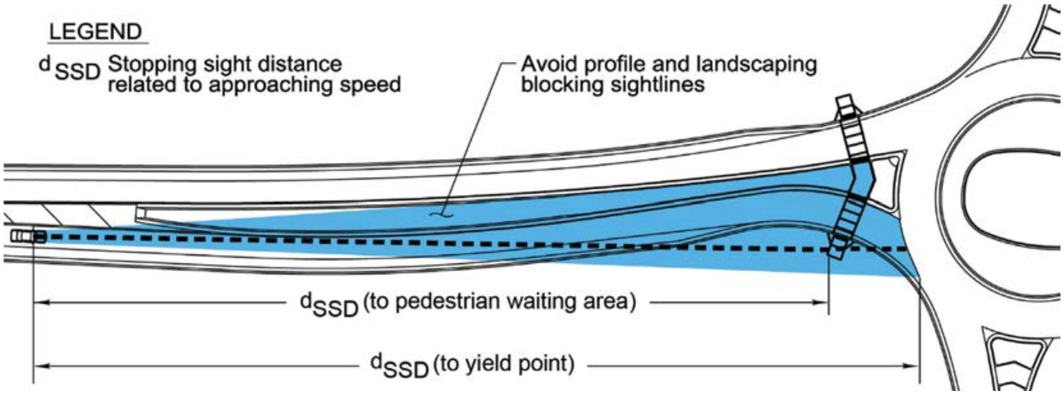
SOURCE: Adapted from Georgia Department of Transportation (*1*).

Exhibit A.10. Stopping sight distance for a right-turn bypass lane.



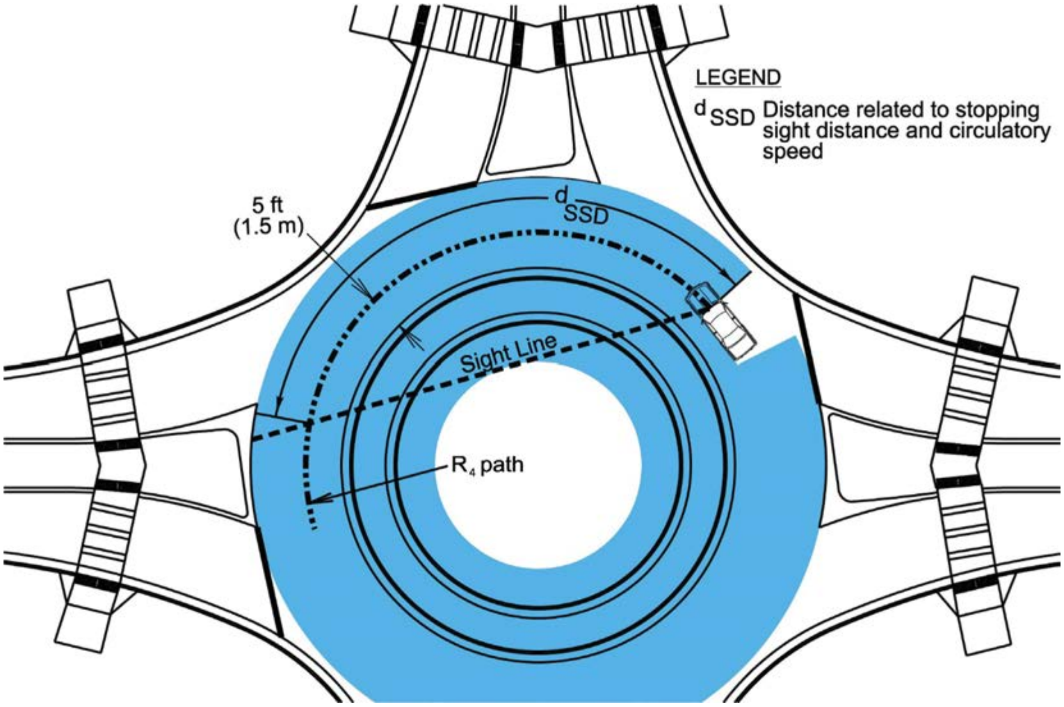
SOURCE: Adapted from Georgia Department of Transportation (*1*).

Exhibit A.11. Stopping sight distance for approach curvature.



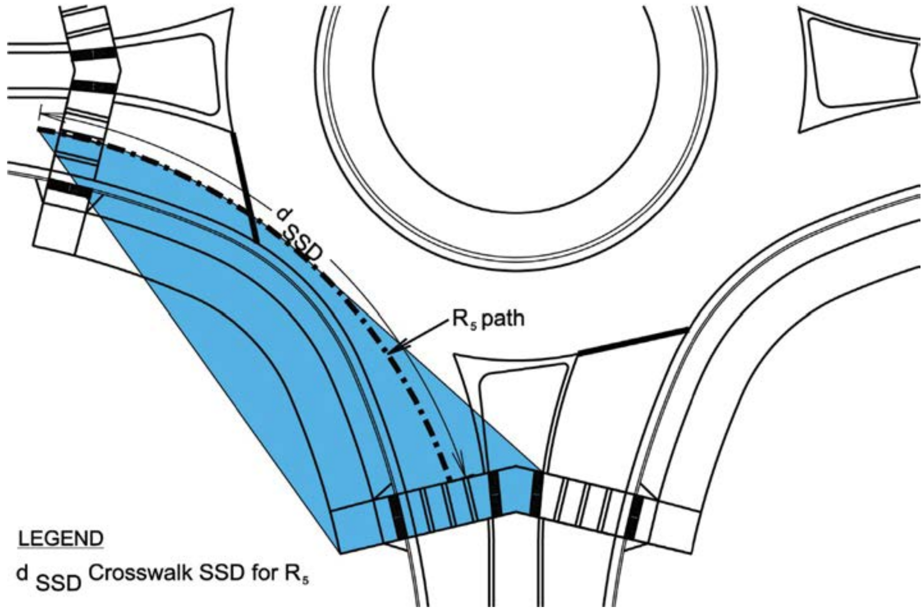
SOURCE: Adapted from Georgia Department of Transportation (*1*).

Exhibit A.12. Stopping sight distance on a circulatory roadway.



SOURCE: Adapted from Georgia Department of Transportation (*1*).

Exhibit A.13. Sight distance to a crosswalk on exit.



