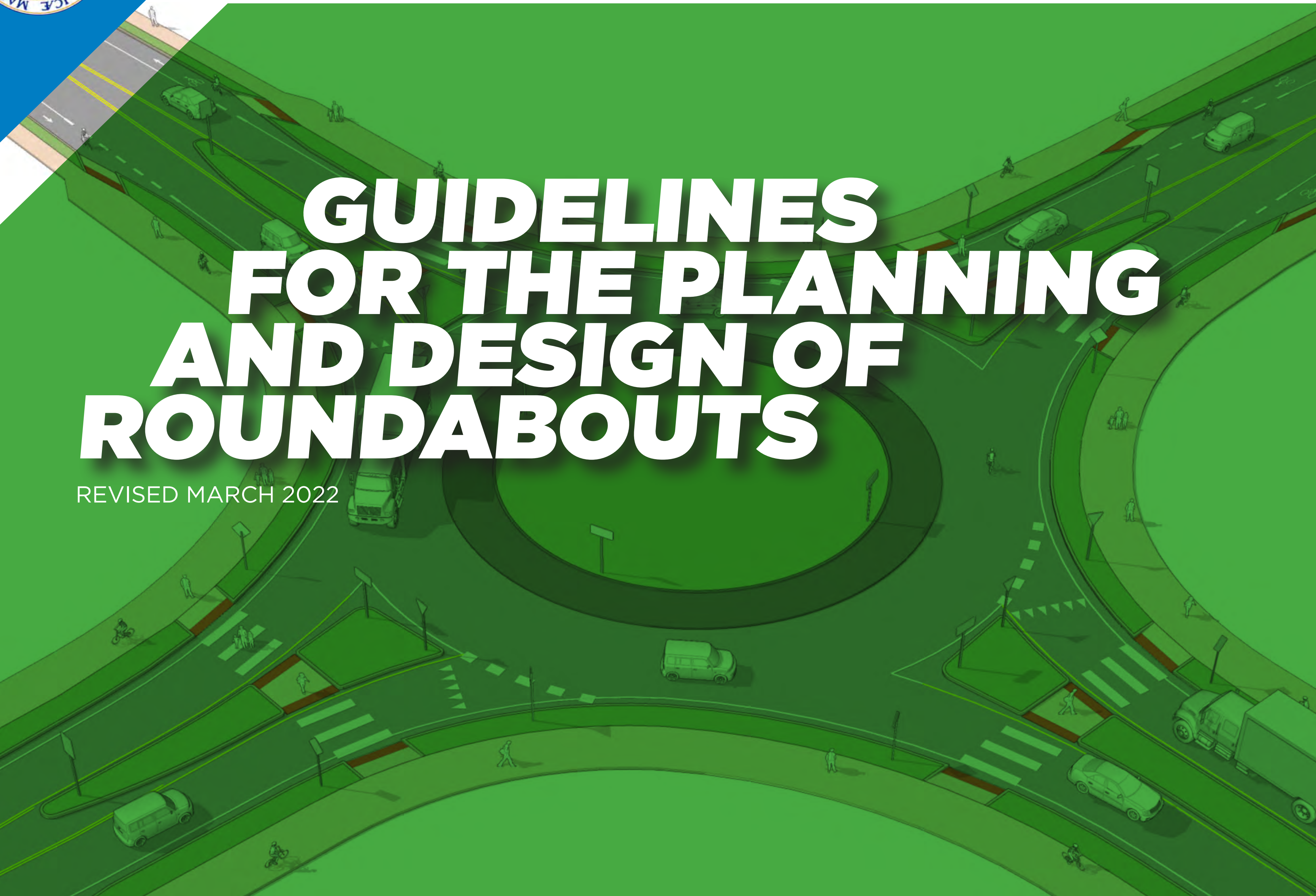
Massachusetts Department of Transportation

GUIDELINES FOR THE PLANNING AND DESIGN OF ROUNDABOUTS

REVISED MARCH 2022



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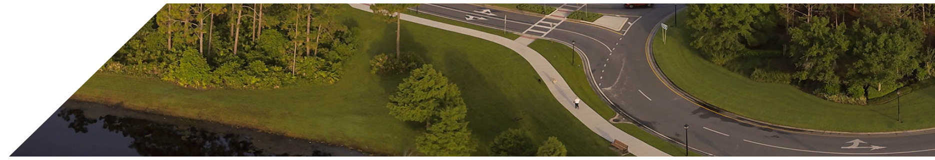

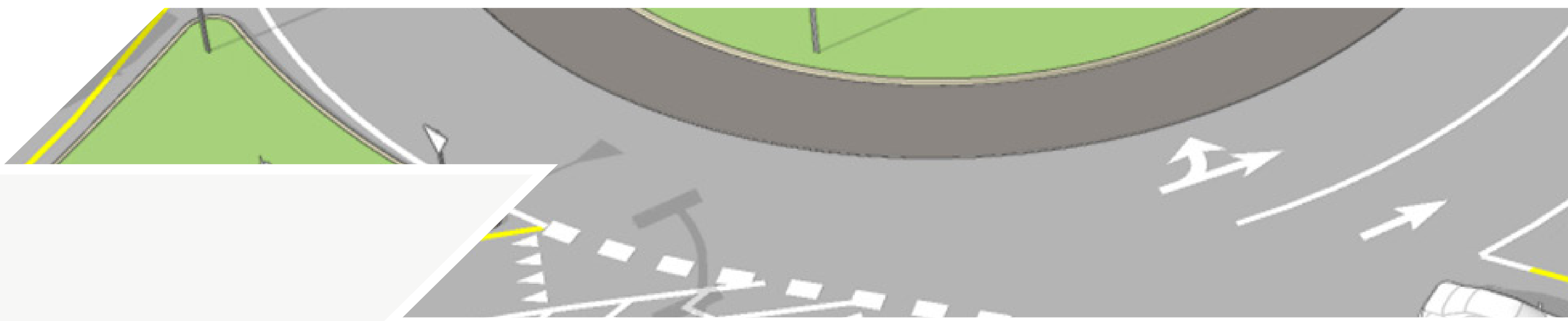

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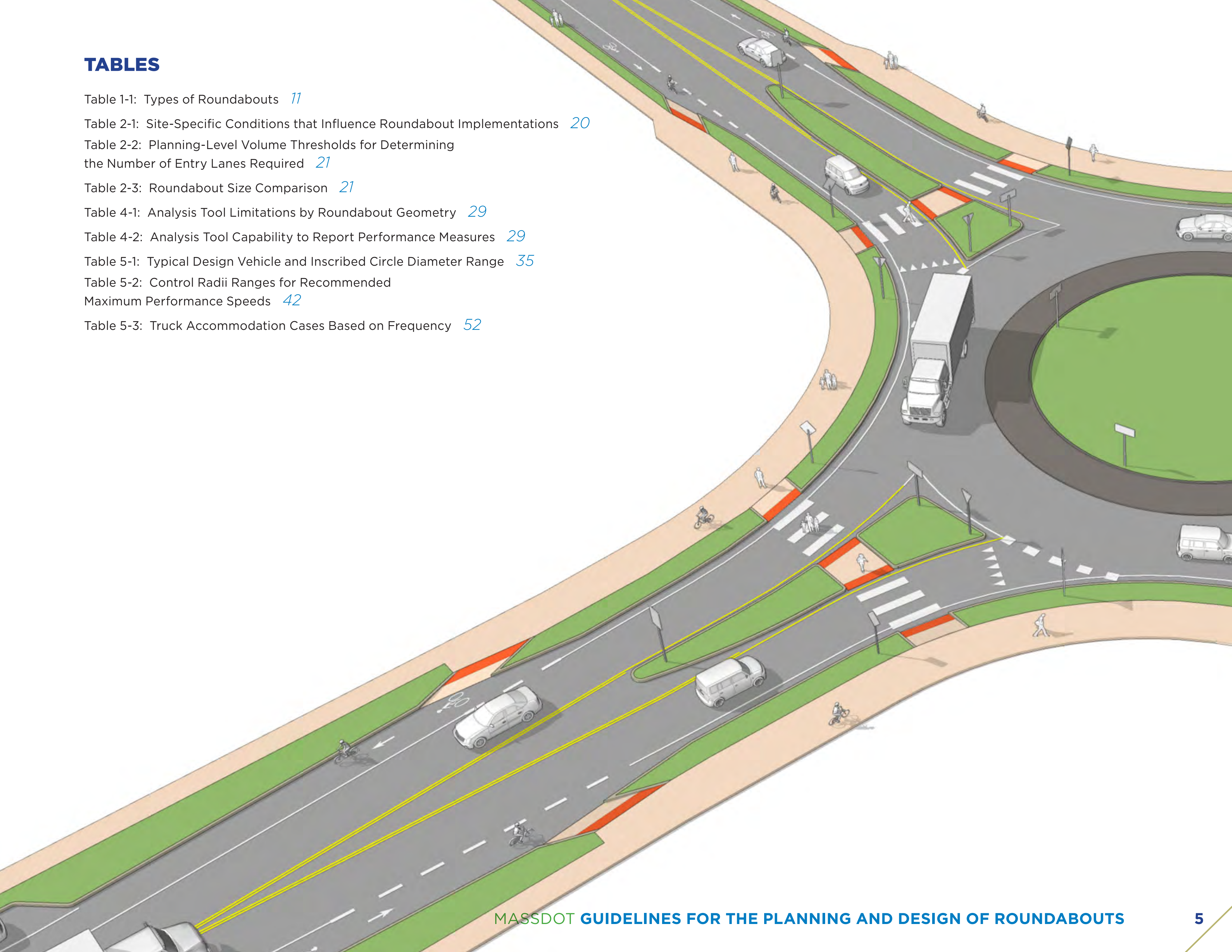


SECTION 1

INTRODUCTION TO ROUNDABOUTS

1 INTRODUCTION TO ROUNDABOUTS

A roundabout is a circular intersection in which traffic travels counterclockwise around a central island and entering traffic must yield to circulating traffic. The geometric features of a roundabout promote slow and consistent speeds for all movements.

1.1 HISTORY OF CIRCULAR INTERSECTIONS

1906

Columbus Circle, the first one-way traffic circle, was constructed in New York City in 1906.

1950

In the United States, traffic circles became larger and evolved into the rotary. Due to later operational and safety concerns with rotaries, these fell out of favor in the 1950s, and state agencies like MassDOT stopped constructing new rotaries.

1966

With the implementation of yield-on-entry (sometimes called off-side priority) In 1966, the roundabout was invented in the United Kingdom, and began spreading through Europe and other Commonwealth nations.

1990

In 1990, the first roundabout was constructed in the United States.

Throughout the 1990s, several states began constructing roundabouts; however, many states did not implement them largely because of the confusion between roundabouts and rotaries and a lack of public support.

First modern roundabout in Massachusetts is constructed at the intersection of Route 149 and Race Lane in the Town of Barnstable, in 1999.

2000

In 2000, the Federal Highway Administration (FHWA) published *Roundabouts an Informational Guide* largely based on international roundabout experience and supplemented with some U.S. knowledge.

Throughout the 2000s, most states began implementing roundabouts, and some states started producing their own design guides.

2010

In 2010, the National Cooperative Highway Research Program (NCHRP) published *NCHRP Report 672, Roundabouts an Informational Guide*, Second Edition, which was based on U.S. experience and knowledge, and adopted by FHWA as the second edition of their 2000 guide.

2020

At the time of publication, 59 roundabouts have been constructed in Massachusetts, and at least 4,600 have been constructed nationwide.

(Source: roundabout.kittelson.com)

1.2 CIRCULAR INTERSECTIONS IN NEW ENGLAND

1.2.1 ROTARIES VS. ROUNDABOUTS

Rotaries and roundabouts are both circular intersections; however, they are designed differently with different operational and safety characteristics. Roundabouts are small traffic circles designed before the intersection to promote slow entry and circulating driving speeds. Lane assignments are designed to avoid lane changing within the roundabout. Rotaries, on the other hand, have much higher entry and circulating speeds, and lane changing is often needed to complete certain movements.

Roundabouts always require entering traffic to yield to circulating traffic; this may not be the case at some rotaries, where the entry movement is a merge, signalized, or sometimes stop controlled. Figure 1-1 shows a roundabout replacing a rotary within the existing footprint of the rotary. Figure 1-2 illustrates the main operational differences between roundabouts and rotaries.

FIGURE 1-1: ROTARY TO ROUNDABOUT CONVERSION IN KINGSTON, NY

Courtesy of NYSDOT

Legacy rotaries and town square circles around Massachusetts allow the following intersection features not typically implemented with a roundabout:

- Stop- or traffic signal-controlled entries
- Pedestrian walkways or amenities in the central island
- Parking within the circulatory roadway

FIGURE 1-2: DIFFERENCES BETWEEN A ROTARY AND A ROUNDABOUT

1.2.2 MASSACHUSETTS ROUNDABOUT EXAMPLES

The following images are examples of roundabouts located in different contexts around the commonwealth:

WORCESTER, WASHINGTON SQUARE
URBAN MULTILANE ROUNDABOUT

LYNN, MARKET SQUARE
FIVE-LEG ROUNDABOUT

BEVERLY, ROUTE 128/BRIMBAL AVENUE/SOHIER ROAD
FREEWAY INTERCHANGE SIDE-BY-SIDE ROUNDABOUTS

NANTUCKET, SPARKS AVENUE/HOOPER FARM ROAD
ROUNDABOUT NEAR FIRE STATION

NORTHAMPTON, US 5/CONZ STREET
TOWN GATEWAY ROUNDABOUT

ADAMS, ROUTE 8/FRIEND STREET/RENFREW STREET
ROUNDABOUT NEAR RAILROAD CROSSING

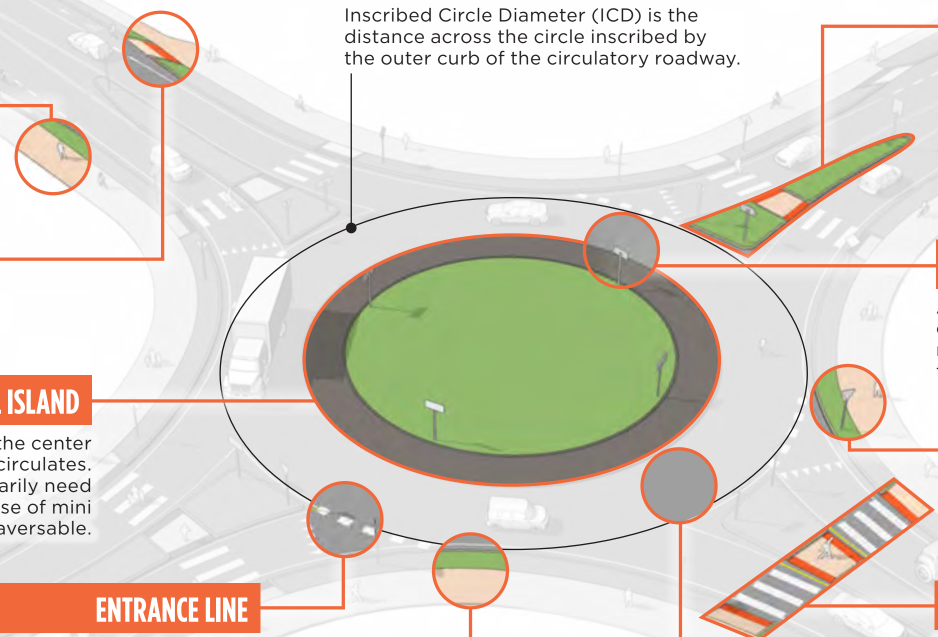
Courtesy of Google Earth

1.3 ROUNDABOUTS

1.3.1 DISTINGUISHING CHARACTERISTICS

Figure 1-3 identifies key roundabout features and describes how each contributes to the functionality of the roundabout. Refer to Section 5 of this guide for further discussion related to each of the design features and dimensions.

FIGURE 1-3: KEY ROUNDABOUT FEATURES



SIDEWALK (CONTEXT BASED)

Sidewalks should connect to existing pedestrian facilities or planned networks.

BIKE RAMP (CONTEXT BASED)

Bicycle ramps should be compatible with the surrounding cycling system or future planned facilities.

CENTRAL ISLAND

The central island is the raised area in the center of a roundabout around which traffic circulates. The central island does not necessarily need to be circular in shape. In the case of mini roundabouts, the central island is traversable.

ENTRANCE LINE

The entrance line marks the point of entry into the circulatory roadway. Entering vehicles must yield to any circulating traffic coming from the left before crossing this line into the circulatory roadway.

WAYFINDING BUFFER

Landscape strips separate people driving and people walking and assist with guiding people walking to the designated crossing locations. This feature is particularly important as a wayfinding cue for individuals who are visually impaired. Landscape strips can also improve the aesthetics of the intersection.

Inscribed Circle Diameter (ICD) is the distance across the circle inscribed by the outer curb of the circulatory roadway.

SPLITTER ISLAND

A splitter island is a raised or painted area on an approach used to separate entering from exiting traffic, deflect and slow entering traffic, and allow pedestrians to cross the road in two stages.

TRUCK APRON

An apron is the traversable portion of the central island adjacent to the circulatory roadway that may be needed to accommodate the wheel tracking of large vehicles.

YIELD SIGN AT ENTRANCES

Entering traffic always yields to circulating traffic at roundabouts.

ACCESSIBLE PEDESTRIAN CROSSINGS

For roundabouts designed with pedestrian pathways, the crossing location is typically set back from the entrance line. A break in the splitter island allows pedestrians, wheelchairs, strollers, and others to pass through. The pedestrian crossings must be accessible with detectable warnings and appropriate slopes in accordance with ADA requirements.

CIRCULATORY ROADWAY

The circulatory roadway is the curved path used by vehicles to travel counterclockwise around the central island.