SOURCE: Adapted from Georgia Department of Transportation (*1*).

approach, the sightline to the waiting area can be established. For roundabouts with a separated right-turn lane, the stopping sight distance should be provided to the pedestrian waiting area and entrance line.

3. Measure the distance along the roadway approach path to the entrance line. From the vehicle positioned at the distance along the traveled approach, establish the sightline to the entrance line.
4. Verify that there are no sight distance obstructions within the inscribed sightline.
5. Assess the stopping sight distance along the circulatory roadway using the computed R_4 speed. Measure the distance along the circulatory roadway with an offset of 5 ft (1.5 m) from the central island curb. Then, establish a sightline to a forward position on the circulating path. Note that this sightline can be projected as if the driver circulated the entire roundabout to provide stopping distance at the central island. For noncircular roundabouts, practitioners can use the various geometric speed check speeds and establish sightlines similarly.
6. Assess the stopping sight distance to the pedestrian waiting area on the exit by locating the vehicle at the entrance line and establishing the sightline to the pedestrian waiting area. Even if a crosswalk is not provided, it is prudent not to preclude a future crossing, so the sight distance to the exit should be established.
7. Verify that there are no sight distance obstructions within the inscribed sightline on the central island.

Exhibit A.14 illustrates a possible intersection sight distance method that includes the following steps:

1. Consider a vehicle waiting at the entry and the two potential conflicts on the circulatory roadway and the immediate upstream entry.
2. Consider sight distance in advance of the entry: The length of the approach leg of the sight triangle and of the conflicting branch for the immediate upstream entry, b_1, should be limited to 50 ft (15 m). The length of the conflicting branch on the circulatory roadway, b_2, is calculated as previously described. If the combination of sight distance along the approach leg and the immediate upstream entry leg of the sight triangle exceeds these recommendations, it may be advisable to add landscaping that restricts sight distance to the minimum requirements.

3. Use Equation A.1 through Equation A.4 to compute the intersection sight distance for the two branches, b_1 and b_2. Exhibit A.14 shows the lengths of the two conflicting branches.

US Customary	Metric
Equation A.1 $$b_1 = 1.47 V_{ent} t_g$$	Equation A.3 $$b_1 = 0.278 V_{ent} t_g$$
Equation A.2 $$b_2 = 1.47 V_{circ} t_g$$ where b_1 = length of entering branch of sight triangle, ft b_2 = length of circulating branch of sight triangle, ft V_{ent} = speed of vehicles from upstream entry for the conflicting through movement, assumed to be average of V_1 and V_2, mph V_{circ} = speed of circulating vehicles, assumed to be V_4, mph t_g = design headway, s, assumed to be 5.0 s	Equation A.4 $$b_2 = 0.278 V_{circ} t_g$$ where b_1 = length of entering branch of sight triangle, m b_2 = length of circulating branch of sight triangle, m V_{ent} = speed of vehicles from upstream entry for the conflicting through movement, assumed to be average of V_1 and V_2, km/h V_{circ} = speed of circulating vehicles, assumed to be V_4, km/h t_g = design headway, s, assumed to be 5.0 s

Exhibit A.15 shows the computed length of the conflicting leg of an intersection sight triangle using an assumed value of design headway, t_g, of 5.0 s. This design headway is based on the amount of time required for a vehicle to safely enter the conflicting stream. This is an assumed value based on judgment and experience, originally developed using observational data for critical headways from *NCHRP Report 572* and more recent observational data from FHWA research (*3*, *4*). Some agencies use smaller values for design headway or other alternatives for locations with restricted sight distance.

Exhibit A.14. Intersection sight distance.

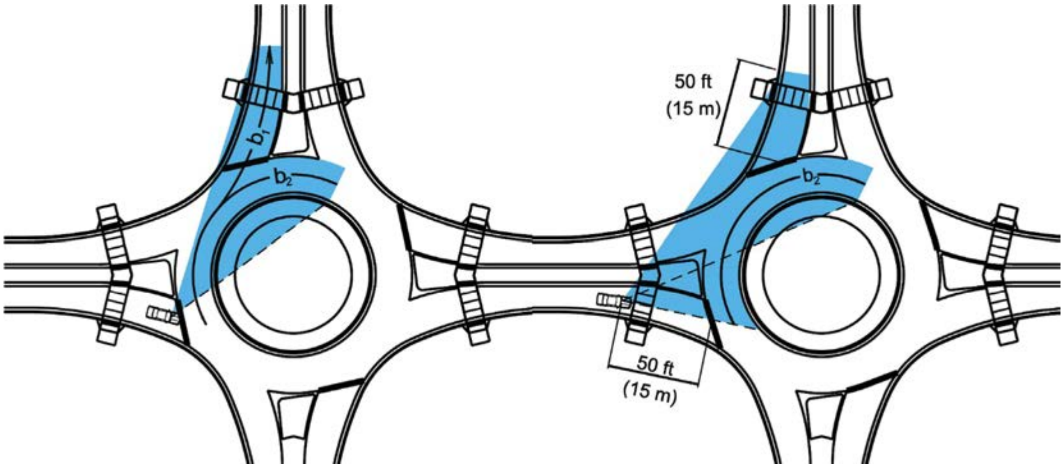
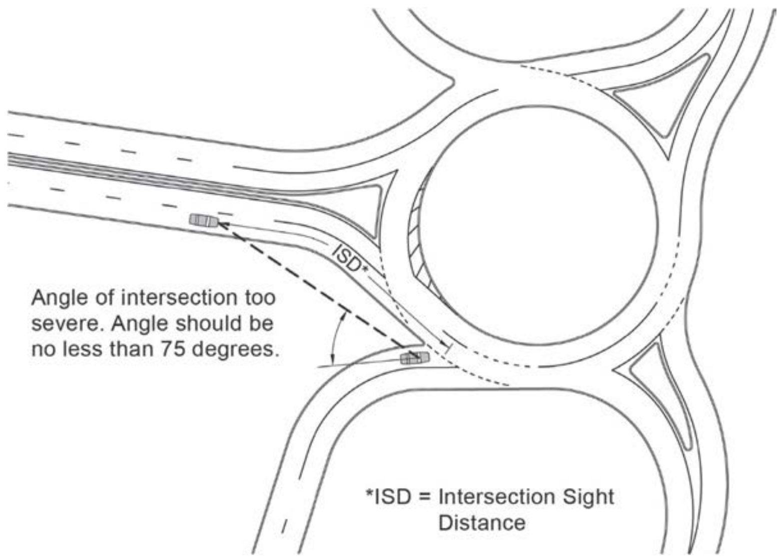


Exhibit A.15. Computed length of a conflicting leg of an intersection sight triangle.