1.3.2 TYPES OF ROUNDABOUTS

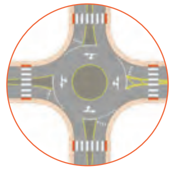


TABLE 1-1: TYPES OF ROUNDABOUTS

DESIGN ELEMENT	MINI-ROUNDABOUT	SINGLE-LANE ROUNDABOUT	MIXED LANES ROUNDABOUT	MULTILANE ROUNDABOUT
Maximum number of circulating lanes	1	1	2*	2*
Typical inscribed circle diameter	45 to 90 feet	90 to 150 feet	120 to 180 feet	135 to 300 feet
Central island treatment	Traversable	Raised with traversable truck apron	Raised with traversable truck apron	Raised with traversable truck apron
Typical daily service volumes on four-leg roundabout	Up to approximately 15,000	Up to approximately 25,000	Up to approximately 35,000 for a two-lane road intersecting a four-lane road	Up to approximately 45,000 for a four-lane road intersecting a four-lane road
Desirable entry speed range	15 to 20 MPH	20 to 25 MPH	20 to 30 MPH	25 to 30 MPH

** Roundabouts can be configured with more than two circulating lanes based on detailed traffic analysis approved by MassDOT.*

1.3.3 ADVANTAGES AND DISADVANTAGES OF ROUNDABOUTS

Policymakers, planners, and designers should consider the following advantages and disadvantages of roundabouts.

ADVANTAGES

NON-MOTORIZED USERS

- People walking must cross only one direction of traffic at a time and and are able to wait in the approach splitter island.
- People biking have the option to negotiate the roundabout in the travel lanes or on a shared-use path, depending on their comfort level.

SAFETY

- Reduce crash severity for all users, allow safer merges into circulating traffic, and provide more time for all users to detect and correct for their mistakes or mistakes of others due to lower vehicle speeds. See Figure 1-4.
- Fewer number of overall conflict points and no left-turn conflicts. See Figure 1-5.

OPERATIONS

- May have fewer delays and shorter queues than other forms of intersection control.
- Minimize the control delay compared with traffic signals during off-peak periods when traffic volumes are low.
- Create possibility for adjacent signals to operate with more efficient cycle lengths where the roundabout replaces a signal that is setting the controlling cycle length.

DISADVANTAGES

NON-MOTORIZED USERS

- People with vision impairments may have trouble finding crosswalks and determining when/if vehicles have yielded at crosswalks and if there are sufficient gaps in traffic.
- Bicycle ramps at roundabouts may be confused with pedestrian ramps.

SAFETY

- Increase in single-vehicle and fixed-object property-only crashes compared to other intersection treatments
- Multilane roundabouts present difficulties for people who are blind or have visual impairments due to challenges in detecting gaps and determining if vehicles have yielded at crosswalks.

OPERATIONS

- Equal priority for all approaches can reduce the progression for high volume approaches.
- Cannot provide explicit priority to specific users (e.g., trains, emergency vehicles, transit, pedestrians) unless supplemental traffic control devices are provided.
- High left-turn movements or a surge in traffic on an approach with low conflicting volume can lead to extensive delays on the adjacent legs.

FIGURE 1-4: PRIMARY CRASH TYPE ALTERATION AT ROUNDABOUTS

Courtesy of Kittelson & Associates, Inc.

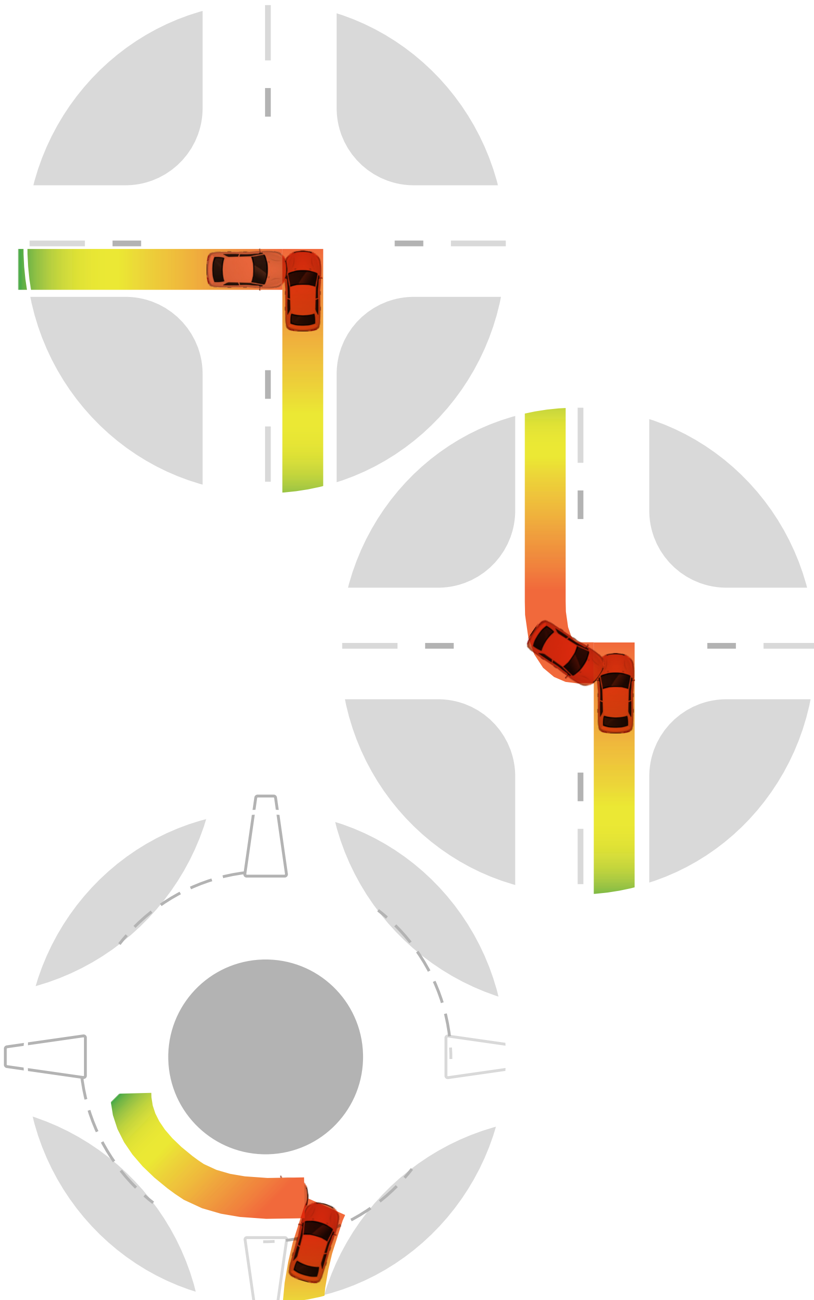
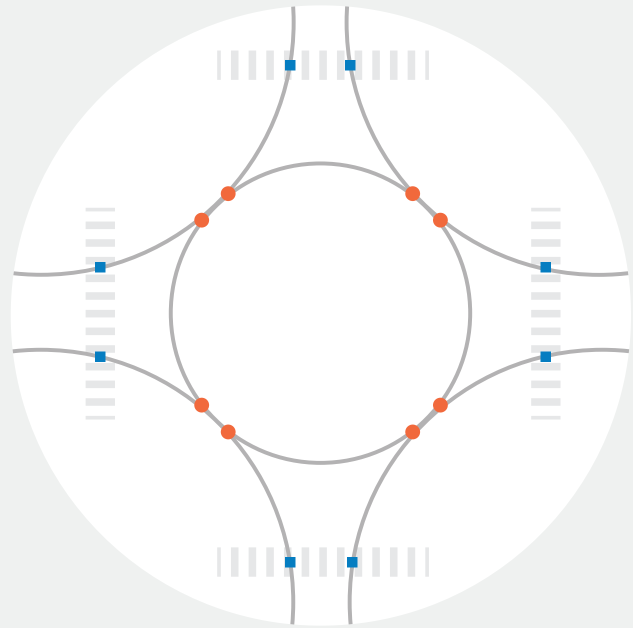


FIGURE 1-5: POTENTIAL CONFLICT POINTS WITHIN AN INTERSECTION

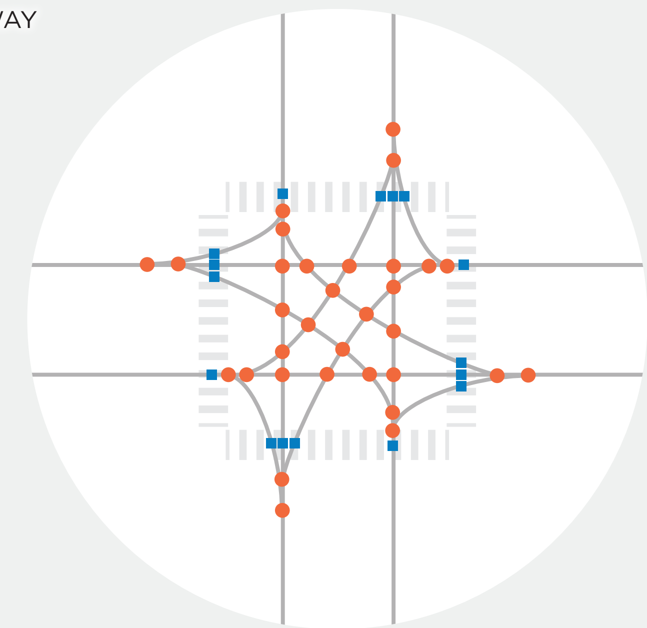
SINGLE-LANE ROUNDABOUT

- 8 Vehicle-to-Vehicle Conflict Points
- 8 Vehicle-to-Pedestrian Conflict Points



TRADITIONAL FOUR-WAY INTERSECTION

- 32 Vehicle-to-Vehicle Conflict Points
- 16 Vehicle-to-Pedestrian Conflict Points



ADVANTAGES

ACCESS MANAGEMENT

- Often require less queue storage space on intersection approaches – can allow for closer intersection and access spacing.
- Roundabout corridors allow easier U-turn movements than traffic signals and make installing raised medians more practical.

ENVIRONMENTAL FACTORS

- Noise, air quality impacts, and fuel consumption may be reduced.
- Fewer stops during off-peak periods

TRAFFIC CALMING

- Reduced vehicular speeds
- Beneficial in transition areas by reinforcing the notion of a significant change in the driving environment

DISADVANTAGES

ACCESS MANAGEMENT

- May reduce the number of available gaps for mid-block unsignalized intersections, driveways, and crosswalks.

ENVIRONMENTAL FACTORS

- Possible impacts to natural and cultural resources due to greater spatial requirements at intersections

TRAFFIC CALMING

- More expensive than other traffic calming treatments

ADVANTAGES

SPACE

- Reduce the roadway cross-section between intersections, including along bridges between interchange ramp terminals.
- Reduce the intersection approaches widths where turning lanes and queue storage are needed with other control types.
- More feasibility to accommodate parking, wider sidewalks, planter strips, wider outside lanes and/or bicycle lanes on the approaches

MAINTENANCE

- No signal hardware or equipment to power and maintain
- Continues to operate at full capacity during power outages

VISUAL QUALITIES

- Provide attractive gateways or centerpieces to communities.
- Used in tourist or shopping areas to separate commercial uses from residential areas.

Adapted from NCHRP Report 672 (4), Exhibit 2-5

DISADVANTAGES

SPACE

- Require more right-of-way at the intersection with the potential loss of trees compared to other types of control.

MAINTENANCE

- May require street lighting maintenance when crosswalks are provided.
- May require pedestrian signal maintenance at multi-lane roundabouts.
- May require landscape maintenance when a large central island is created.

VISUAL QUALITIES

- May alter the character of the area.

1.4 USER CONSIDERATIONS

1.4.1 PEOPLE WALKING

Pedestrian facilities should be provided at all roundabouts that connect to an existing or planned pedestrian network. Roundabouts can offer a safer environment for people walking than traffic signals because the crosswalk is split between the entry and exit lanes, allowing people walking to cross one stream of traffic at a time. Roundabout designs should balance operating speeds between entering, circulating and exiting vehicles. Predictable, slow vehicle speeds are key to yielding compliance at all crosswalks, especially on the exits from roundabouts. People with visual impairments may find navigating roundabouts difficult. They rely on geometric features like the buffer between the roadway and the sidewalk to locate crosswalk ramps and listen to the traffic for opportunities to cross. Installing pedestrian hybrid beacons or raised crosswalks may be necessary to facilitate crossings for people with visual impairments.

1.4.2 PEOPLE BIKING

Roundabouts can be an integral part of high comfort bicycle networks. Roundabouts reduce conflict points, provide higher visibility to people biking, and reduce the speed differential between people biking and people driving. Bicycle facilities at roundabouts should be compatible with the surrounding networks and adjacent land use, both today and in the future. Depending on context and roundabout configuration, people biking may be accommodated in a variety of methods such as:

- In a shared-use path,
- In separated bike lanes, and/or
- In the roadway as a vehicle.

More information is provided in Section 5.4.3.

1.4.3 OLDER AND INEXPERIENCED DRIVERS

Roundabouts may be easier to navigate for less experienced or less confident drivers due to the slower speed. Slower entry and circulating speeds at roundabouts create more opportunities to correctly judge entry and merge gaps. Driver education and the proper use of roundabout advance warning signs and directional signs will help older and inexperienced people driving understand how to navigate a roundabout.

1.4.4 LARGE VEHICLES

The presence of large vehicles on a corridor does not preclude the use of roundabouts but may require special design. A traversable truck apron is used to accommodate large vehicles while minimizing other roundabout dimensions. Traffic data and site observations help guide the selection of an appropriate design vehicle mix for intersection based on observed intersection movements and expected future demands.

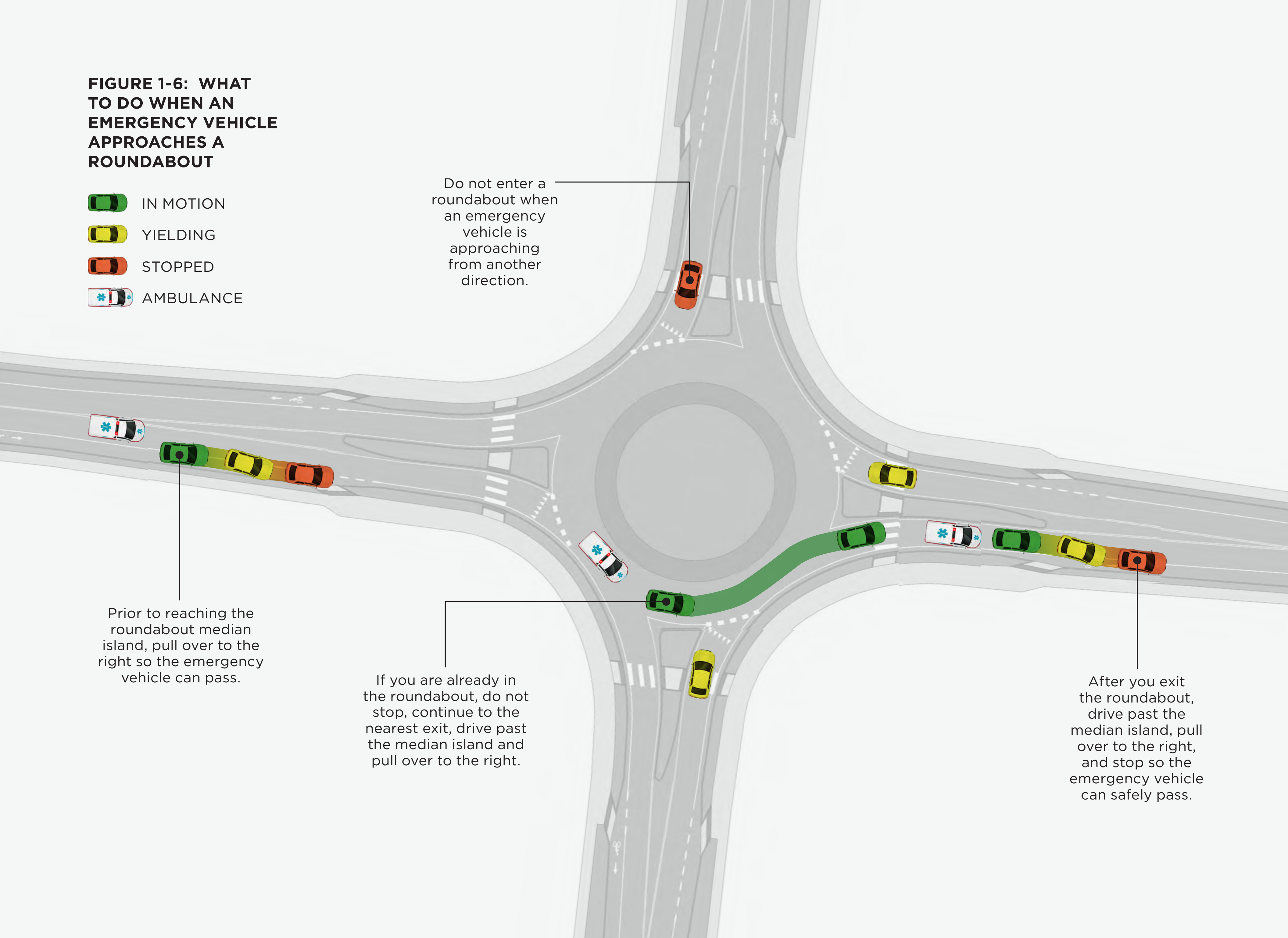
1.4.5 TRANSIT

Transit vehicles can be accommodated at a roundabout through the selection of an appropriate design vehicle. Buses should be able to navigate the roundabout without using the truck apron to minimize passenger discomfort. Bus stop locations should be planned to prevent the potential for vehicle queues to spill back into the circulatory roadway. Bus stops on the far side of the roundabout should have pullouts or be further downstream than the splitter island.

1.4.6 EMERGENCY VEHICLES

Roundabouts should be designed to accommodate emergency vehicles, like other large vehicles. As discussed in *NCHRP 672*, "roundabouts provide emergency vehicles the benefit of lower vehicle speeds, which may make roundabouts safer for them to negotiate than signalized crossings. Unlike at signalized intersections, emergency vehicle drivers are not faced with through vehicles unexpectedly running the intersection and hitting them at high speed" (p. 2-20). As illustrated in Figure 1-6, drivers are directed not to enter a roundabout when an emergency vehicle is approaching on another leg. Drivers already in the roundabout should clear out of the circulatory roadway and proceed beyond the splitter island before pulling over.