Conflicting Approach Speed (mph)	Computed Distance (ft)	Conflicting Approach Speed (km/h)	Computed Distance (m)
10	73.4	20	27.8
15	110.1	25	34.8
20	146.8	30	41.7
25	183.5	35	48.7
30	220.2	40	55.6

NOTE: Computed distances are based on a critical headway of 5.0 s.

Exhibit A.16. Example design with a severe angle of visibility to the left.



SOURCE: Adapted from Tian et al. and *NCHRP Report 672* (*5, 6*).

View angles use the intersection sight distance values from this section. A possible method for conducting view angle evaluations includes the following steps:

1. Determine the vehicle location at the yield line. For multilane entries, each lane should be checked. View angles must also be checked for right-turn bypass lanes.
2. Establish the sightline assuming there is a vehicle at the yield line and a vehicle upstream at the location needed for intersection sight distance (distance b_1).
3. Measure the angle between the alignment of the vehicle at the yield line and the alignment of the sightline.

Exhibit A.16 depicts an approach with an intersection angle less than 75 degrees.

A.3 Vehicle Path Alignment

Chapter 9: Geometric Design Process and Performance Checks discusses vehicle path alignment evaluations, which are specific to multilane roundabouts. The natural vehicle paths are the paths approaching vehicles will take through the roundabout geometry, guided by their speed and orientation in the presence of other vehicles. The key consideration in evaluating vehicle path alignment is that drivers cannot change the direction or speed of their vehicle instantaneously.

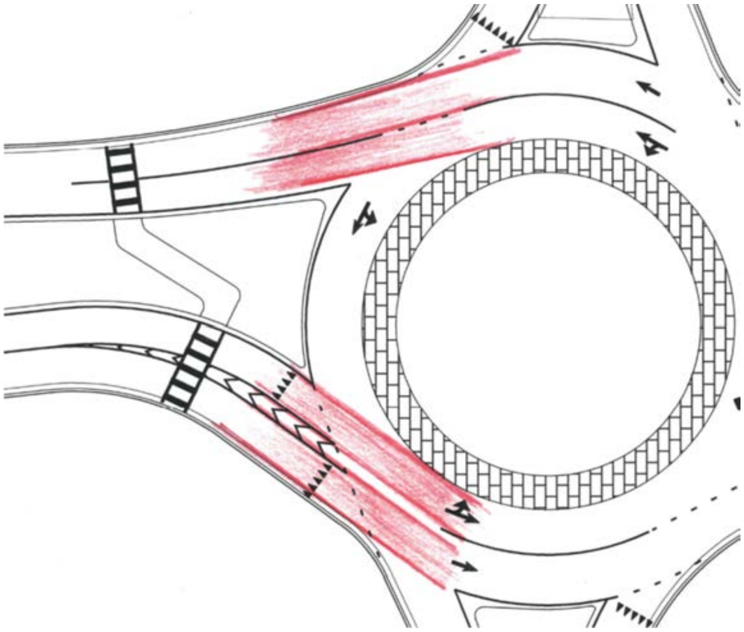
A possible method for vehicle path alignment evaluations includes the following steps:

1. Ensure that the roundabout entry directs vehicles to their intended lanes in the circulatory roadway.
2. Assess if the roundabout approach and entry channelization (e.g., splitter islands or traffic islands for right-turn lanes) allow transitions (tangents) between reverse curves (i.e., no back-to-back reverse curves).
3. Verify that consecutive vehicle path curves have a relatively similar radius that supports consistent speeds.
4. Assess if the vehicles circulating the roundabout are being directed to their intended exit lanes.
5. Verify that there is a tangent between the circulating lanes and the exit curve.
6. Assess if the exit curve provides speeds that are comparable to or larger than the circulating curve.
7. Inspect roundabouts (especially noncircular forms) for circulating speeds that are faster than exit speeds and require drivers to decelerate. However, if entry speeds are kept low, the added speed associated with a noncircular configuration may be 2 mph to 3 mph (3 km/h to 5 km/h) and have few adverse effects.

Exhibit A.17 shows a hand sketch of paths to assess vehicle alignment at a roundabout entry and exit. It also shows how to assess how effectively the geometry guides entering vehicles to their correct circulating lanes and how vehicles exiting the circulatory roadway are guided to their exit lanes.

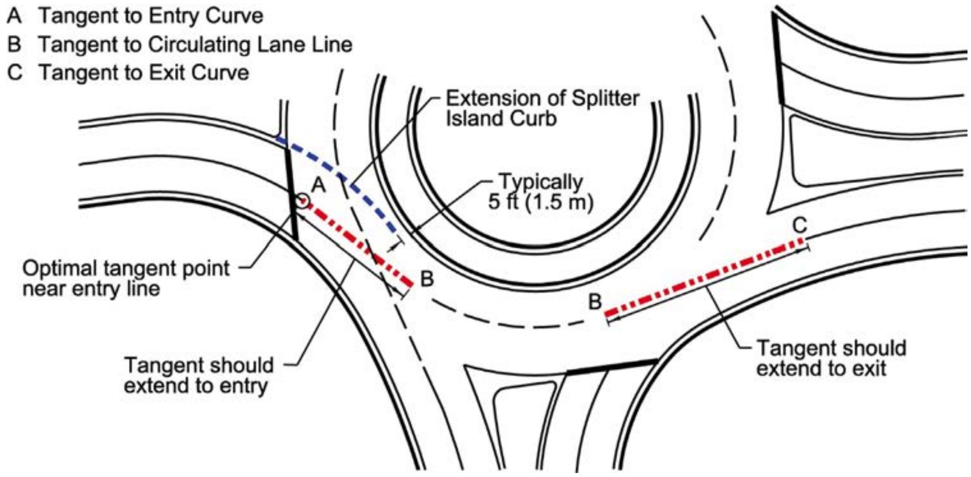
Exhibit A.18 presents a CAD-based example of assessing entry and exit configurations. The entry includes a tangent portion that guides the driver in the right lane along that bearing to the right circulating lane. This tangent also helps guide the left lane to the left circulating lane. It is common to include 2 ft to 5 ft (0.6 m to 1.5 m) of tangent on the left side of the left lane, with a

Exhibit A.17. Vehicle path alignment entering and exiting the roundabout.