FIGURE 1-6: WHAT TO DO WHEN AN EMERGENCY VEHICLE APPROACHES A ROUNDABOUT



SECTION 2

PLANNING

2 PLANNING

The MassDOT PD&DG (8) provides a context-sensitive and multimodal approach to roadway planning and design. This section focuses on roundabout considerations applied to Step II: Planning of the project development process outlined in Exhibit 2-1 of the PD&DG (8).

2.1 PLANNING STEPS

MassDOT promotes the evaluation of roundabouts in the range of alternatives at all intersections where improvements are being considered.

DOES THE NEED FOR THE PROJECT ALIGN WITH ROUNDABOUT OPPORTUNITIES?

Consider design outcomes:

- Operational or safety improvements
- Speed control
- Aesthetic or placemaking upgrades

IS A ROUNDABOUT APPROPRIATE FOR THIS LOCATION?

Consider the context of the intersection. Section 2.2 provides guidance on site-specific conditions under which the use of a roundabout is challenging or straightforward.

WHAT SIZE SHOULD THE ROUNDABOUT BE?

Section 2.3 provides guidance on determining the preliminary number of lanes based on capacity requirements. Section 4 provides additional detail on operational analysis. Table 2-3 provides a range of roundabout diameters used to assess the right-of-way space needed.

HOW DOES THE ROUNDABOUT COMPARE TO THE OTHER INTERSECTION TREATMENTS?

Use Intersection Control Evaluation (ICE) tools. Section 4.3 provides guidance on determining the life cycle costs and safety impact of each treatment.

WHAT ARE THE POTENTIAL CHALLENGES?

Consider potential challenges:

- Right-of-way
- Utilities
- Existing buildings/structures
- Business access
- Historic sites or features
- Healthy Mature Trees
- Sensitive environmental areas

WHAT ARE THE OPPORTUNITIES?

Consider potential opportunities:

- Improves access management
- Stimulates redevelopment
- Improves safety
- Improves conditions for people walking and biking
- Improves oddly shaped intersection or other poor geometric condition

IS A ROUNDABOUT FEASIBLE AND THE PREFERRED ALTERNATIVE?

- Consider engaging the public and key stakeholders to collect additional input and provide more information about roundabouts.
- Perform more detailed analysis and functional design.

2.2 CONTEXT

Each individual location has its own unique characteristics, issues, and objectives for improvement that influence the choice between traffic control alternatives. Roundabouts offer benefits under many circumstances; however, they may also be more complicated to implementcompared to other control types. The site-specific characteristics of a given intersection, shown in Table 2-1, should be considered when assessing the feasibility of a roundabout. Sites or conditions that are not advantageous for constructing roundabouts can also be problematic for other intersection alternatives; therefore, these conditions should not be considered a fatal flaw test.

TABLE 2-1: SITE-SPECIFIC CONDITIONS THAT INFLUENCE ROUNDABOUT IMPLEMENTATIONS

SITES WHERE ROUNDABOUTS ARE OFTEN ADVANTAGEOUS	SITES WHERE ROUNDABOUTS MAY NOT BE ADVANTAGEOUS
• Intersections with documented safety concerns • Intersections with relatively balanced traffic volumes • Intersections with a high percentage of turning movements, particularly left turns • Intersections with high traffic volumes at peak hours but relatively low traffic volumes during non-peak hours • Existing two-way stop controlled intersections with high side-street delays (particularly those that do not satisfy signal warrants) • Intersections that must accommodate U-turns • Intersections at a gateway or entry point to a campus, neighborhood, commercial development, or urban area • Intersections where a community enhancement may be desirable • Intersections or corridors where traffic calming is a desired outcome of the project • Intersections where widening the approaches may be difficult or cost prohibitive, such as at bridge terminals • Intersections with five or more approaches • Locations where the speed environment of the road changes (for instance, at the fringe of an urban environment) • Locations with a need to provide a transition between land use environments (such as between residential and commercial uses) • Roads with excessive speed problems, where cars routinely exceed the posted or target speed	• Intersections near a signalized intersection where queues may spill back into the roundabout • Intersections located within a coordinated arterial signal system • Intersections with a heavy flow of through traffic on the major street opposed by relatively light traffic on the minor street • Intersections with a heavy concentration of pedestrians and bicyclists • Intersections that regularly serve oversize/overweight (OSOW) vehicles • Intersections with acute angles between approaches • Locations with unfavorable topography that may limit visibility • Intersections adjacent to buildings or other structures • Intersections adjacent historically significant or sensitive sites • Intersections where significant habitat or otherwise significant landscape would be adversely affected

2.2.1 SITE SPECIFIC CONDITIONS

It is important to understand the site environment in which a roundabout is proposed. Key factors include:

- Constraints including right-of-way, utilities, structures, environmental issues, etc. that may impact the space available. Roundabouts often require more property at the corners of existing intersections; however, they can result in less widening of approach roadways than signalized intersections.
- Roundabout location and user population. Is the intersection in a rural or urban environment? Will the roundabout have frequent pedestrian and/or bicycle activity? The roundabout design should support all intended modes of travel.
- Issues that make it difficult for other types of traffic control (e.g., acute angles and challenging vertical profiles) can also be difficult with a roundabout.

2.2.2 PUBLIC EDUCATION & AWARENESS

- Include adequate time for public awareness. Roundabouts introduced into new areas may require additional effort to inform the public about roundabouts and the proper way to use them.
- Consider the local history related to other traffic circles, including rotaries and downtown traffic circles, and build in time and effort to inform the public and other key stakeholders about the differences between traffic circles, rotaries, and roundabouts.

2.3 PLANNING-LEVEL SIZING & SPACE REQUIREMENTS

One of the first steps in examining the feasibility of a roundabout is determining the preliminary lane configuration. This is determined based on the number of entry lanes needed on each approach to serve the design traffic volumes. Section 3.4.1 of the PD&DG (8) discusses how to select a design year. **A roundabout design horizon should be between 15 and 25 years given the high capital investment**. The number of circulatory lanes required is then set to accommodate the entry lanes. Roundabouts are typically identified in terms of the number of circulatory lanes (i.e. single-lane or multilane).

Table 1-1 provides daily traffic volume ranges that help select or reject a roundabout as a viable option in the early stages of the decision-making process. Table 2-2 provides additional planning-level lane requirements based on ranges of entering and conflicting circulating volumes.

TABLE 2-2: PLANNING-LEVEL VOLUME THRESHOLDS FOR DETERMINING THE NUMBER OF ENTRY LANES REQUIRED

SUM OF ENTERING AND CIRCULATING VEHICLES	NUMBER OF LANES REQUIRED
0 to 1,350 vehicles per hour	• Single-lane entry likely to be sufficient
1,350 to 1,800 vehicles per hour	• Two-lane entry may be needed • Single-lane may be sufficient based upon more detailed analysis
1,800 to 2,600 vehicles per hour	• Two-lane entry likely to be sufficient
Above 2,600 vehicles per hour	• More than two entering lanes may be required • A more detailed capacity evaluation should be conducted to verify lane numbers and arrangements

Note: Operational analysis needed to verify upper limit for specific applications or for roundabouts with more than two lanes or four legs.

Table 2-3 provides a range of inscribed circle diameters (ICD) for each category to assist in estimating the size of the roundabout footprint and create a preliminary assessment of right-of-way impacts.

TABLE 2-3: ROUNDABOUT SIZE COMPARISON

DESIGN VEHICLE	MINI-ROUNDABOUT	SINGLE-LANE ROUNDABOUT	MULTILANE ROUNDABOUT*
SU-30	60-foot ICD	90-foot ICD	120-foot ICD
WB-50	90-foot ICD	105-foot ICD	150-foot ICD
WB-67	90-foot ICD	130-foot ICD	165-foot ICD

** Assumes two entry lanes on four approaches.*

Note: All values assume 90-degree angles between entries and no more than four legs. List of possible design vehicles not all-inclusive.

Source: NCHRP Report 672 (4)

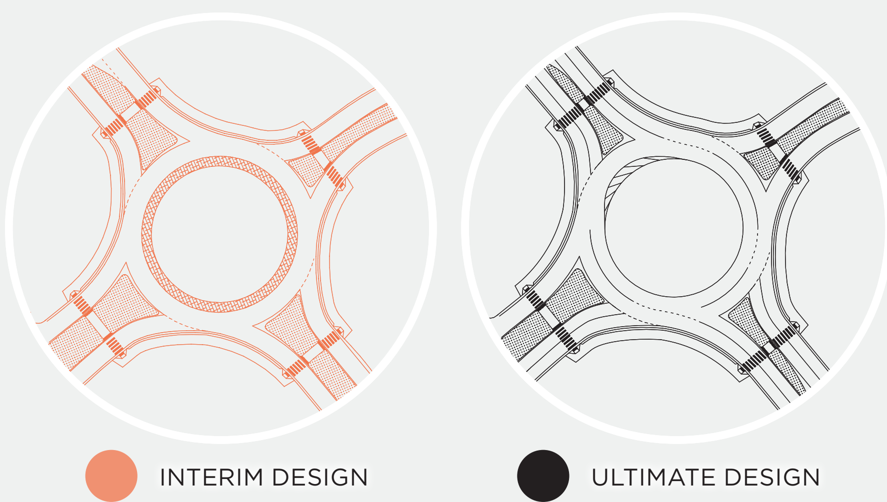
2.4 PHASED BUILD-OUT APPROACH

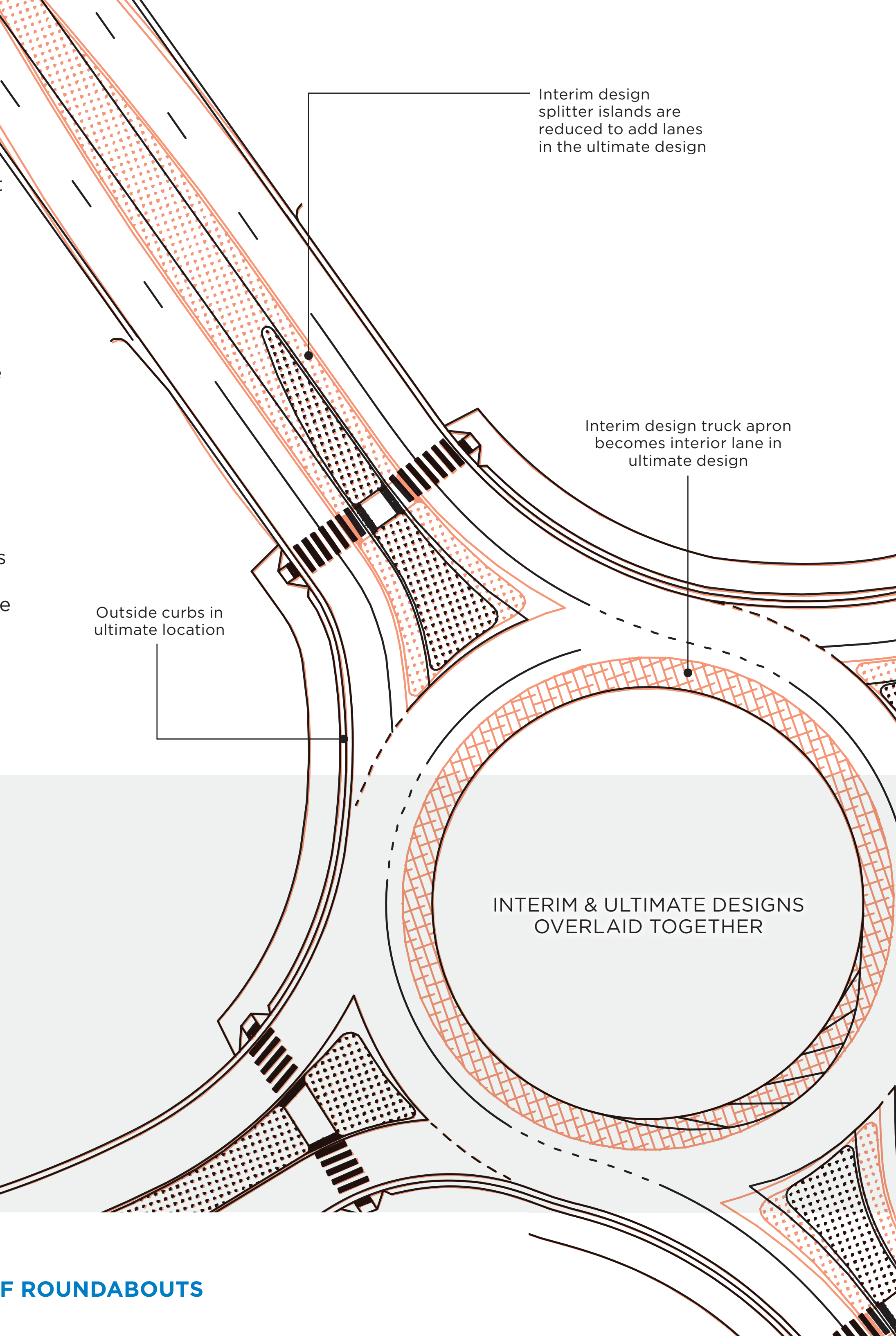
Overbuilding roundabouts and providing multilane configurations without the corresponding traffic volumes can increase crash frequency. Multilane designs reduce crash severity compared to a signalized intersection but have more conflicts than single-lane configurations. Larger diameters of multilane configurations and wider entries and exits can result in higher speeds compared to single-lane configurations. As a result, many agencies, including Massachusetts, are using a phased build-out design approach to roundabout construction. Section 5.3.3.3 of the PD&DG (8) provides flexibility in selecting the design year number of lanes to provide sidewalks, landscape buffers, bicycle lanes, and crossing islands.

At a phased build-out approach, the ultimate design is established to set the outside curb lines, drainage inlets, and sidewalks during the original construction. Then, the design is modified to remove lanes from the interior by widening splitter islands or extending truck aprons. This allows the roundabout to open in a configuration that satisfies opening-year traffic volumes. Operating with fewer lanes reduces conflicts, allows local drivers to become familiar with a single-lane roundabout design, and supports a potential future expansion. Figure 2-1 displays an example of a roundabout designed to accommodate future year volumes with an interim design to accommodate existing volumes.

FIGURE 2-1: INTERIM AND ULTIMATE ROUNDABOUT DESIGNS

Adapted from NCHRP Report 672 (4), Exhibit 6-92





SECTION 3

STAKEHOLDER & PUBLIC OUTREACH

3 STAKEHOLDER & PUBLIC OUTREACH

Public outreach is essential throughout the project development process and should be integrated into every task. As part of the public outreach process, stakeholders should be identified early, and the outreach process should be initiated as soon as practical while other intersection designs are also being considered.

Feedback garnered from the outreach process must be used in further design and analysis to refine alternatives and gain public acceptance. It must be emphasized that the outreach process does not end until the project has been implemented and the intersection is operating satisfactorily.

The Project Development & Design Guide outlines efforts to encourage public outreach throughout planning, design, environmental review, and construction so that those affected by transportation projects understand the project's need, the selected approach to meet this need, and the refinements to the project that result as the process evolves.

This section discusses timing and outreach tools and methods when a roundabout is being considered in the process.

3.1 OUTREACH TIMING

Early outreach is key when implementing new or unfamiliar infrastructure, including roundabouts.

3.1.1 COLLECT INPUT

The initial outreach should be focused on collecting input from users to help identify problems, needs, and opportunities. Understanding the needs of the users will help the project team decide if a roundabout is the best solution. When moving forward with design and implementation of a roundabout it should be communicated what input was received and how the roundabout is meeting these needs.

3.1.2 ROUNDABOUT EDUCATION OUTREACH

Unlike traditional intersection projects, roundabouts require additional educational outreach to help users understand how and why the roundabout was selected and how they will navigate the roundabout once it is built. The education phase of the outreach should begin as soon as a roundabout is being considered. Making sure that stakeholders and the public understand how a roundabout operates allows them to provide informed input during the project selection phase.

Educational outreach materials should illustrate how different users navigate and benefit from the roundabout. Key groups that should be targeted during this education phase include:

- People who bike
- People who walk
- People with mobility or visual impairments
- Older people who drive
- Freight/maintenance operators
- Transit operators/agencies
- Emergency services providers

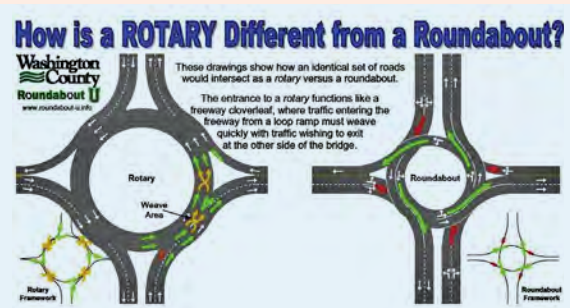
Example education materials for these groups is available through Massachusetts Department of Transportation webite at Mass.gov.

3.2 OUTREACH METHODS & TOOLS

The selection of which methods will be used to convey information to different groups of stakeholders is vital. The effectiveness of each of these methods depends on the type of stakeholder and timing of the project. Because each stakeholder is affected differently, it may be prudent to use more than one method to convey information.