SOURCE: Kittelson & Associates, Inc.

Exhibit A.18. Vehicle path alignment using CAD.



SOURCE: Adapted from Georgia Department of Transportation (*1*).

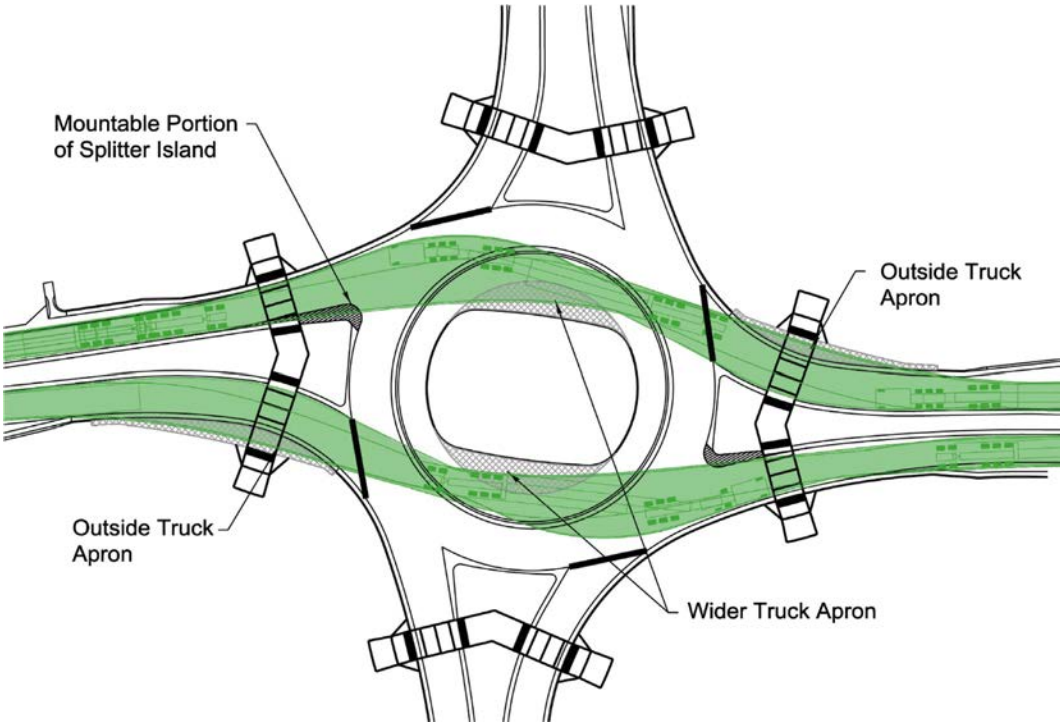
forward bearing that is tangential to the left edge of the left circulating lane. The exhibit also shows a tangent from the circulating lanes to the exit. This tangent provides a transition between reverse curves and guides the driver to the exit, where their path follows the exit curvature. Lines A–B and B–C need to be in the range of 40 ft to 60 ft (12 m to 18 m).

A.4 Design Vehicle

Chapter 9: Geometric Design Process and Performance Checks discusses design vehicle performance and checks. Software is commonly used to conduct design vehicle checks. However, some agencies continue to use truck templates to support early concept design development. A possible method for conducting a design vehicle evaluation includes the following steps:

1. Establish and document the design vehicle, which is the primary design check for trucks. Ensure that the design vehicle can travel through the roundabout between curbs, with some movements possibly using a truck apron for trailer off-tracking.
2. Establish and document what larger vehicle must be *accommodated*. This is based on serving a less frequent but larger control vehicle (or *check vehicle*). The check vehicle is an anticipated but infrequent user of the roundabout that simply needs to "get through." The check vehicle may require design features, such as additional truck aprons along the exterior, hardened surfaces beyond the curb, passageways through splitter islands or the central island, removable signs, or other treatments. A check vehicle may be required to allow a truck driver to drive their cab onto the truck apron to complete some movements.
3. For multilane roundabouts, establish and document if design vehicles may straddle lanes (use the entire curb-to-curb width for entering, circulating, and exiting plus the truck apron as needed) or be required to stay in-lane.
4. Conduct design vehicle performance checks:
   a. For the design vehicle, AASHTO recommends providing 1 ft to 2 ft (0.3 m to 0.6 m) of shy distance between the vehicle path (the traveled way) and the curb (*2*). Buses are to be accommodated within the circulatory roadway without tracking over the truck apron.
   b. Swept paths should be prepared for each turning movement. Frequently, right-turn movements are critical for truck movements, particularly at single-lane roundabouts.
   c. A smooth vehicle path should reflect a driver's realistic travel path. The cab of a tractor trailer design vehicle is typically assumed to stay within the travel lanes and not mount curbs, with truck aprons supporting off-tracking of only the trailer.

Exhibit A.19. Through movement swept path of an OSOW vehicle.



SOURCE: Adapted from Georgia Department of Transportation (*1*).

d. When conducting the design vehicle check, avoid using crawl speed and going wheel-lock to wheel-lock, as these are unrealistic operational assumptions. Understand and show the difference between the tire locations relative to the curb and the truck envelope itself, which may extend above and beyond the curb.

Exhibit A.19 presents the typical swept paths for an oversize/overweight (OSOW) vehicle making a through movement.

A.5 Bicycle and Pedestrian Design Flags

This section considers the design flag procedure in *NCHRP Research Report 948: Guide for Pedestrian and Bicyclist Safety at Alternative and Other Intersections and Interchanges* (*7*). Of the 20 design flags (Exhibit A.20 through Exhibit A.22) identified in *NCHRP Research Report 948* and summarized in Chapter 9: Geometric Design Process and Performance Checks, many can apply to roundabouts. Each flag can have a comfort aspect, a safety performance aspect, or both. A design review can proceed through the set of design flags and identify if any comfort or safety flags are present. These flags can provide a metric for comparing alternatives in the ICE activities, and they can also support preliminary design, including identifying potential design modifications to reduce or eliminate the flag.