PRINTED MATERIALS

- Flyers/brochures (useful in creating general awareness of roundabouts)
- Media engagement (useful in creating general awareness of roundabouts)
- Kids' workbooks (useful in creating general awareness of roundabouts)
- 3D models (useful in communicating with people with visual disabilities)



VIRTUAL MATERIALS

- Presentations (convey more details about roundabouts or a specific project)
- Social media (engage the community and allow feedback)
- Videos and simulations (useful in explaining how roundabouts are used)
- Online surveys (gather specific input at the project level)

IN-PERSON TRAINING

- Mock roundabouts (scaled plots that can be used with toy vehicles)
- Roundabout rodeos (closed-course driving exercises on full size roundabout setups)
- Walking/biking tours (group tours of existing roundabouts)
- Kids' activities (children's group tours of roundabouts or playing activities on scaled models)

FHWA has developed the Roundabout Outreach and Education Toolbox, an online reference that connects transportation professionals with outreach resources from across the country to help them obtain public support for roundabouts. The search portal includes:

CASE STUDIES OF OUTREACH SUCCESS STORIES

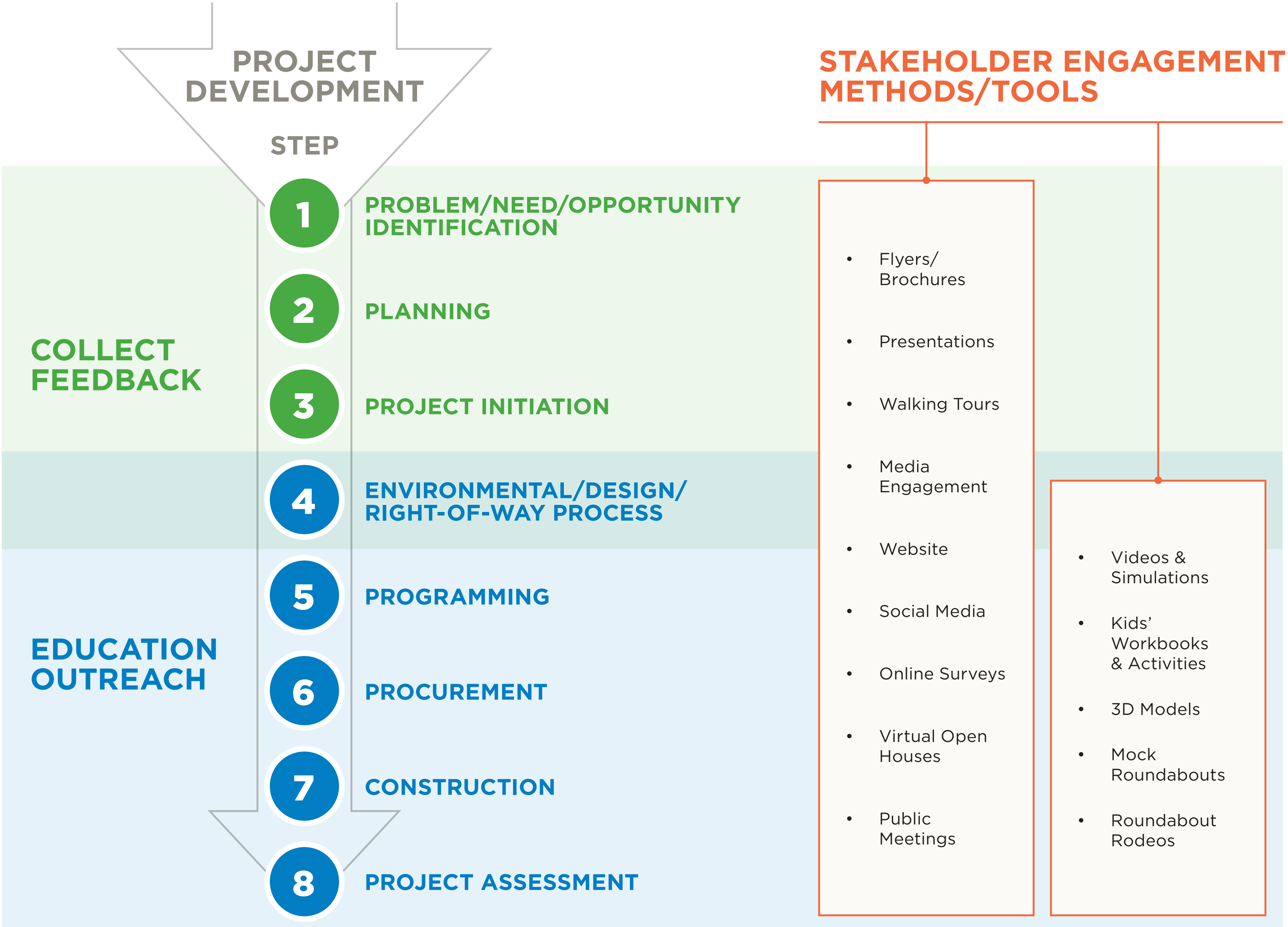
OUTREACH IMPLEMENTATION GUIDANCE

PRODUCTS INCLUDING PRESENTATIONS, VIDEOS, AND BROCHURES

MassDOT prepared a presentation with an overview of roundabouts and frequently asked questions. This material is available online as a starting point to a roundabout information campaign.

Figure 3-1 presents the types of stakeholder engagement methods or tools that should be considered throughout the project development process.

FIGURE 3-1: STAKEHOLDER ENGAGEMENT TOOLS BY PROJECT DEVELOPMENT STEP



The Project Development Steps are consistent with PD&DG Exhibit 2-1.

SECTION 4

ANALYSIS

4 ANALYSIS

4.1 OPERATIONS ANALYSIS

Typically, the analysis level of detail increases as a roundabout study progresses. Initially, only a rough analysis using the planning-level techniques discussed in Section 2.3: Planning-Level Sizing & Space Requirements may be necessary to determine the roundabout type (number of lanes). Individual roundabout approach lane configurations should be confirmed by conducting operational analysis using deterministic or simulation software.

4.1.1 PERFORMANCE MEASURES

MassDOT uses the following key performance measures to evaluate roundabout operations:

1

VOLUME-TO-CAPACITY RATIO

Volume-to-capacity (V/C) ratios are the primary measure of effectiveness for evaluation. V/C ratios for roundabouts are calculated based on the entry demand and capacity for the most critical approach (i.e. approach with the highest v/c ratio) for single-lane roundabouts and the most critical lane (i.e. individual lane with the highest v/c ratio) for multilane roundabouts. A V/C ratio under 1.0 during the design year is desired, but other factors like queuing, delay, and potential safety implications need to be considered.

2

DELAY

Delay is a standard parameter used to measure the performance of an intersection. Control delay is the standard measure used in the *Highway Capacity Manual (HCM)* (6) to represent the delay component of a roundabout performance, as it is the same measure used to represent the delay for other types of intersections. Vehicular delay can also be used to estimate emissions that result from various forms of intersection control.

3

QUEUE LENGTH

Queue length is important for assessing the adequacy of the geometric design of the roundabout approaches and potential interactions with adjacent intersections. The 95th percentile queue length is determined to estimate the design queue for a given lane. The queue length should be checked against available storage to assess potential interactions with adjacent lanes and intersections. Average queue lengths should be reported for all approaches to gain an understanding of typical vehicular stacking.

These three performance measures should be assessed for each lane and approach, and the intersection as a whole during all relevant analysis periods. The results can be used to compare two or more roundabout configuration options or additional intersection control treatments.

4.1.2 ROUNDABOUT OPERATIONS MODELS

Highway Capacity Manual, 6th Edition (HCM 6) (6) provides an analytic method for assessing the operations of a roundabout and is based on the largest and most recent sample of roundabout data collected in the United States at the time of writing. The method is applicable to existing or planned one- or two-lane roundabouts given traffic demand levels. The *HCM 6* (6) roundabout operations model provides techniques for calibrating the model to local conditions using locally collected followup time data where available. MassDOT preference is to use the *HCM 6* (6) roundabout operations model for all roundabout projects in Massachusetts.

4.1.3 OPERATIONS ANALYSIS TOOLS

Analysis tools should be consistent with the methodologies described in the *HCM 6* (6), either by implementing the *HCM* method directly or by calibration to the field data underlying the *HCM* method. At this time, MassDOT accepts the following software methods for conducting screening and performance analysis at roundabouts:

- Capacity Analysis for Planning of Junctions (CAP-X) Tool (screening only)
- Highway Capacity Software (HCS)
- Spreadsheet tools incorporating the *HCM 6*, namely Georgia Department of Transportation (GDOT) Roundabout Analysis Tool 4.2 or newer
- SIDRA software package, US *HCM 6* mode (SIDRA)
- Traffic simulation software packages, namely VISSIM (calibrated to latest US data from FHWA or Highway Capacity Committee)

There are advantages and considerations associated with each analysis tool; therefore, the onus is on the analyst to select the appropriate tool and show compliance with *HCM* methodologies. Discussions with MassDOT on a case-by-case basis can help guide this selection. Table 4-1 and Table 4-2 provide a overview of analysis tool limitations and capabilities.

TABLE 4-1: ANALYSIS TOOL LIMITATIONS BY ROUNDABOUT GEOMETRY

GEOMETRY	HCS	GDOT	SIDRA	VISSIM
≥4 Int legs	Yes	Yes	Yes	Yes
2 entry/circ lanes	Yes	Yes	Yes	Yes
<4 Int legs	No	Yes	Yes	Yes
3 entry/circ lanes	No	No	Yes	Yes
Closely spaced intersections	No	No	Yes	Yes
Roundabout corridors	No	No	Yes	Yes

TABLE 4-2: ANALYSIS TOOL CAPABILITY TO REPORT PERFORMANCE MEASURES

PERFORMANCE MEASURES	HCS	GDOT	SIDRA	VISSIM
Volume-to-capacity ratio	Yes	Yes	Yes	Yes
Delay	Yes	Yes	Yes	Yes
Average (50%) queue	No	Yes	Yes	Yes
Peak (95%) queue	Yes	Yes	Yes	Yes

4.1.4 MICROSIMULATION

Microsimulation provides an option for analyzing roundabouts in unique or special circumstances. Roundabout analysis should always begin with the use of deterministic tools, and advance into microsimulation only after consultation with MassDOT staff. Appropriate calibration parameters need to be determined in consultation with MassDOT staff prior to proceeding with microsimulation. Situations in which microsimulation may be appropriate include:

- Closely spaced intersections (other roundabouts, traffic signals, or unsignalized intersections)

  IF THE 95TH-PERCENTILE QUEUE FROM AN ADJACENT INTERSECTION EXCEEDS 80% OF DISTANCE BETWEEN THE INTERSECTIONS, THE SYSTEM SHOULD BE MODELED WITH MICROSIMULATION SOFTWARE.

- Metering of an approach
- Corridors of roundabouts – three or more roundabouts
- On-street parking where maneuvers may impact roundabout operations
- Rail crossings in close proximity to roundabouts or through the roundabout
- Roundabouts with more than two circulating lanes
- Visualization for public involvement

Simulation models are sensitive to factors at an individual vehicle level, such as car following behavior and gap acceptance. Therefore, care should be taken to apply the simulation model appropriately. If simulation is used, the preferred model for MassDOT is VISSIM. MassDOT best practices for modeling roundabouts in VISSIM should be followed to ensure consistent and reproducible application of the roundabout microsimulation.

4.2 SAFETY ANALYSIS

4.2.1 PERFORMANCE MEASURES

Research over the past decades of U.S. roundabouts led to the development of empirical based safety performance functions (SPF) and crash modification factors (CMF) that can predict the changes in crashes experienced at a roundabout. An SPF is an equation used to predict the average number of crashes per year at a location as a function of exposure (traffic volumes) and, in the case of roundabout evaluation, the number of entering and circulating lanes. SPFs are used alone or in conjunction with the crash history to estimate the long-term crash frequency for baseline conditions (without treatment), and CMFs are applied to estimate the crashes with treatment as shown in the equation below.

Predicted Crashes WITH Treatment
= CMF × Predicted Crashes WITHOUT Treatment

The outcome of crash predictions using either SPFs or CMFs are reported as total crashes per year and crashes resulting in injury or fatalities per year. The results of a roundabout crash rate prediction should be compared with historical averages or other intersection treatments to determine its viability. Lower rates in annual crashes or crashes resulting in injury or death are good measures of safety improvement.

4.2.2 ROUNDABOUT SAFETY MODELS

MassDOT calibrated a state-specific Safety Performance for Intersection Control Evaluation (SPICE) tool. This macro-powered Excel spreadsheet modeled on FHWA Office of Safety's tool enables users to select intersection control strategies including roundabouts, provide basic information such as annual average daily traffic (AADT) and the number of lanes, and receive planning-level predictive safety analysis for each control strategy. Roundabout crash predictions can only be calculated based on historic information collected at existing stop controlled or signalized intersections. A full *Highway Safety Manual (HSM)* (7) analysis is also available with more detailed information based on roundabout SPFs developed by NCHRP Project 17-70: Development of Roundabout Crash Prediction Models and Methods.

4.3 LIFE CYCLE COST ANALYSIS

A life cycle cost analysis allows for a consistent framework for comparing outcomes between intersection control devices by assigning dollar values to monetize outcomes. The results are more understandable by decision-makers and the general public compared to traditional performance measures and take into account benefits not often included in analyses, such as safety benefits, and off-peak delay. MassDOT provides an Intersection Control Evaluation (ICE) tool allowing for the comparison of alternative intersection designs based on initial construction costs, ongoing maintenance and operations costs, and safety effects.

SECTION 5

DESIGN

5 DESIGN

5.1 DESIGN PRINCIPLES

Roundabout design principles are consistent with those of other intersection types. The designer must consider the project context and provide geometry and traffic control devices appropriate for that context. The following principles should guide roundabout design development and are based on the principles outlined in *NCHRP Report 672, Roundabouts: An Informational Guide, Second Edition* (4):

- ROUNDABOUT TYPE & LANE CONFIGURATION - Provide the commensurate number of lanes and lane assignment to achieve target capacity, lane volume balance, and lane continuity considering near-term and long-term needs.
- NON-MOTORIZED USERS - Integrate the needs of people walking and people biking at the earliest stages of conceptual design.
- DESIGN VEHICLE - Select design vehicle sizes based on each approach context and accommodate their movements within the entry, exit, and circulatory roadways.
- SPEED CONTROL - Provide slow entry speeds and consistent speeds through the roundabout and between conflicting movements.
- SIGHT DISTANCE, VISIBILITY, & VIEW ANGLES - Provide sight distance and visibility for driver recognition of the intersection and conflicting users commensurate with approach and circulating speeds.
- PATH ALIGNMENT - Provide intuitive, conspicuous channelization that naturally directs vehicles to intended lanes.

Figure 5-1 illustrates a general roundabout design process.

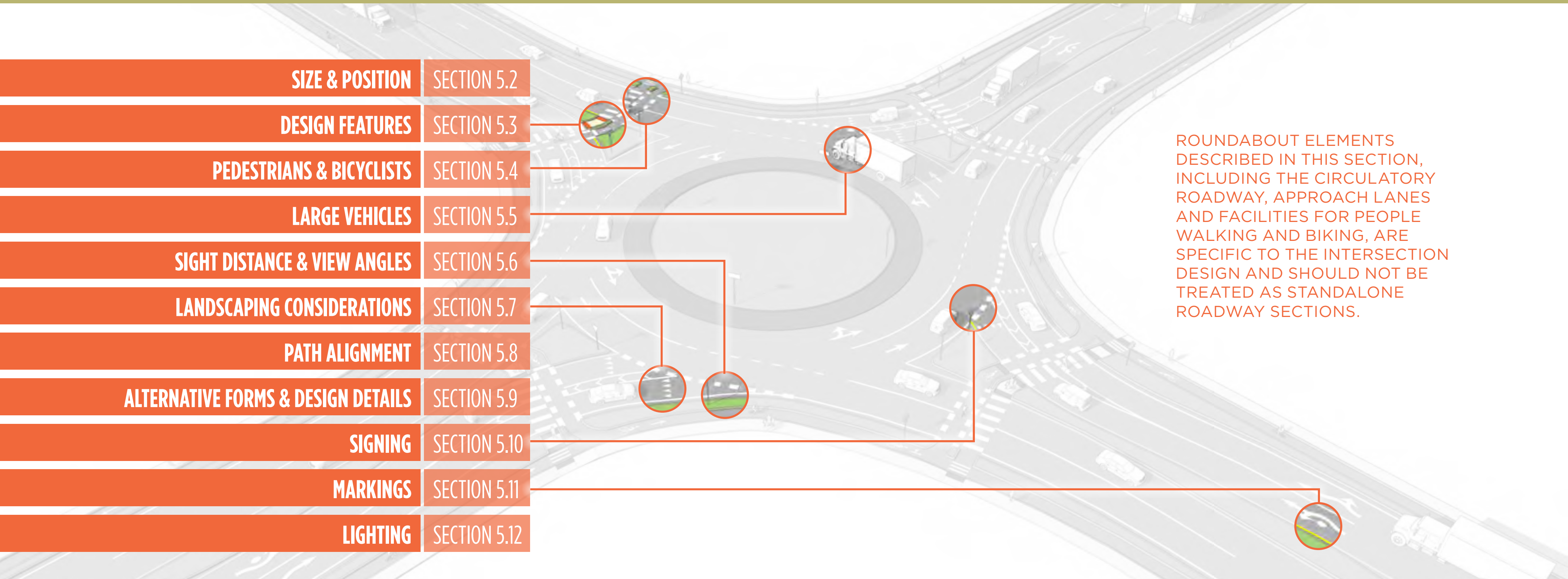
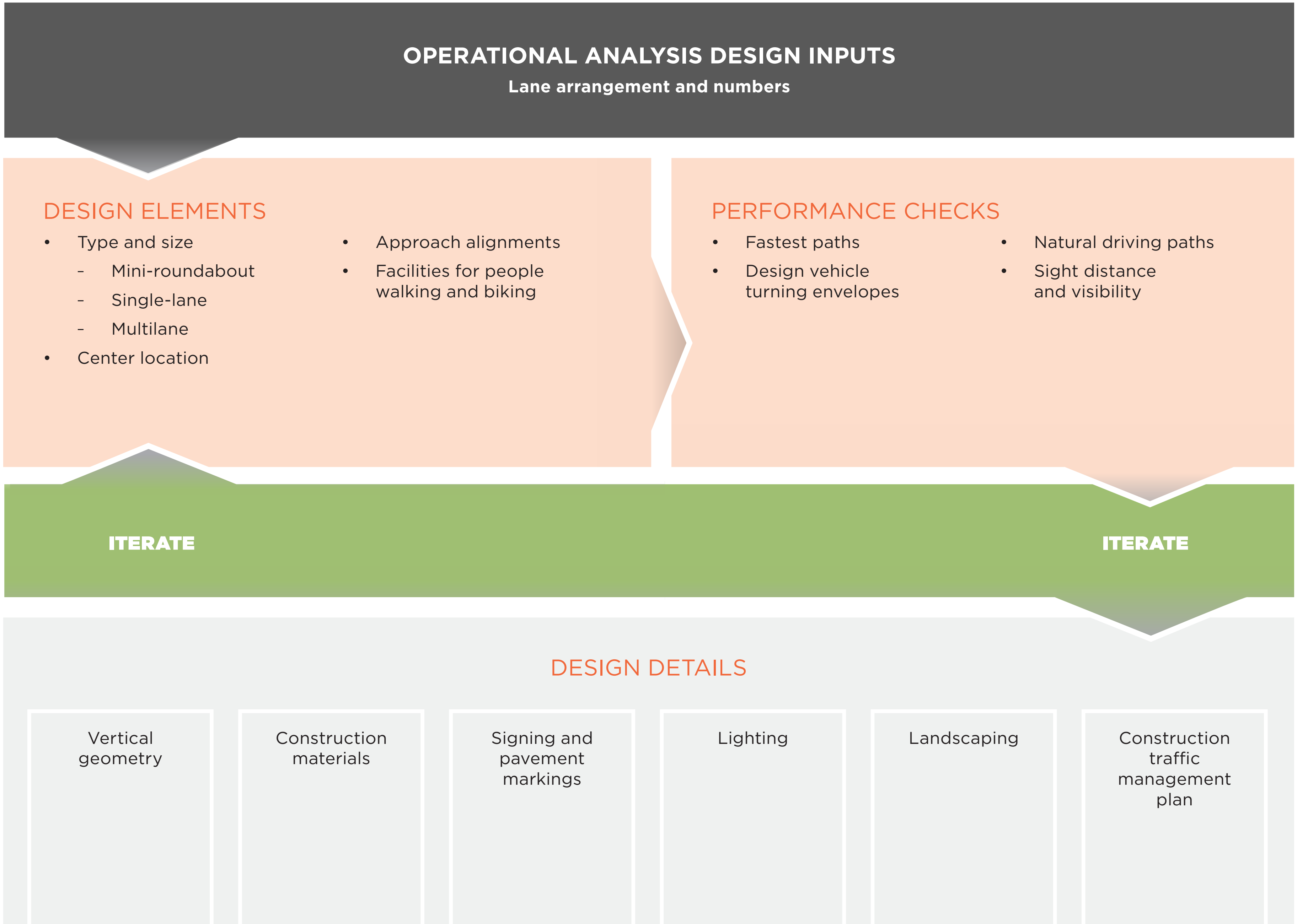


FIGURE 5-1: DESIGN PROCESS



5.2 SIZE & POSITION

5.2.1 INSCRIBED CIRCLE DIAMETER

The inscribed circle diameter (ICD) is the diameter of the roundabout measured from the outer edge of traveled way and is one of the first design elements to consider in roundabout planning and design. The ICD dimension is typically influenced by the design vehicle, lane number and arrangements, approach geometry, and site constraints. The ICD and features outside the ICD should be established early in the roundabout design, as adjusting the ICD can result in a complete redesign. Table 5-1 lists typical design vehicles and ICD ranges for mini, single lane, and multilane roundabouts. The final ICD is affected by the number of intersection legs and skew between approaches.

TABLE 5-1: TYPICAL DESIGN VEHICLE AND INSCRIBED CIRCLE DIAMETER RANGE

	ICD RANGE (FEET)	DESIGN VEHICLE
Mini-Roundabout	45 to 90	SU-30
Single-lane Roundabout	90 to 150	B-40
	105 to 150	WB-50
	130 to 180	WB-67
Multilane Roundabout	150 to 220	WB-50
	165 to 220	WB-67

Note: Assumes 90-degree angles between entries and no more than four legs. List of possible design vehicles not all-inclusive.

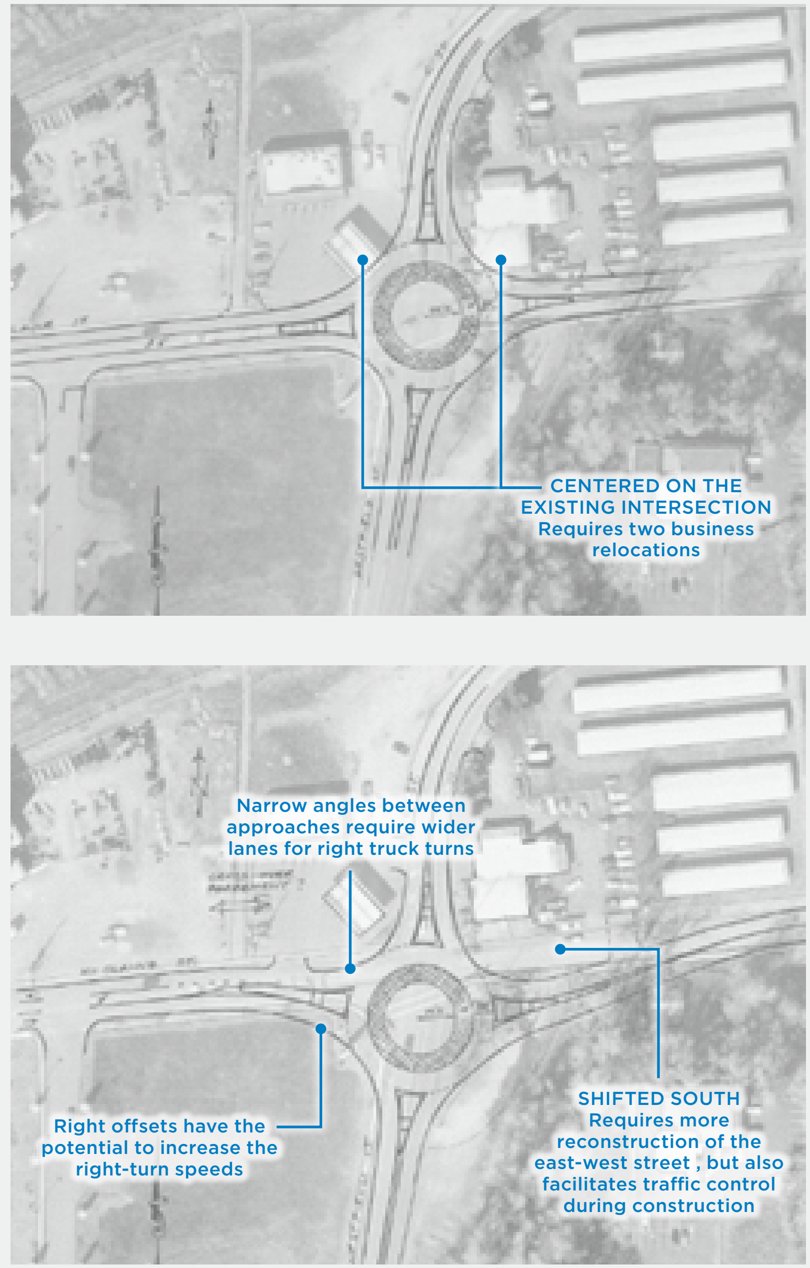
While the ICD is an input in the design process, the final size of the ICD is an outcome of meeting the performance objectives of the roundabout. As a result, ICDs can vary from roundabout to roundabout, as each site has its own unique opportunities and constraints.

5.2.2 CENTER POSITION

The roundabout position influences many aspects of the roundabout performance, including entry speeds, design vehicle accommodations, pedestrian and bicycle accommodations, and view angles. The roundabout position can be affected by the availability of right-of-way in certain parcels, the potential alignment of the approaches, and ability to provide speed control on the roundabout entries. Figure 5-2 displays potential options for positioning the same-sized roundabout at an intersection. In each scenario, the approach geometry has been modified to achieve performance objectives. Designers should also consider how traffic flows and large trucks are accommodated during construction before finalizing the roundabout position. Constructing more of the future geometry off the existing alignment simplifies the temporary traffic control plans.

FIGURE 5-2: POTENTIAL OPTIONS FOR POSITIONING A ROUNDABOUT AT AN INTERSECTION

Adapted from NCHRP Report 672 (4), Exhibit 6-8



5.2.3 NUMBER OF LANES

Roundabout design is influenced by the number and arrangement of entering, circulating, and exiting lanes; and is an outcome of the design year traffic analysis. The number of entry, circulating, and exit lanes may vary throughout the roundabout to serve localized travel patterns. In these cases, the shape of the central island, ICD, or splitter islands may be adjusted. Figure 5-3 illustrates two circulating lanes in the southbound direction, while the remaining movements are accommodated by a single circulating lane.

5.2.3.1 RIGHT-TURN BYPASS LANES

Right-turn bypass lanes can improve traffic operations on approaches with a high volume of right-turning traffic. They may allow a single-lane roundabout approach to continue to function acceptably to avoid upgrading to a multilane roundabout. Right-turn bypasses increase conflicts with people walking and biking, and create at least one additional roadway crossing.

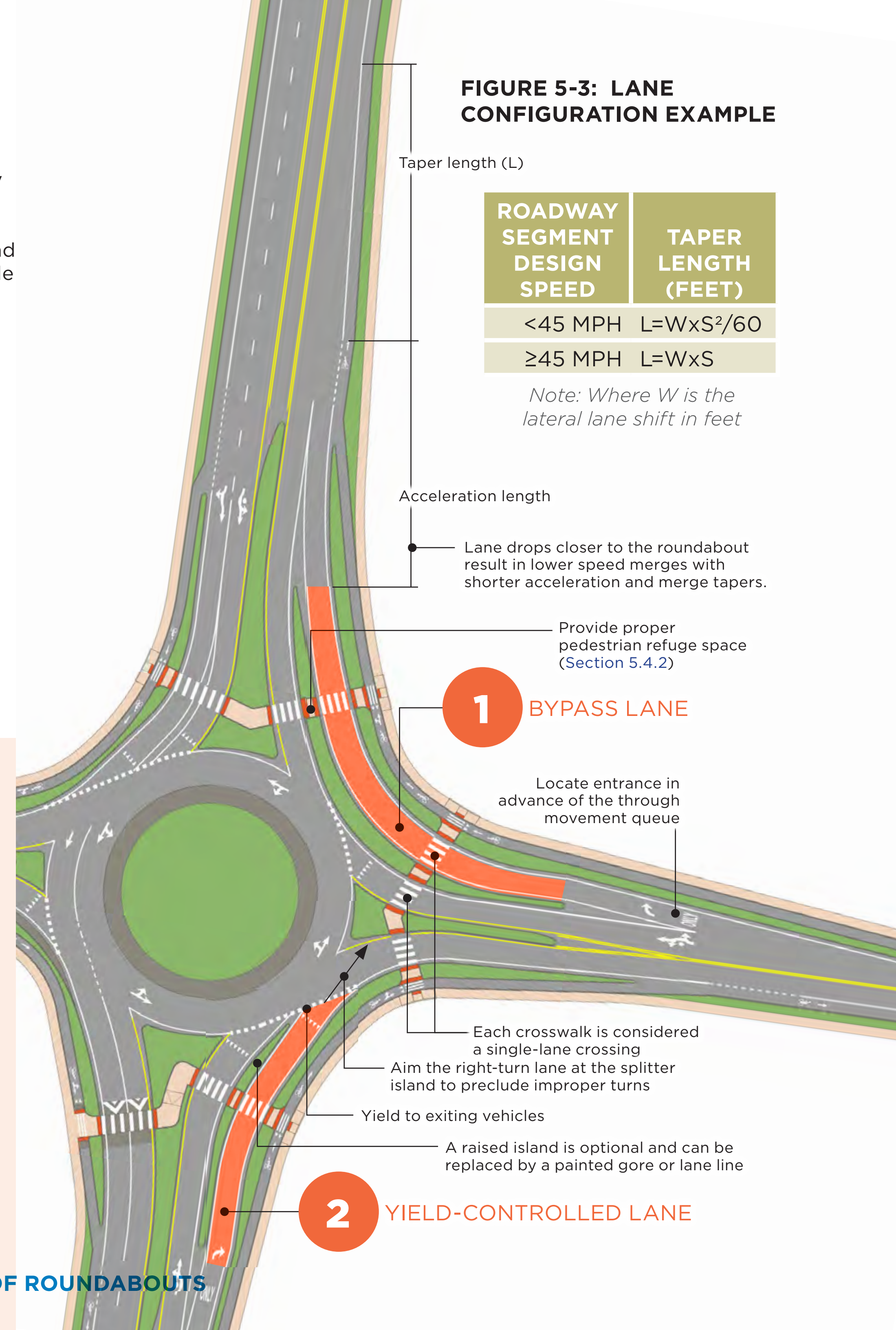
A capacity analysis is only one consideration of integrating a right-turn bypass lane. Right-turn bypass lanes can also be beneficial in locations where the geometry is too tight to allow design vehicles to make right turns within the roundabout. The radius of the bypass lane should result in speeds similar to vehicles entering and exiting the roundabout. This keeps vehicle speeds in the bypass lane similar to those of vehicles traveling through the roundabout.

THERE ARE TWO DESIGN OPTIONS FOR RIGHT-TURN BYPASS LANES:

1. Add the bypass lane parallel to the adjacent exit roadway. The bypass lane can then merge into the adjacent lane, illustrated in Figure 5-3, or continue on as a roadway widening. The entrance to the bypass lane should be outside the queue length for vehicles entering the roundabout.

2. Provide a yield-controlled entrance onto the adjacent exit roadway (partial bypass). This concept improves entry capacity since the right-turning traffic yields only to exiting traffic versus all traffic circulating in the roundabout. While this option does not provide equal operational benefits compared to the first option, it generally requires less construction and right-of-way. This option eliminates downstream weaving and merging conflicts and is recommended in areas where bicyclists and pedestrians are prevalent.

FIGURE 5-3: LANE CONFIGURATION EXAMPLE



ROADWAY SEGMENT DESIGN SPEED	TAPER LENGTH (FEET)
<45 MPH	$L=WxS^2/60$
≥45 MPH	L=WxS

Note: Where W is the lateral lane shift in feet

5.3 DESIGN FEATURES

5.3.1 CIRCULATORY ROADWAY AND CENTRAL ISLAND

Roundabouts with a mix of two-lane entries and one-lane entries should have a variable circulatory roadway width that matches the number of through or turning movement lanes of the approach. An example of one potential combination is illustrated in Figure 5-4. The typical circulatory roadway widths are 18 feet for a single-lane roundabout and 30 feet for two circulating lanes.

Roundabouts should be designed so that buses and other fixed-chassis vehicles, such as ambulances, do not have to use the truck apron; however, single-lane circulatory widths wider than 20 feet are not desirable and may create the impression that two vehicles can circulate side-by-side.

Lane widths on multilane circulatory roads do not need to be equal. For example, the inside lane nearest to the truck apron can be 14 feet wide, while the outside lane can be 16 feet wide. Variable lane widths can improve path alignments through multilane roundabouts and help larger vehicles circulate within their own lanes.

The central island includes the traversable truck apron and the raised, non-traversable middle of the intersection. The raised portion of the central island should be developed with plantings or other attractive vertical elements to block views across the intersection and to provide visual cues to approaching drivers. They may be hardscaped or paved, as described in Section 5.6.3. The central island features should not include features that attract people walking to the central island.

The size of the central island is influenced by the ICD and the width of the circulatory roadway and truck apron. Larger islands are desirable in rural areas and on higher speed roadways to maximize visibility of the roundabout. The size of the central island is a key geometric element in establishing a deflected path for traffic entering and traveling through a roundabout. Avoid designs in which a large truck apron consumes most of the central island to the point of the island becomes inconspicuous. A shoulder is not required around the truck apron.

RANGE OF CIRCULATORY ROADWAY WIDTHS

SINGLE LANE	TWO LANES COMBINED
16 to 20 feet	28 to 32 feet

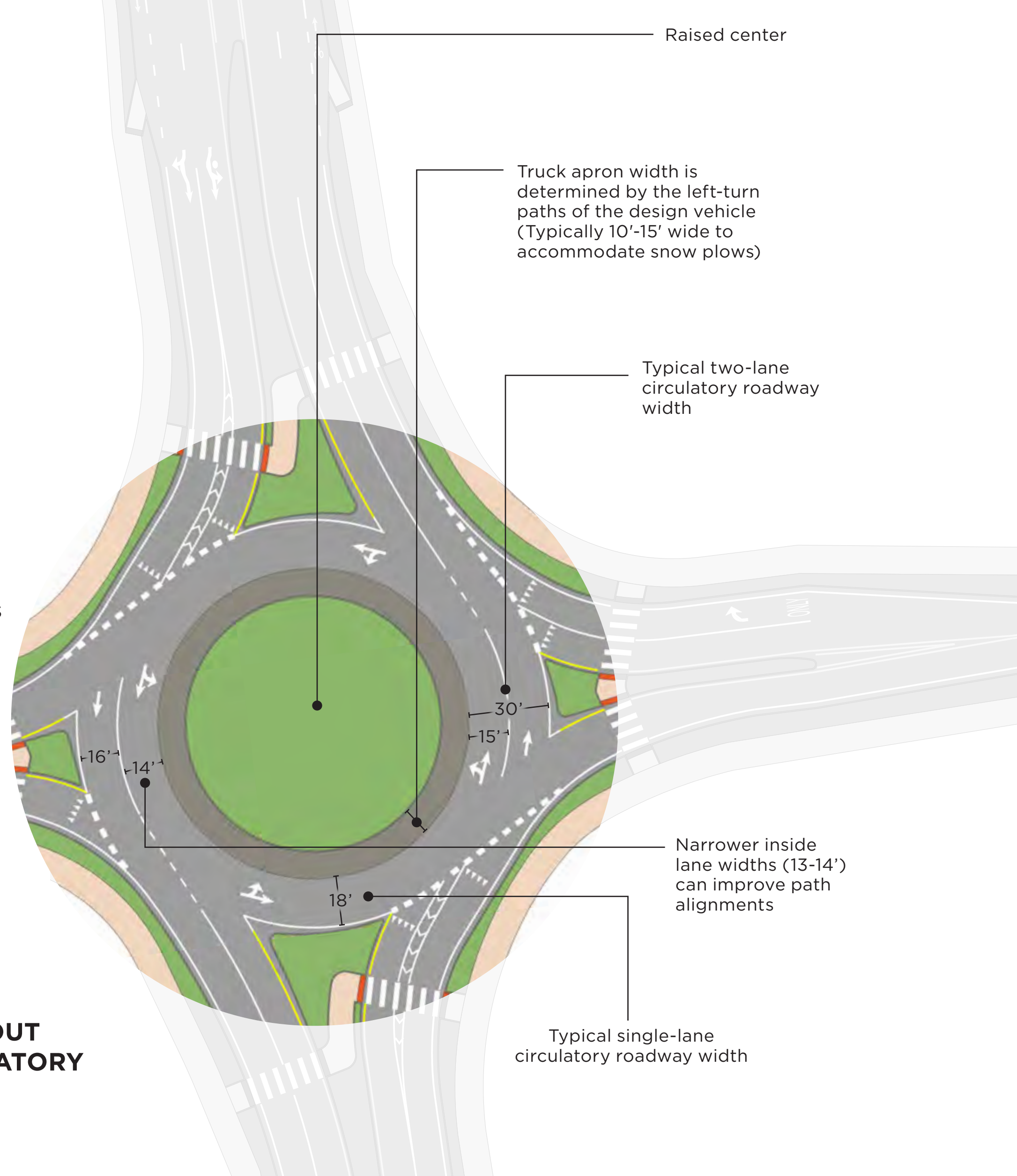


FIGURE 5-4: ROUNDABOUT WITH VARIABLE CIRCULATORY ROADWAY WIDTHS

5.3.2 INTERSECTION LEG GEOMETRY

Roundabouts are most effective when geometric elements on the approaches gradually slow down the entering traffic and then allow for a smooth and moderate acceleration on the exit. Approach alignment is one of the elements that can be adjusted to attain target speed control metrics. The theoretical entry speeds should be 25 mph or less for single-lane approaches and 30 mph or less for multilane approaches. These speeds are derived from a theoretical fastest path alignment that occupies the entire roadway width regardless of lane lines, as described in Section 5.3.3.