A possible method for applying the design flags includes the following steps:

1. Review a design for each of the flags and identify if there are any comfort-related or safety-related flags. Practitioners should evaluate these flags for each of the bicyclist or pedestrian movements through the intersection, depending on the nature of the design flag.
2. If possible, modify the design to address any identified flags, or identify the modification that would be necessary for the concept to advance for further design refinement.

Exhibit A.20. Summary of design flags for pedestrian and bicycle intersection assessment, part 1 of 3.

Design Flag	Comfort Flag	Safety Flag	Notes
Motor vehicle right turns	na	na	The typical roundabout design of setting bicycle and pedestrian crossings at least one vehicle length away from the circulatory roadway addresses this flag. This flag is more common at other intersection forms.
Uncomfortable/tight walking environment	Pedestrian facilities less than 5 ft (1.5 m) of effective width.	Pedestrian facilities that do not meet ADA requirements, which creates significant out-of-direction travel and exposure for people who are blind or have low vision.	na
Nonintuitive motor vehicle movements	na	na	The typical roundabout design of setting bicycle and pedestrian crossings at least one vehicle length away from the circulatory roadway addresses this flag. This flag is more common at other alternative intersection forms.
Crossing yield or uncontrolled vehicle paths	Pedestrian crossings that result in high pedestrian delay.	Pedestrian crossings that do not satisfy pedestrian crossing assessment for people who are blind or have low vision.	na
Indirect paths	Pedestrian crossings that are farther than one to two vehicle lengths from the circulatory roadway if unsignalized or farther than 80 ft (25 m) from the circulatory roadway if staggered and signalized.	Pedestrian crossings that are omitted from a leg of a roundabout, forcing other routing around the roundabout or to adjacent intersections.	na
Executing unusual movements	na	na	The typical roundabout design of setting bicycle and pedestrian crossings at least one vehicle length away from the circulatory roadway addresses this flag. This flag is more common at other alternative intersection forms.
Multilane crossings	Pedestrian crossings with splitter islands that are too narrow for refuge can confuse pedestrians who are blind or have low vision, who may mistake a narrow island for a place where they can stop.	Multilane pedestrian crossings that do not have supplemental vertical deflection or active traffic control devices (signals, pedestrian hybrid beacons, or rectangular rapid-flashing beacons).	Multilane crossings at roundabouts are shorter than multilane crossings at other intersection forms, but multilane crossings are typically signalized at other intersection forms.
Long red times	na	Can occur if pedestrian crossings are signalized and coordinated with a long background cycle length.	This does not generally apply to roundabouts, except possibly when signalized crossings are implemented. This flag is more common at signalized intersections of various forms.

NOTE: na = not applicable. SOURCE: Adapted from *NCHRP Research Report 948* (*7*).

Exhibit A.21. Summary of design flags for pedestrian and bicycle intersection assessment, part 2 of 3.

Design Flag	Comfort Flag	Safety Flag	Notes
Undefined crossing at intersections	na	na	Pedestrian crossings are typically marked at roundabouts.
Motor vehicle left turns	na	na	The typical roundabout design of setting bicycle and pedestrian crossings at least one vehicle length away from the circulatory roadway addresses this flag. This is more common at other intersection forms.
Driveways and side streets at or near intersection	Driveways and side streets within or in proximity to the roundabout may adversely affect wayfinding for pedestrians with vision disabilities.	Driveways may introduce conflicts with both pedestrians and bicyclists.	At roundabouts with high vehicular volumes or where ambient noise is high, it may not be possible for pedestrians who are blind or have low vision to hear vehicles entering from a driveway or side street. Geometric speed control may be needed to ensure yielding by vehicles entering from a driveway or side street close to a circulatory roadway.
Sight distance and auditory distance for gap acceptance movements	na	Inadequate sight distance between drivers and pedestrians. Inadequate auditory distance, especially in noisy environments, for pedestrians who are blind or have low vision to make gap or yield judgments.	In noisy environments, it may be difficult to hear vehicles well enough to make safe gap or yield judgments at even single-lane roundabouts.
Grade change	na	Inadequate sight distance between drivers and bicyclists or between drivers and pedestrians.	These are most often caused by grade breaks or vertical curves adjacent to intersections.
Riding or walking in mixed traffic	Roundabouts with a shared bicycle-pedestrian facility around the perimeter.	Multilane roundabouts without any type of bicycle facility that is separated from motor vehicles around the perimeter.	This is typically more of an issue with on-street bicycle facilities on high-speed or high-volume roads. Separated bicycle and pedestrian facilities are more comfortable for people riding and walking. Pedestrians, especially those who are elderly or who have disabilities, may be unable to hear or see bicycles or to quickly move out of the path of bicyclists who assume that pedestrians will move out of their way.
Bicycle clearance times	na	na	This does not apply to roundabouts and is more common with larger signalized intersections.

NOTE: na = not applicable. SOURCE: Adapted from *NCHRP Research Report 948* (*7*).

Exhibit A.22. Summary of design flags for pedestrian and bicycle intersection assessment, part 3 of 3.

Design Flag	Comfort Flag	Safety Flag	Notes
Lane change across motor vehicle travel lane(s)	na	Left-turning bicyclists at multilane roundabouts without a separated bicycle or shared bicycle-pedestrian facility around the perimeter; nonyielding, right-turn bypass lanes, where through bicyclists using the travel lanes must cross bypass lane to continue.	na
Channelized lanes	na	na	The typical roundabout design does not have bicyclists traveling next to motor vehicles in long channelized lanes. This is more common at other intersection forms.
Turning motorists crossing bicycle path	na	na	The typical roundabout design of setting bicycle and pedestrian crossings at least one vehicle length away from the circulatory roadway addresses this flag. This is more common at other intersection forms.
Riding between travel lanes, lane additions, or lane merges	Right-turn bypass lanes where a parallel acceleration lane or deceleration lane is next to a bicycle lane.	na	na
Off-tracking trucks in multilane curves	na	na	The typical roundabout design of not using bicycle lanes at entry or exit or in the circulatory roadway addresses this flag. This is more common at other intersection forms.

NOTE: na = not applicable. SOURCE: Adapted from *NCHRP Research Report 948* (*7*).