5.3.2.1 ENTRY GEOMETRY

Entry geometry helps alert drivers of the approaching roundabout and supports their gradual speed reduction prior to entering the circulatory road. Slow entry speeds are obtained through horizontal or vertical deflection. Horizontal deflection is attained by creating a curvilinear alignment that drivers must navigate upon entering the roundabout. Figure 5-5 illustrates radial approach design elements for a single-lane roundabout. For multilane entries, the geometry should generate a natural path alignment that directs vehicles into the appropriate lane in the circulatory roadway. Figure 5-6 illustrates curvilinear approach design elements. Multilane entry paths are presented in Section 5.8.

Additional curvature on the entry approach is sometimes needed to obtain appropriate deflection and attain target entry speeds or path alignment for multilane entries. Back-to-back reverse curves in the alignment should be joined by a tangent section that provides drivers space to change wheel direction. Figure 5-5 illustrates a combination of entry geometry curvatures and an example of an alignment offset to the left of the roundabout center. On a divided highway, the entry alignment can narrow the median to attain deflection. When median width is not sufficient to allow for additional curvature on the entry, shifting the entire approach alignment toward the exit can help achieve greater deflection on the entry.

Offset-left approach alignments can also benefit smaller ICD single-lane roundabouts, make the central island more visible, and improve right-turn space for large vehicles.

On roadway segments with posted speed limits higher than 40 mph, larger curves could be provided approaching the roundabout, and successively smaller curve radii could be used as the approach speeds decrease. Figure 5-7 illustrates details for such a design.

Offset-right approach alignment design should be avoided.

FIGURE 5-5: SINGLE-LANE ROUNDABOUT LEG GEOMETRY ELEMENTS

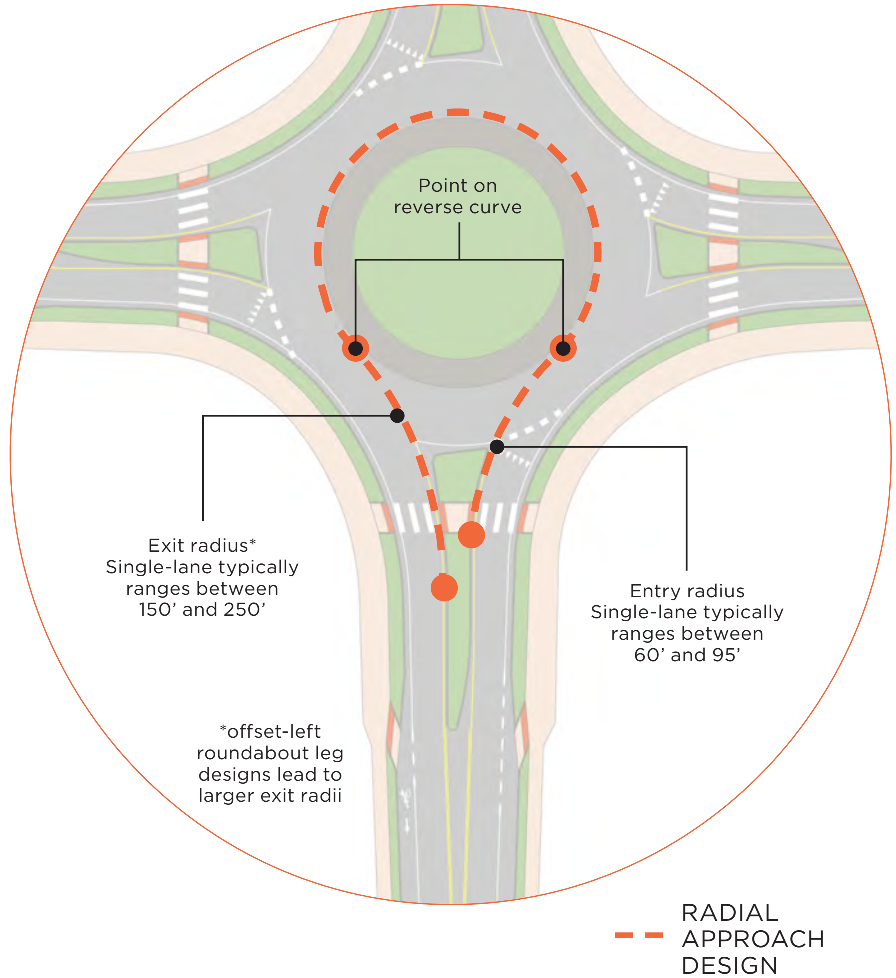


FIGURE 5-6: MULTILANE ROUNDABOUT LEG GEOMETRY ELEMENTS

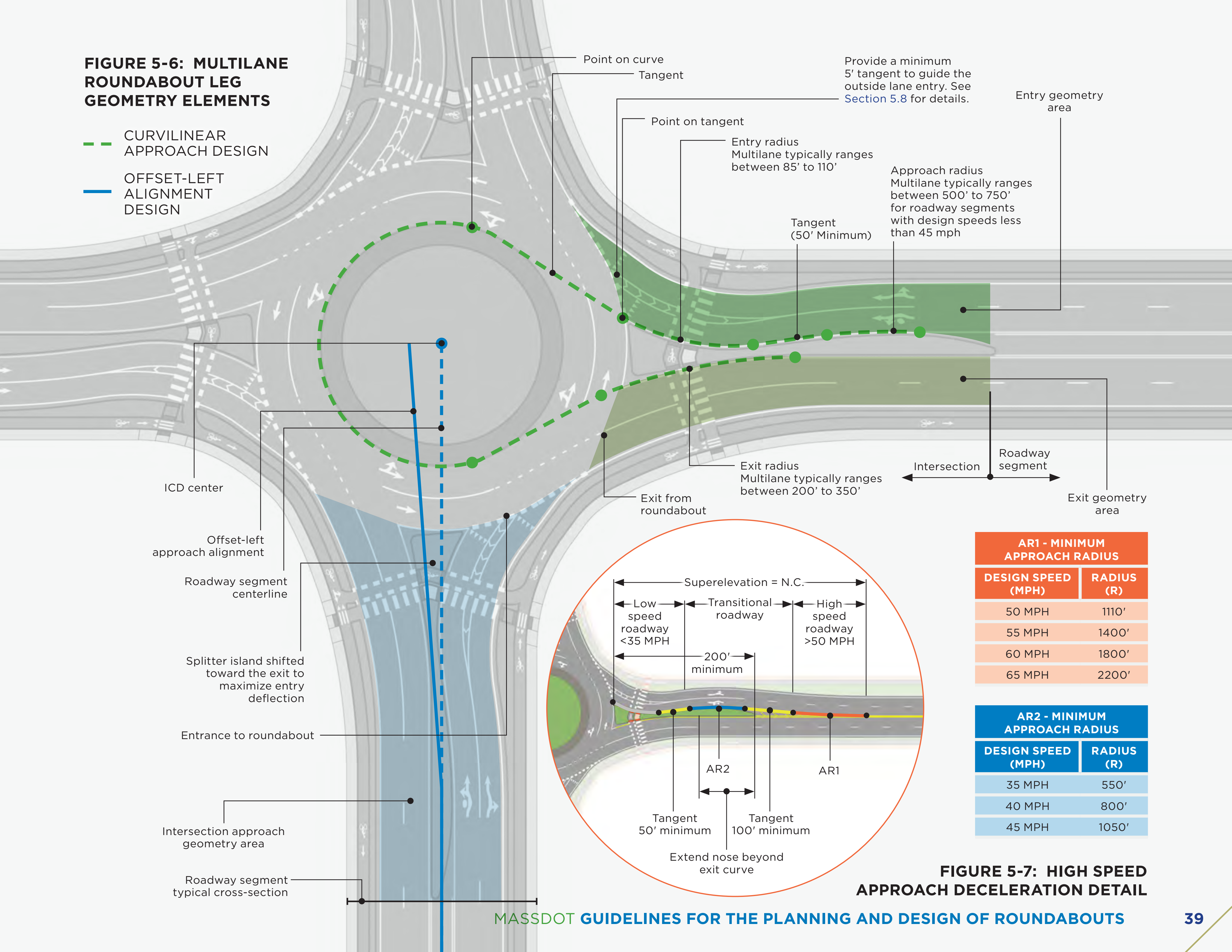


FIGURE 5-7: HIGH SPEED APPROACH DECELERATION DETAIL

AR1 - MINIMUM APPROACH RADIUS

DESIGN SPEED (MPH)	RADIUS (R)
50 MPH	1110'
55 MPH	1400'
60 MPH	1800'
65 MPH	2200'

AR2 - MINIMUM APPROACH RADIUS

DESIGN SPEED (MPH)	RADIUS (R)
35 MPH	550'
40 MPH	800'
45 MPH	1050'

5.3.2.2 EXIT GEOMETRY

Exit geometry should balance the same design principles as the entry design and accommodate the design vehicle. 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.

Typical entry and exit radii are shown in Figure 5-6. Single-lane exits can be designed with no curvature or with reverse curves between the splitter island and the central island.

5.3.2.3 ENTRY AND EXIT WIDTH

The entry and exit widths are measured perpendicularly from the termini point of the inside edge line at the circulatory roadway to the outside edge line. An entry or exit is a turning roadway and should be designed with sufficient width to account for vehicle tracking. The entry width should be balanced between the number of lanes and the need to accommodate the design vehicle and meet speed management performance objectives.

Single-lane entry widths commonly range from 14 to 18 feet. A common single-lane entry is 15 feet wide. A typical entry width for a two-lane entry ranges from 24 to 30 feet and from 36 to 45 feet for a three-lane entry. A common two-lane entry width is 28 feet. Typical widths for individual lanes at entry range from 11 to 15 feet. Using 12-foot lane widths separated by a buffer is preferred. Narrower lanes promote slower entry speeds. The buffer between entry lanes provides better guidance and can reduce the potential for path overlap.

Outside truck aprons should be considered on entries that become wider than the circulatory roadway or exceed 20 feet to avoid implying there are multiple entry lanes. Truck aprons are raised two to three inches from the pavement or are built with scored concrete to deter smaller vehicles from using them. Truck aprons should terminate at crosswalks or be discontinued through them in order to maintain an accessible walking path.

Single-lane exits may be as wide as 20 feet to serve design vehicles. The exit lanes taper down to the typical traffic lane widths. Multilane exits are generally as wide as the circulating roadway. Individual exit lanes range from 12 to 14 feet. Figure 5-8 illustrates typical entry and exit dimensions.