3. If a concept continues to have flags (which it might, depending on the alternative), the flags can be tallied to determine the total number of comfort-related flags and safety-related flags. *NCHRP Research Report 948* provides examples of forms for this process.
4. If desired, use a qualitative rating or ranking to compare alternatives based on the number of comfort-related or safety-related design flags, recognizing that these design flags are only part of the overall evaluation process. If a concept has safety-related design flags that cannot be addressed through design modifications, the concept could be flawed enough to eliminate from subsequent evaluations. If a concept has comfort-related design flags, the quantity and nature of these flags may help differentiate alternatives.

A.6 Pedestrian Crossing Assessment

This section summarizes the key assessment models for crossing delay and expected level of risk as presented in *NCHRP Research Report 834: Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities: A Guidebook* and its successor project, NCHRP Project 03-78c, "Training and Technology Transfer for Accessibility Guidelines for Roundabouts and Channelized Turn Lanes," which amended the assessment procedure in *NCHRP Research Report 834* (*8*, *10*, *11*). Further detail can be found in those documents, including sample checklists and worksheets. Crossing sight distance has been integrated into the sight distance procedure presented in Chapter 9: Geometric Design Process and Performance Checks.

A.6.1 Possible Method

A possible method for conducting a pedestrian crossing assessment may include the following steps:

1. Assess vehicle path speeds using one of the techniques described in Section A.1.
2. Assess sight distance using one of the techniques described in Section A.2.
3. Assess pedestrian delay and crossing risk using the models presented in this section, supported by *NCHRP Research Report 834* as amended by NCHRP Project 03-78c (*10*).
4. Assess the sufficiency of these calculated performance measures to determine an appropriate crossing treatment, if any. Section A.6.2 illustrates a possible application.

The worksheets and models in Exhibit A.23 and Exhibit A.24 were developed for NCHRP Project 03-78c in US Customary units only. Appropriate conversions need to be used for inputs and outputs.

A.6.2 Possible Application

This section presents an example of a possible application based on unpublished work prepared for the Montana Department of Transportation and the Pennsylvania Department of Transportation (*10*, *11*). **This example of a possible application should not be misconstrued as a standard, as it requires deciding what constitutes an acceptable level of risk, which is beyond the scope of this document and the Transportation Research Board.**

Exhibit A.25 shows results from this possible application. The three models used for this possible application are as follows:

- **Intervention model.** This model predicts *high risk* at two-lane exits for fastest path speeds exceeding 25 mph. The research defines an intervention as an event when a pedestrian who is blind or has low vision makes a crossing decision that would have resulted in a certified orientation and mobility specialist stopping the person from crossing, such as stepping in front of an oncoming vehicle that the person who is blind or has low vision did not detect. This is based on an assumed maximum acceptable crossing risk of 4 percent, which is comparable to most single-lane roundabouts studied under *NCHRP Research Report 834*. Using this threshold, two-lane entries show acceptable risk up to 40 mph based on the NCHRP Project 03-78c models and, therefore, do not suggest the need to evaluate a risk-based treatment for entries unless ambient noise level is high. The intervention model results in the region denoted high risk in Exhibit A.25.
- **Delay model.** This model predicts *high delay* at a combination of high speeds (results in low yielding) and high volumes (results in low gap availability). The maximum acceptable pedestrian delay was set at 30 seconds, based on the *Highway Capacity Manual* observation (HCM Exhibit 20-3) that for delays exceeding 30 seconds per pedestrian, the delay approaches a tolerance level with the risk-taking behavior likely (*12*). Everything above the trend line in Exhibit A.25 is considered high delay.
- **Yielding model.** This model predicts yielding as a function of speed and other variables. The *high yield* (more than 50 percent) is shown in Exhibit A.25. In low-speed environments, low yielding is typically only a concern in combination with high volume, which results in high delay. As a result, the yielding model results are shown for reference only and are not used in the guidance development.

Exhibit A.23. Pedestrian crossing assessment, part 1 of 2.

Crossing Assessment Worksheet Task	Default Values	Units	Quadrant A for CTL or Crossing A-B Entry	Crossing A-B Exit	Quadrant B for CTL or Crossing B-C Entry	Crossing B-C Exit	Quadrant C for CTL or Crossing C-D Entry	Crossing C-D Exit	Quadrant D for CTL or Crossing D-A Entry	Crossing D-A Exit
Step 1. Gather Site Data and Other Inputs										
Step 2. Predict Vehicle Speed at Crosswalk										
Speed at crosswalk, $V_{critical}$	(none)	[mph]								
Step 3. Calculate Crossing Sight Distance										
Crosswalk length, L_n	(none)	[ft]								
Design ped walking speed, S_p	3.5	[ft/s]								
Ped start-up time and end clearance time, t_s	2	[s]								
Critical headway, $t_{n,c} = \frac{L_n}{S_p} + t_s$	(none)	[s]								
Crossing sight distance, $d_n = 1.47\, V_n t_{n,c}$	(none)	[ft]								
Step 4. Checking Sight Distance Provisions										
Performance Check 1: Is Adequate Sight Distance Available?										
Step 5. Predict Crossing Opportunities (Gaps and Yields)										
Volume, N_{veh}	(none)	[veh]								
Crossing type	1L, 2L, CTL	[]								
Probability of encountering usable gap, $P_g = e^{\frac{-t_{n,c} * N_{veh}}{3600}}$	(none)	[]								
Single-lane crossing/CTL crossing										
Indicator variable for exit, I_{ex}	1 = exit, 0 = entry/CTL	[]								
Indicator variable for entry, I_{en}	1 = entry, 0=exit/CTL	[]								
Indicator variable for high compliance region, I_{HC}	1=high, 0=low	[]								
Prob. of yields, single-lane roundabout/CTL, $P_Y = (0.6888 - 0.07688 * I_{ex} + 0.62954 * I_{en} + 0.37418 * I_{HC})e^{-0.03465 * V}$	(none)	[]								
Two-lane crossing										
Indicator variable for RRFB, I_{RRFB}	1=yes, 0=no	[]								
Indicator variable for exit, I_{ex}	1=exit, 0=entry	[]								

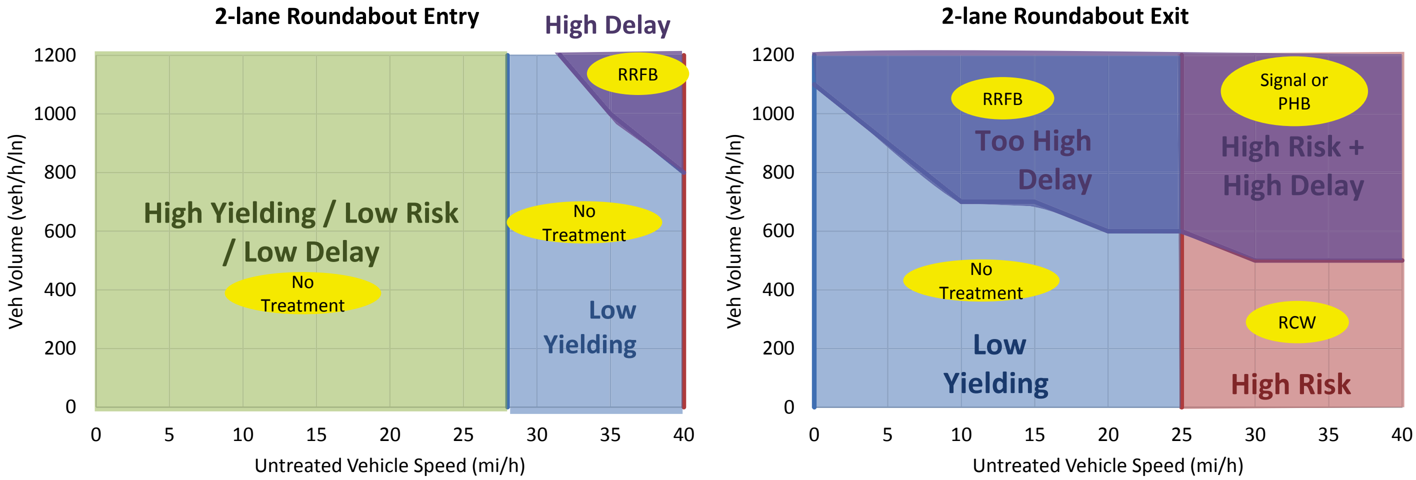
SOURCE: NCHRP Project 03-78c (*9*).

Exhibit A.24. Pedestrian crossing assessment, part 2 of 2.

Crossing Assessment Worksheet			Quadrant A for CTL or		Quadrant B for CTL or		Quadrant C for CTL or		Quadrant D for CTL or	
Task	Default Values	Units	Crossing A-B Entry	Crossing A-B Exit	Crossing B-C Entry	Crossing B-C Exit	Crossing C-D Entry	Crossing C-D Exit	Crossing D-A Entry	Crossing D-A Exit
Indicator variable for high compliance region, I_{HC}	1=high, 0=low	[]								
Prob. of yields, two-lane roundabout, $P_Y = (0.7259 + 0.2105 * I_{RRFB} - 0.2574 * I_{ex} + 0.3244 * I_{HC})e^{-0.0129 * V}$	(none)	[]								
Probability of yields, P_Y (select row based on 1L/2L/CTL)	(none)	[]								
Probability of yield crossing opportunities, $P_{YC} = P_Y * (1 - P_G)$	(none)	[]								
Step 6. Estimate Utilization of Gaps and Yields										
Probability of using a gap, P_{UG} (default for roundabouts = 65%)	Rbt = 0.65, CTL = 0.60	[]								
Probability of using a yield, P_{UY} (default for roundabouts = 70%)	Rbt = 0.70, CTL = 0.35	[]								
Step 7. Estimate Blind Pedestrian Delay										
Probability of crossing, $P_C = P_{YC} * P_{UY} + P_G * P_{UG}$	(none)	[]								
Delay, single-lane crossing, $d_p = 9.37 - 9.78 * ln(P_C)$	(none)	[s/veh]								
Delay, two-lane crossing, $d_p = 6.14 - 8.53 * ln(P_C)$	(none)	[s/veh]								
Delay, CTL, $d_p = 10.75 - 9.95 * ln(P_C)$	(none)	[s/veh]								
Delay, d_p (select row based on 1L/2L/CTL)	(none)	[s/veh]								
Step 8. Determine Delay-Based Pedestrian LOS										
Performance Check 2: Is the Pedestrian LOS within the guidelines for your agency?										
Step 9. Estimate Crossing Risk										
Indicator variable for entry/exit, I_{ex}	1=exit, 0=entry/CTL	[]								
Indicator variable for noise, I_N	1=noisy, 0=low noise	[]								
Indicator variable for number of lanes, I_{1L}	1=1L or CTL, 0=2L	[]								
Probability of intervention, $P_I = (0.011895 + 0.008443 * I_{ex} + 0.021915 * I_N - 0.007186 * I_{1L})e^{0.027697 * V}$	(none)	[]								
Step 10. Check Crossing Risk										
Performance Check 3: Is probability of an intervention within range allowable by your agency?										
Step 11. Visibility of Traffic Control Devices										
Step 12. Complete Crosswalk Assessment										

SOURCE: NCHRP Project 03-78c (*9*).

Exhibit A.25. Example of a possible assessment of treatments by risk, delay, and yielding for two-lane roundabouts in low-noise environments.



SOURCE: Montana Department of Transportation and Pennsylvania Department of Transportation (*10, 11*). RRFB = rectangular rapid-flashing beacon; PHB = pedestrian hybrid beacon; RCW = raised crosswalk.

For each of the different regions, the treatment selection is as follows:

- **High Risk + High Delay.** This condition suggests using a traffic control signal or a pedestrian hybrid beacon (PHB).
- **High Risk + Low Delay.** This condition suggests using at least a raised crosswalk (RCW) and may require more advanced treatments, like a traffic control signal or a PHB. A rectangular rapid-flashing beacon (RRFB) is not suggested because vehicle speeds are too high.
- **Low Risk + High Delay.** This condition suggests at least an RRFB and may require more advanced treatments, like a traffic control signal or a PHB. An RCW is not suggested because vehicle volumes are too high.
- **Low Risk + Low Delay.** This condition suggests no additional treatments are needed, but additional treatments could certainly be considered.

This exhibit is based on assumed thresholds for acceptable performance and is an example of possible guidance. This should not be misconstrued as a recommended standard or guidance in this Guide or by the Transportation Research Board.

Exhibit A.25 suggests that under certain vehicle speed and vehicle volume conditions, it may be possible to provide equivalent accessibility using treatments other than active regulatory devices, such as a traffic control signal or a PHB. As noted in Chapter 12, to meet pedestrian and driver expectations, the same crossing treatment should be used on the entry and exit of a roundabout leg.