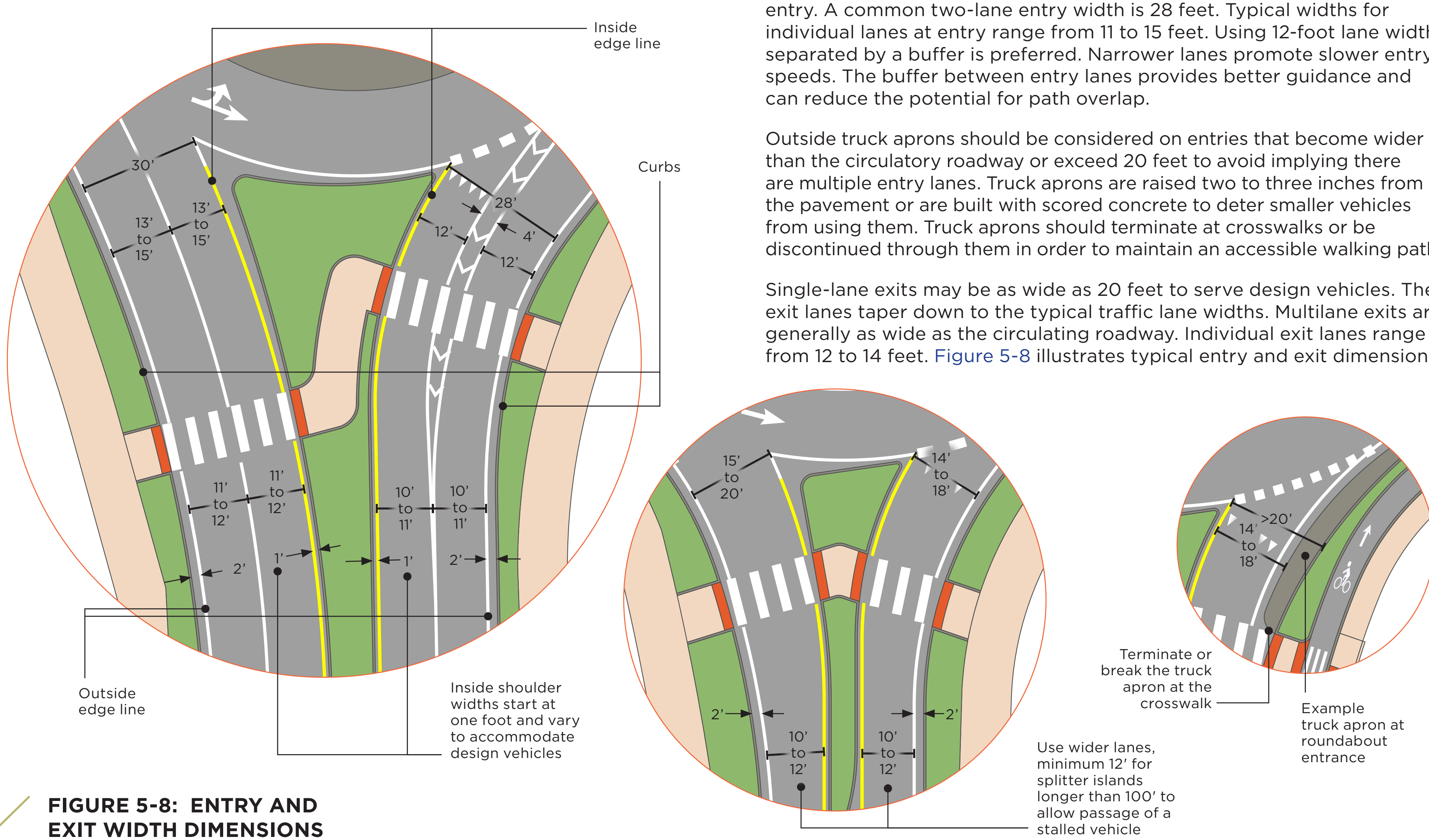


FIGURE 5-8: ENTRY AND EXIT WIDTH DIMENSIONS

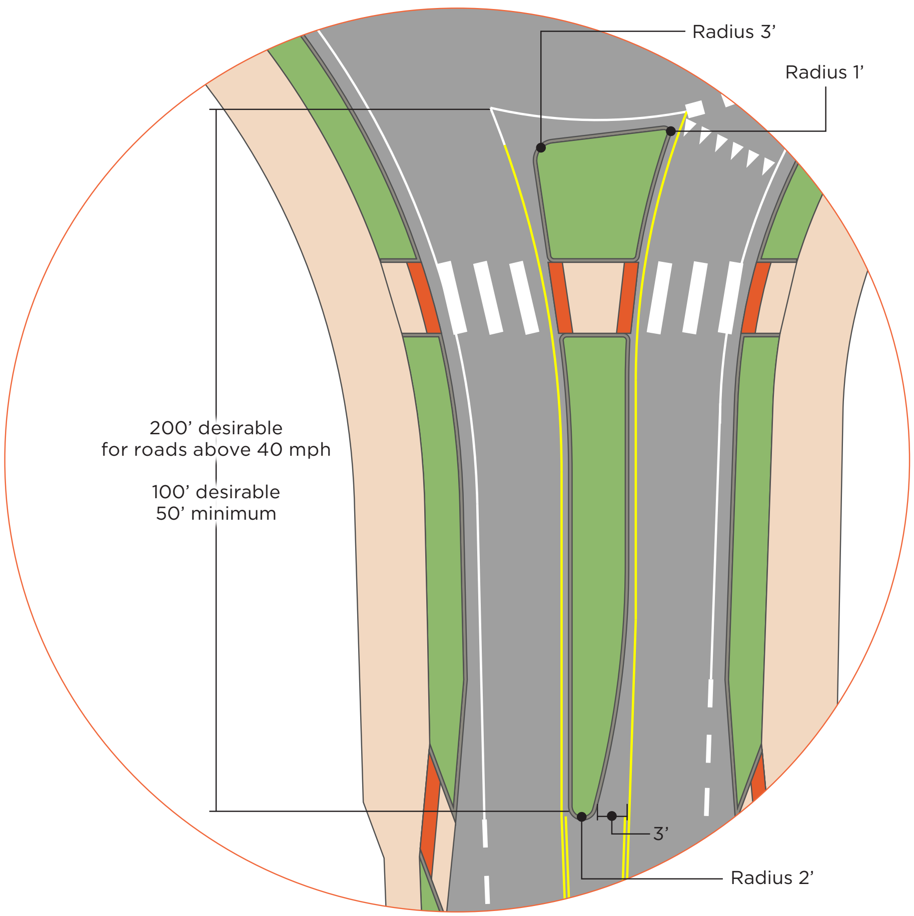
5.3.2.4 SPLITTER ISLANDS

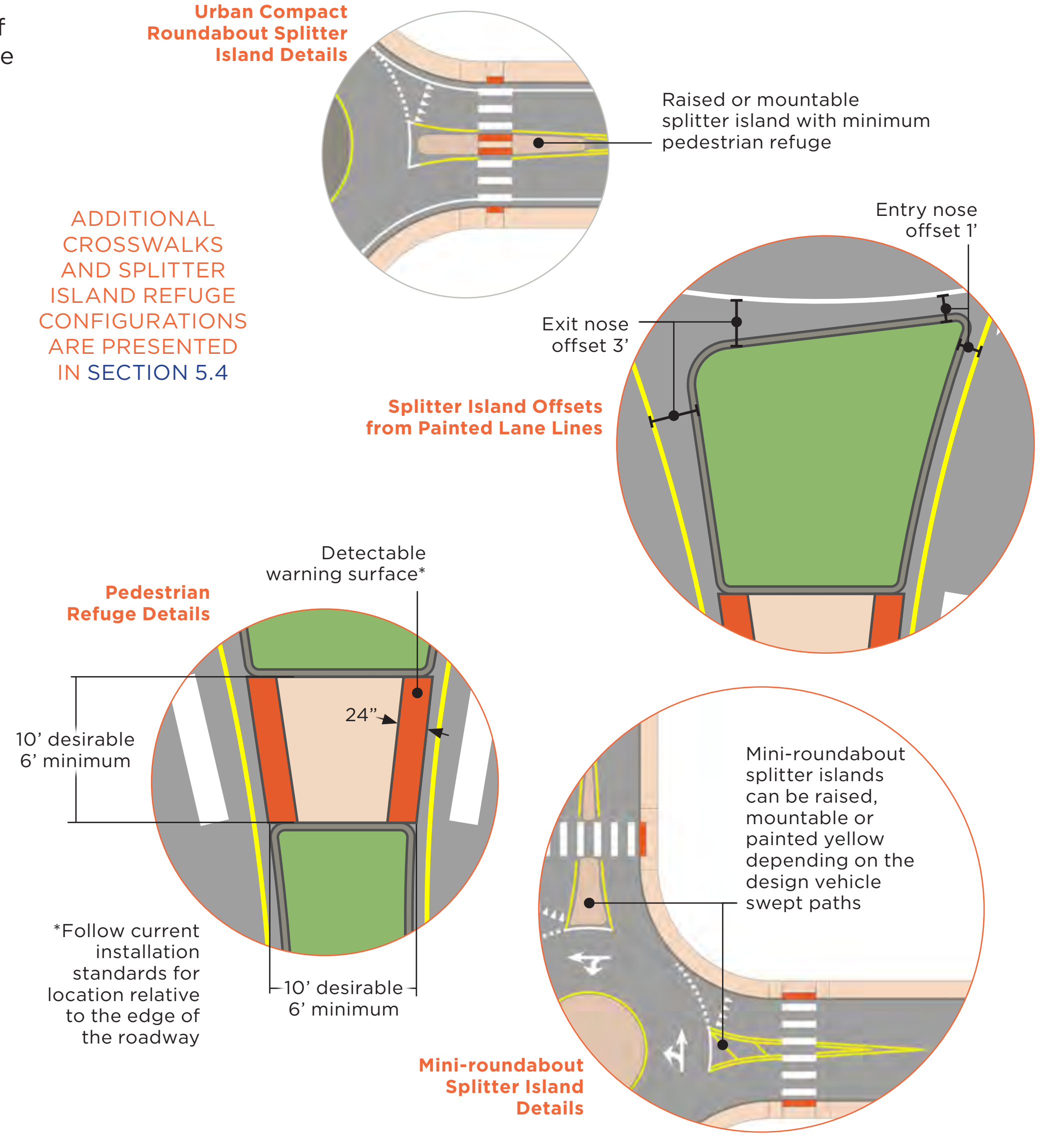
Splitter islands influence roundabout performance including speed reduction and positive guidance. With few exceptions, splitter islands should be provided on all roundabout approaches. Splitter islands alert the driver of the approaching roundabout, physically guide traffic into the correct direction of the circulatory road and provide refuge for pedestrians. Minimum design dimensions are illustrated in Figure 5-9. Raised splitter islands are not required on approaches that already experience 85th percentile driving speeds less than 25 mph. Mountable or painted islands are appropriate in those circumstances.

Laying out the splitter island geometry starts with the development of the entry and exit geometry. The splitter island dimensions balance the need to accommodate the design vehicle, provide a pedestrian refuge and reduce the entrance speed into the roundabout. Splitter island elements do not need to be symmetrically built along the center of the approaching road as illustrated in Figure 5-9.

Longer splitter islands should be used on roads with posted speed limits above 40 mph or when the approaching road curvature obstructs the view of the intersection. The minimum splitter island length should be 200 feet on approaches posted at or above 40 mph.

FIGURE 5-9: SPLITTER ISLAND ELEMENTS AND DIMENSIONS





5.3.3 FASTEST PATH CHECKS

Fastest path evaluations represent a means of testing roundabout geometrics and assessing the resultant predicted speeds and speed relationships between successive movements in the roundabout. Fastest path reported speeds are direct inputs to determining stopping and intersection sight distance values. Fastest paths should be drawn for each through and right-turn movements on all approaches to a roundabout. Illustrated in Figure 5-10 are the performance check radii.

The fastest path is the flattest, smoothest, single vehicle path traversing the roundabout in the absence of all other traffic and with disregard for pavement markings, as illustrated in Figure 5-11. Drawing the fastest path assumes the center of a six-foot-wide passenger vehicle stays three feet away from the painted lane edge or five feet away from curb or other raised geometric elements such as truck apron edges or mountable channelizing islands.

Section 5.2.3 of *NCHRP Report 672* (4) provides detailed instructions for drawing the fastest vehicle paths for each roundabout movement. Fastest paths can be drawn by hand or in CAD, as illustrated in Figure 5-12. Various techniques are available to draw a fastest path electronically. Fastest paths can require subjective interpretation especially at irregular roundabout design locations. In these cases, developing a complete path from entry through the exit is essential in considering vehicle trajectory and roundabout performance.

Typically, left-turning paths are the slowest movements (R4) and do not control roundabout configurations. Entry and right-turn radii (R1 and R5) ranges for typical roundabout speed performance values are provided Table 5-2. Section 6.7.1.2 of *NCHRP Report 672* (4) provides detailed instructions on estimating theoretical vehicle speeds, with the goal of achieving speed consistency between entering, circulating, and exiting vehicles.

TABLE 5-2: CONTROL RADII RANGES FOR RECOMMENDED MAXIMUM PERFORMANCE SPEEDS

RECOMMENDED MAXIMUM THEORETICAL ENTRY SPEED	CONTROL CURVE RADII RANGE (FT) R1, R5 (E = +0.02)
20 mph (Mini-roundabout)	90-100
25 mph (Single-lane roundabout)	165-175
30 mph (Multilane roundabout)	270-290

If fastest path evaluations indicate speeds exceed targets, the design should be modified until target speeds are reached. Typical geometric changes include: increased deflection on the approach through alignment changes or additional curvilinear elements, and tighter entry radii.

FIGURE 5-10: PERFORMANCE CHECKS RADII

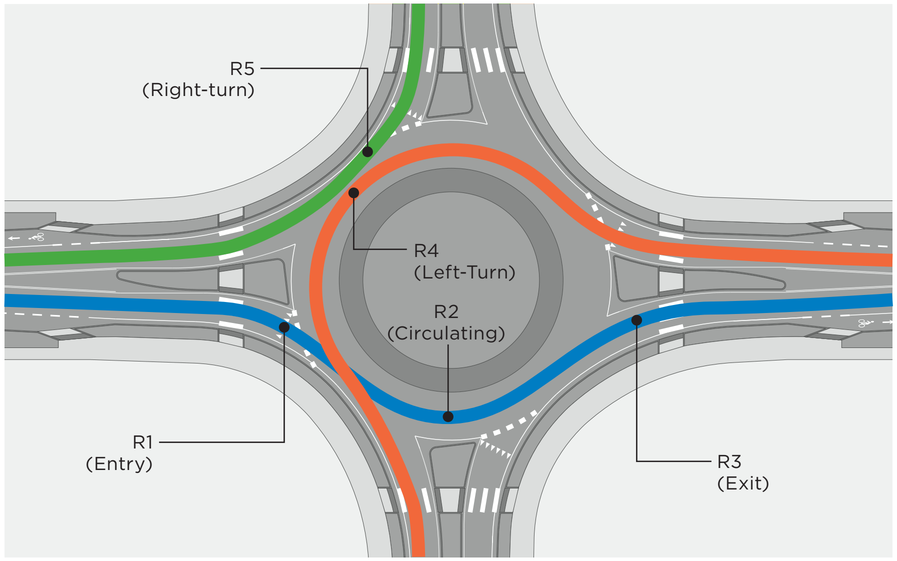


FIGURE 5-11: FASTEST VEHICLE PATHS THROUGH A MULTILANE ROUNDABOUT

Adapted from NCHRP Report 672 (4), Exhibit 6-49

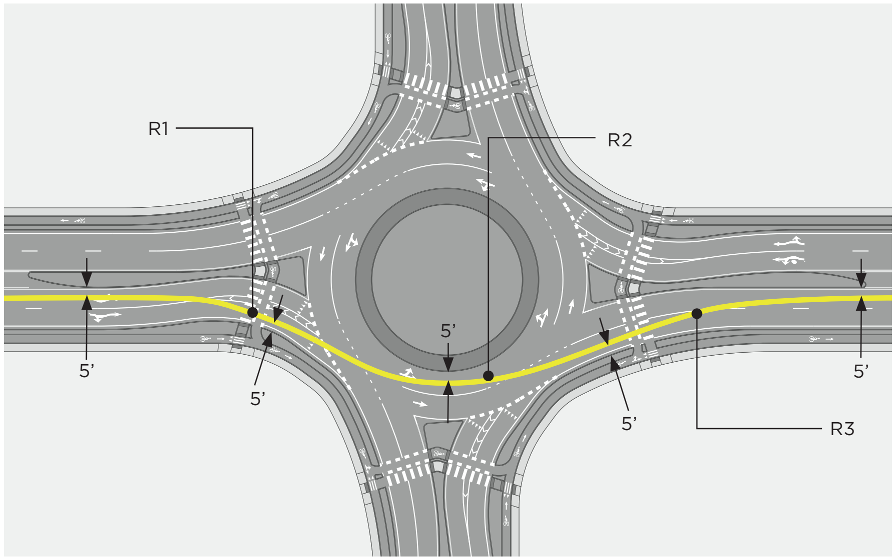
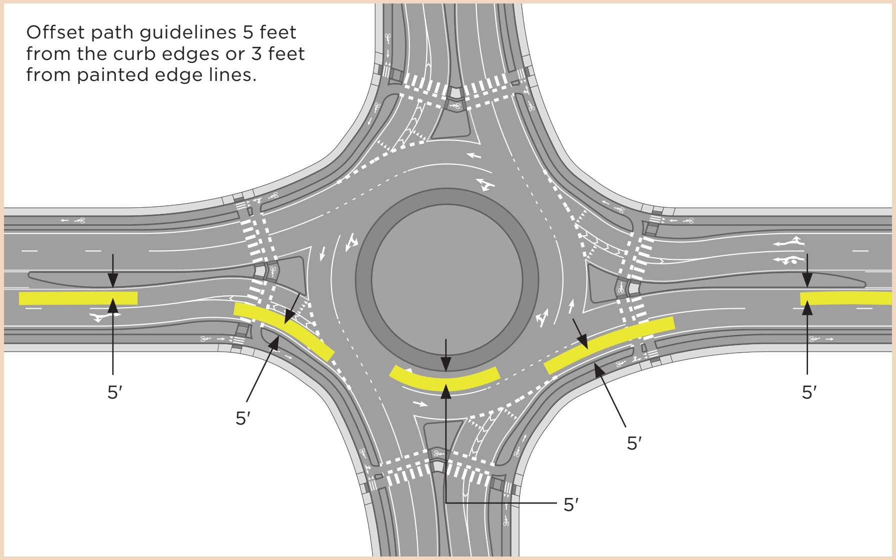
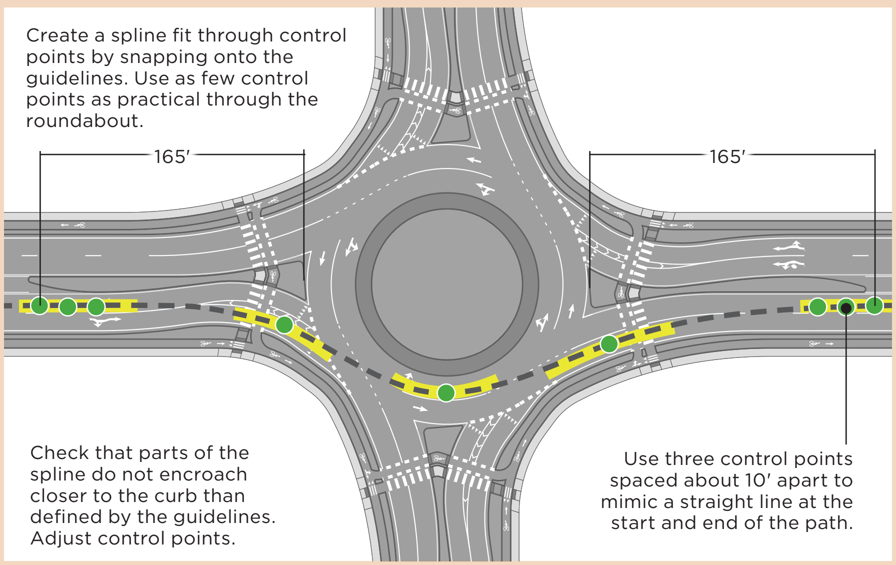


FIGURE 5-12: FASTEST PATH DEVELOPMENT STEPS IN CAD

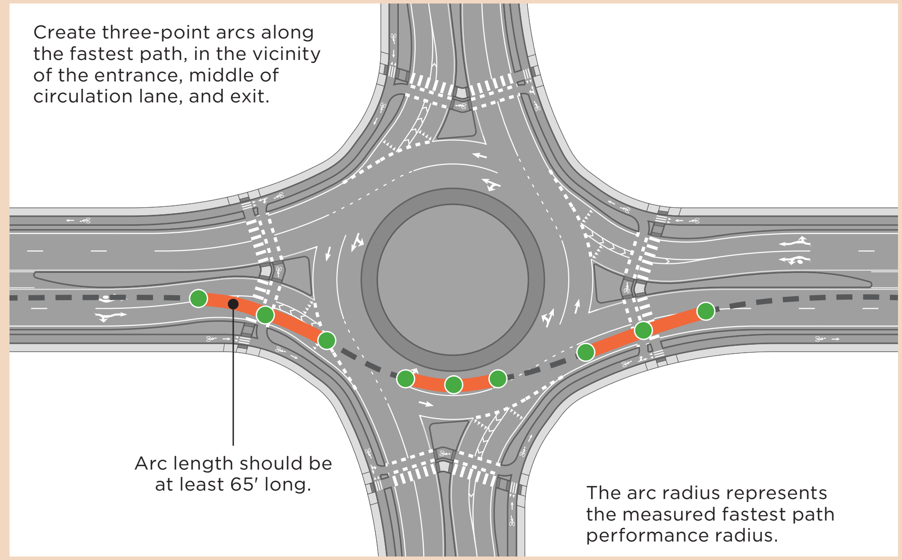
1. ESTABLISH PATH GUIDELINES



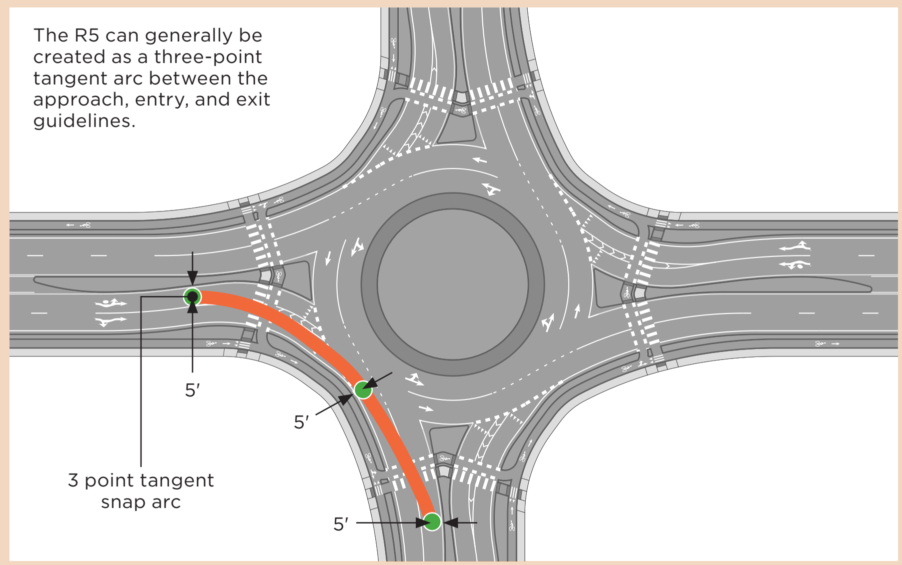
2. BUILD THE PATH



3. CREATE MEASUREMENT ARCS



4. CREATE RIGHT TURN ARC



5.4 PEDESTRIANS & BICYCLISTS

5.4.1 DESIGNING ROUNDABOUTS FOR PEOPLE WALKING

Design elements affecting people walking include crossing locations, sidewalk treatments, splitter island, wayfinding buffer treatments, and curb ramps. Connectivity should be a priority, and pedestrian facilities at a roundabout should connect to a broader pedestrian network. If pedestrian activity is anticipated in the future, splitter islands should be designed wide enough to accommodate people walking through the islands. Figure 5-13 illustrates the crosswalk location in relation to the circulatory roadway and navigation design elements required to find the pedestrian ramps.