A.7 Pedestrian Wayfinding Assessment

Exhibit A.26 provides a checklist for pedestrian wayfinding performance. The checklist has been adapted from Appendix C of the NCHRP Project 03-78c Final Report, which amends *NCHRP Research Report 834* (*9*, *8*). The checklist references *NCHRP Research Report 834* for design details, many of which have been superseded by content in this Guide. The checklist also references US DOT regulations related to the ADA (42 USC 12131-12134) and the *Manual on Uniform Traffic Control Devices* (MUTCD) as well as proposed Public Right-of-Way Accessibility Guidelines (PROWAG) (*13–15*).

Exhibit A.26. Pedestrian wayfinding checklist.

Question	Sources for Information
Determining the Crossing Location	
Do sidewalks lead to the crosswalks?	Chapter 10; *NCHRP Research Report 834* (*8*).
Is continuous, cane-detectable edge treatment or landscaping provided between the sidewalk and the curb?	Chapter 10; *NCHRP Research Report 834* (*8*). Required by proposed PROWAG at roundabouts (*15*).
Are there detectable warning surfaces at the bottom of curb ramps or on the sidewalk at each end of raised crosswalks?	Chapter 10; *NCHRP Research Report 834* (*8*). Required by US DOT ADA regulations (*13*) and proposed PROWAG (*15*).
If other ramps or driveways are nearby, are they adequately delineated and separated from the pedestrian crossing ramps?	Chapter 10; *NCHRP Research Report 834* (*8*).
Are traffic control devices, including push buttons for signals and beacons, accessible?	Chapter 12; *NCHRP Research Report 834* (*8*); MUTCD (*14*). Required by proposed PROWAG (*15*).
Aligning to Cross and Establishing a Correct Heading	
Is the curb ramp width the same as the crosswalk width?	Chapter 10; *NCHRP Research Report 834* (*8*).
Is the curb ramp slope aligned with the crossing?	Chapter 10; *NCHRP Research Report 834* (*8*).
Are ramp edges aligned with the crossing?	Chapter 10; *NCHRP Research Report 834* (*8*).
Is the detectable warning aligned with the slope of the curb ramp?	Chapter 10; *NCHRP Research Report 834* (*8*).
If push buttons for traffic control devices are provided, are they accessible and in the correct location?	Chapter 12; *NCHRP Research Report 834* (*8*); MUTCD (*14*).
Is there a sufficiently level landing for turning at either the top of perpendicular curb ramps or the bottom of parallel ramps?	Required by US DOT ADA regulations (*13*) and proposed PROWAG (*15*).
Maintaining a Correct Heading while Crossing and Staying Within the Crosswalk	
Is the crossing configured at the shortest distance practical?	Chapter 10; *NCHRP Research Report 834* (*8*).
Is the crossing aligned perpendicular to the curb and splitter edges?	Chapter 10; *NCHRP Research Report 834* (*8*).
Are markings clearly visible?	Chapter 12; *NCHRP Research Report 834* (*8*); MUTCD (*14*).
Crossing from Channelization Islands and Splitter Islands	
Are islands wide enough to provide safe refuge?	Chapter 10; *NCHRP Research Report 834* (*8*).
Are there detectable warning surfaces at the bottom of curb ramps or on the sidewalk at each end of raised crosswalks (unless the islands are less than 6 ft, or 1.8 m, in width)?	Chapter 10; *NCHRP Research Report 834* (*8*). Required by US DOT ADA regulations (*13*) and proposed PROWAG (*15*).
Are paths through islands clearly defined by grade difference or landscaping?	Chapter 10; *NCHRP Research Report 834* (*8*).
If push buttons for traffic control devices on the island are provided, are they accessible and in the recommended location?	Chapter 12; *NCHRP Research Report 834* (*8*); MUTCD (*14*).

SOURCE: Adapted from Kittelson & Associates, Inc., and Accessible Design for the Blind, Appendix C (*9*).

A possible method for conducting a pedestrian wayfinding assessment may include the following steps:

1. Evaluate each of the wayfinding questions for each quadrant of the roundabout. Examples of wayfinding assessments are in *NCHRP Research Report 834*.
2. Review a design using each of the wayfinding questions and identify any design gaps. These should be evaluated for each quadrant or leg of the roundabout.
3. If possible, modify the design to address any identified gaps, or identify the modification necessary for the concept to advance for further design refinement.
4. If desired, use a qualitative rating or ranking to compare alternatives based on how well the concept addresses wayfinding. These ratings or rankings may help differentiate alternatives.

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Abbreviations and Acronyms

AADT	annual average daily traffic
AC	asphalt concrete
ACPA	American Concrete Pavement Association
ADAAG	*ADA Accessibility Guidelines*
AWSC	all-way stop-controlled
BIM	building information modeling
CAD	computer-assisted drafting
Cap-X	Capacity Analysis for Planning of Junctions
CAV	connected and automated vehicle
CFR	US Code of Federal Regulations
CMF	crash modification factor
DC	Washington, DC
DOT	department of transportation
DWS	detectable warning surface
DDI	diverging diamond interchange
The Guide	*Guide for Roundabouts*
HCM	*Highway Capacity Manual*
HMA	hot-mix asphalt
ICD	inscribed circle diameter
ICE	intersection control evaluation
IES	Illuminating Engineering Society
IIHS	Insurance Institute for Highway Safety
K	ratio of peak hour to daily traffic
KDOT	Kansas Department of Transportation
LOS	level of service
LTS	level of traffic stress
MUTCD	*Manual on Uniform Traffic Control Devices for Streets and Highways*
NACTO	National Association of City Transportation Officials
OSOW	oversize or overweight
PCC	portland cement concrete
PDO	property damage only
PennDOT	Pennsylvania Department of Transportation
PHB	pedestrian hybrid beacon
PROWAG	Public Right-of-Way Accessibility Guidelines
RCW	raised crosswalk
RRFB	rectangular rapid-flashing beacon
SPF	safety performance function
SPICE	Safety Performance for Intersection Control Evaluation

SU	single unit
TDI	tactile directional indicator
TWD	tactile warning delineator
TWSC	two-way stop control
TWSI	tactile walking surface indicator
V2V	vehicle-to-vehicle
Veh/hr	vehicles per hour
WB	wheelbase

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GHSA	Governors Highway Safety Association
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

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