5.4.2 PEDESTRIAN ACCESSIBILITY

People of all ages and abilities walk along the public rights of way. People walk with children, canes, walkers, and in wheelchairs. Roundabouts present unique travel challenges for people with visual impairments. Meeting their needs through design leads to an equitable solution.

For a person with visual impairments, crossing streets at roundabouts and other intersections consists of four tasks:

- determining the appropriate crossing location;
- aligning to cross (establishing a correct heading);
- determining when to initiate crossing (accepting an appropriate gap or yield crossing opportunity); and
- maintaining the correct heading while crossing (staying in the crosswalk).

Failure in any of the four tasks can result in actions such as crossing from a location where people walking are outside the crosswalk and thus unexpected by drivers, stepping into the roadway without realizing it, or crossing towards the central island of a roundabout. A person follows these steps both in the initial approach to a crosswalk from the sidewalk as well as in finding their way through the splitter islands.

There are two activities that must be considered when serving people with visual impairments: wayfinding and determining when to cross or detecting a traffic gap.

WAYFINDING

The crossing alignment should direct a person walking from one curb ramp to the receiving ramp. Crosswalks that are perpendicular to the outside curbs and create an angle through the splitter island result in shorter crossing lengths. A change in direction through the splitter island should be at least four feet long to provide guidance toward the receiving curb ramp.

GAP DETECTION

People with visual impairments initiate their crossings by listening for gaps in the active traffic stream and/or listening for yielding by drivers. Initiating a roundabout crossing is more complex, as it requires that a person with visual impairments to distinguish between the traffic at the crosswalk and background traffic that generates potentially conflicting noise. Design configurations should minimize vehicle entry and exit speeds and provide drivers with clear sight lines to pedestrian crossing areas. Slow vehicle operating speeds support yielding behavior.

CROSSING SOLUTIONS

NCHRP Report 834, Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities (5) provides four major types of crosswalk treatments to limit the risk experienced by pedestrians with visual impairments: (A) standard pedestrian signal, (B) pedestrian hybrid beacon (PHB), pedestrian activated warning device, such as (C) rectangular rapid flashing beacon (RRFB), and (D) a raised crosswalk (RCW).

FIGURE 5-13: CROSSWALKS AND WAYFINDING DETAILS

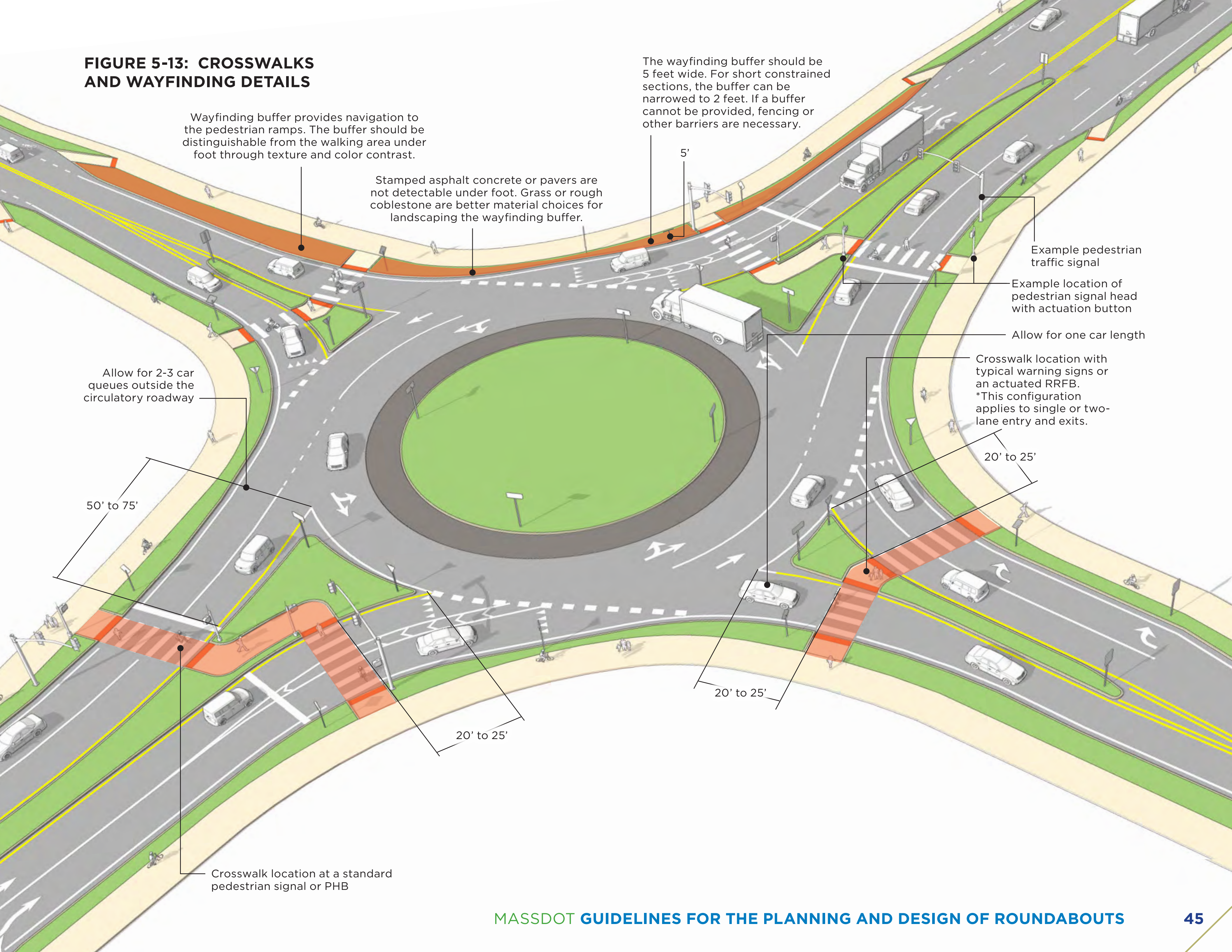
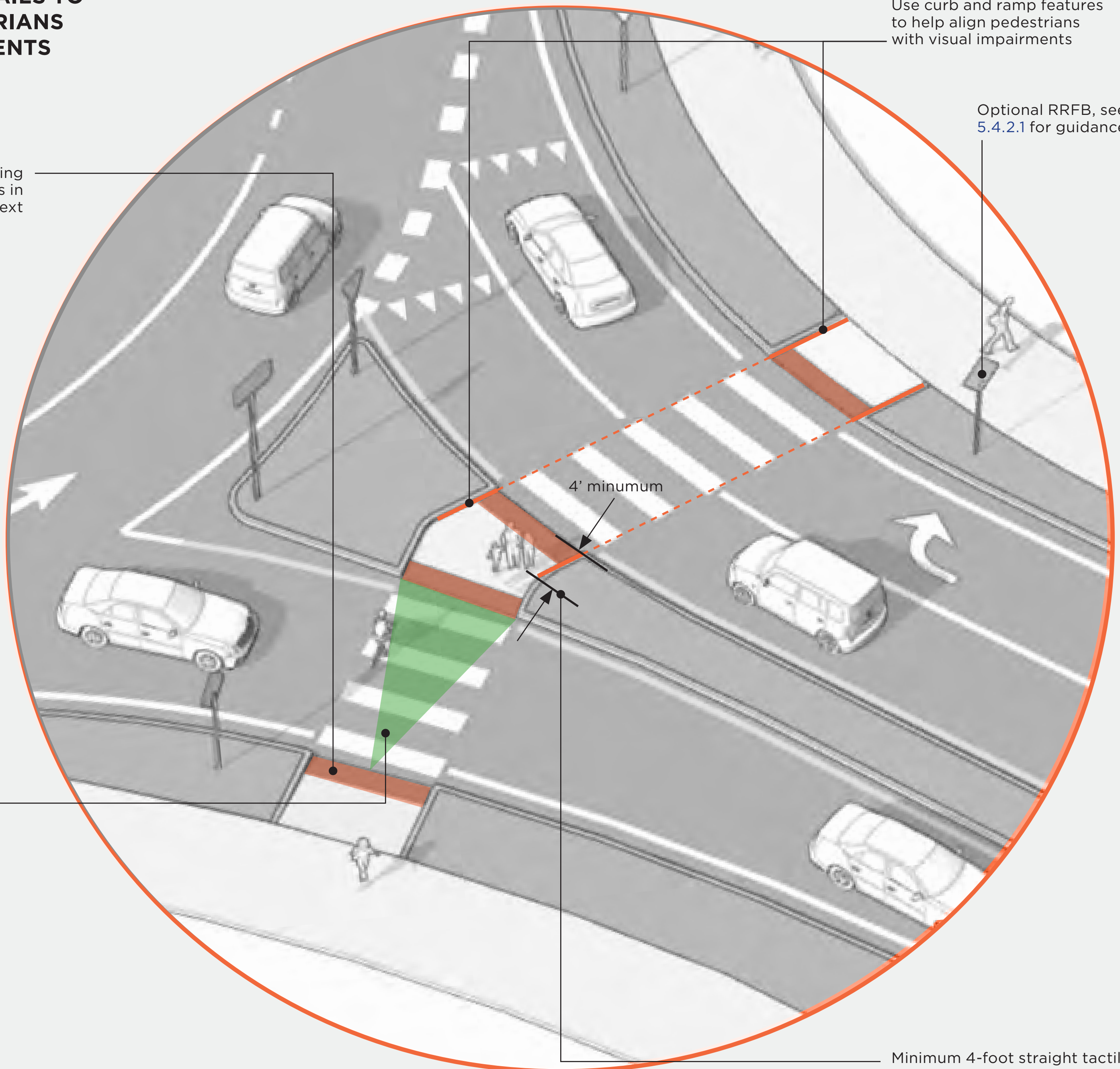


FIGURE 5-14: CROSSWALK AND WAYFINDING DETAILS TO ACCOMODATE PEDESTRIANS WITH VISUAL IMPAIRMENTS



5.4.2.1 GUIDELINES

Title II of the Americans with Disabilities Act (ADA) requires that new and altered facilities constructed by, on behalf of, or for the use of state and local government entities be designed and constructed to be readily accessible to and usable by individuals with disabilities (28 CFR 35.151). The United States Access Board has developed the *Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way* (PROWAG) (3), which are under review at the time of this writing. A full version of the proposed guidelines is available on the Access Board website (http://www.access-board.gov). Section R306.3 of the draft document provides guidelines for accessible pedestrian facilities at a roundabout. FHWA adopted the PROWAG (3) recommendations as best practice.

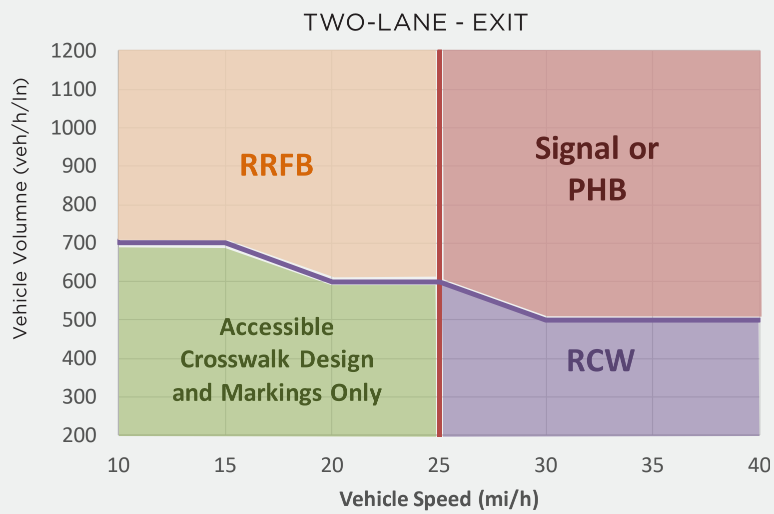
MassDOT encourages the use of the PROWAG (3) guidelines. For roundabouts in Massachusetts, this includes:

- SEPARATION - Sidewalks should be separated from the roadway by a five-foot buffer or as illustrated in Figure 5-13. Where separation is not practical, fencing or other barriers may be necessary to guide people with vision impairments. Detectable warning surfaces shall not be used for edge treatment.
- YIELD BEHAVIOR - The faster vehicles travel, the less likely they are to yield to people at a crosswalk. As described in the Gap Detection section, yielding compliance is necessary for a person with a visual impairment to initiate the crossing. Vehicular yielding compliance at multilane accessible crosswalks with low background noise can be increased by using one or a combination of the treatments indicated in Figure 5-15. The treatment type is based on the highest fastest path speed at the entry or exit from the roundabout. The volumes are peak hour vehicles per lane. *NCHRP Report 834,* Appendix A describes how background noise intensity is evaluated at crosswalks. At high noise locations, a traffic signal or PHB is needed to provide accessibility at multilane roundabout crosswalks. These recommendations and those suggested in Figure 5-15 should be considered in conjunction with *Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD)* (2) warrants for pedestrian signals or a PHBs. To meet the expectations of drivers and people walking, the same crossing treatment should be used on both entry and exit crosswalks of a roundabout leg.

Limited research has shown that crosswalks at single-lane roundabouts are accessible in many cases. It may be appropriate to add a RCW, RRFB, a combination of the two, or a pedestrian signal at single-lane crosswalks if they are located in a high-noise environment, have entry or exit speeds in excess of 30 mph, or have other unique accessibility concerns.

The research also indicates all crosswalks on three-lane entries and exits require a signal or PHB to be accessible. Treatments like a raised crosswalk or RRFB have not been shown to result in an accessible environment for three-lane entries and exits.

FIGURE 5-15: CROSSWALK TREATMENT RECOMMENDATIONS FOR TWO-LANE ROUNDABOUTS IN LOW NOISE ENVIRONMENTS



5.4.3 DESIGNING ROUNDABOUTS FOR PEOPLE BIKING

As defined in the *MassDOT Separated Bike Lane Planning and Design Guide* (SBLP&DG) (10), three elements – safety, comfort, and connectivity – are key principles to designing bicycle facilities and network connections that are comfortable for most people biking. Using the following intersection bicycle design principles helps provide the desired safety, comfort, and connectivity for people biking at roundabouts:

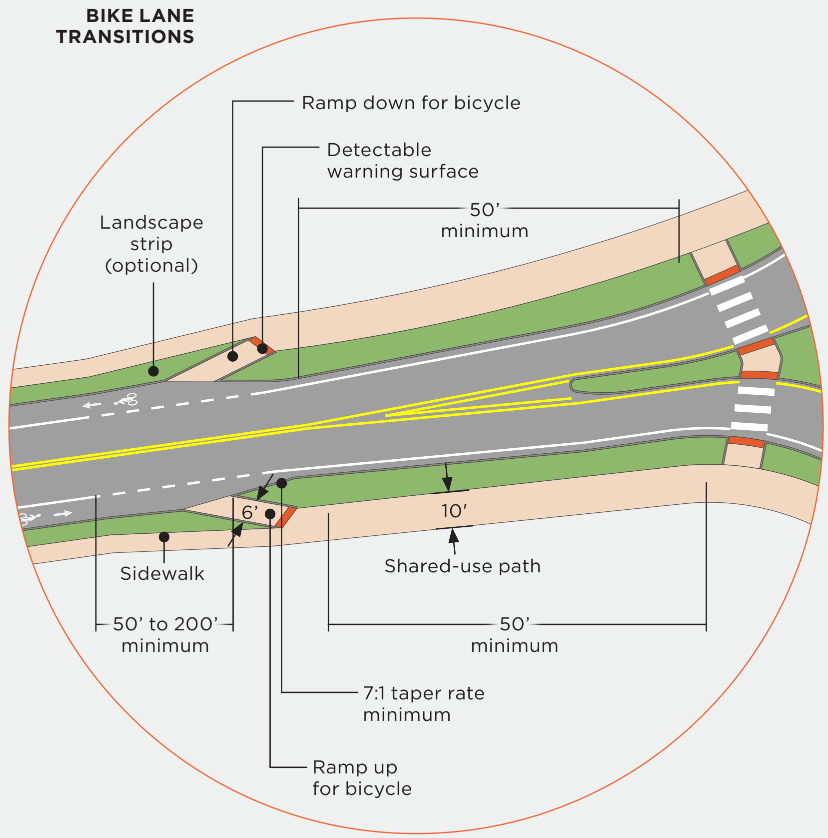
- Provide space for people biking
- Reduce conflict points, especially between modes
- Maximize visibility both for people biking and of people biking
- Reduce speed differential between people biking and other modes
- Provide predictable and direct navigation
- Minimize stop-start maneuvers

Designs consistent with the roundabout design principles discussed in Section 5.1 provide a baseline for designing for people biking. The following section provides a framework for selecting which design options are appropriate for people biking around roundabouts. Figure 5-16 illustrates the locations and dimension details for bicycle ramps. (See SBLP&DG (10) for a more complete discussion on designing for people biking.)

5.4.3.1 FRAMEWORK FOR SELECTING BICYCLE FACILITIES AT ROUNDABOUTS

Bicycle facilities around roundabouts should provide connectivity while also matching or exceeding the safety and comfort levels between planned or existing bicycle facilities on the approach legs. The bicycle design principles listed above provide a starting point for identifying design options that provide connectivity and bicycle comfort levels appropriate for people riding bikes of all ages and abilities. People biking are always offered the option of traveling through a roundabout as a vehicle. However, at locations with planned or existing bicycle facilities on the roundabout approaches, or at more complex multilane roundabouts, people biking are provided additional options for navigating the roundabout. These options include remaining on their bike and using a shared-use path or separated bike lane, or in more constrained locations, traveling through the roundabout as a pedestrian on a sidewalk. Figure 5-18 illustrates different travel options for people biking through a roundabout and bicycle-lane treatments in advance of a roundabout. The flow chart in Figure 5-17 identifies bicycle facility design options appropriate for roundabouts in Massachusetts.

FIGURE 5-16: PEDESTRIAN AND BICYCLE FACILITIES DETAILS



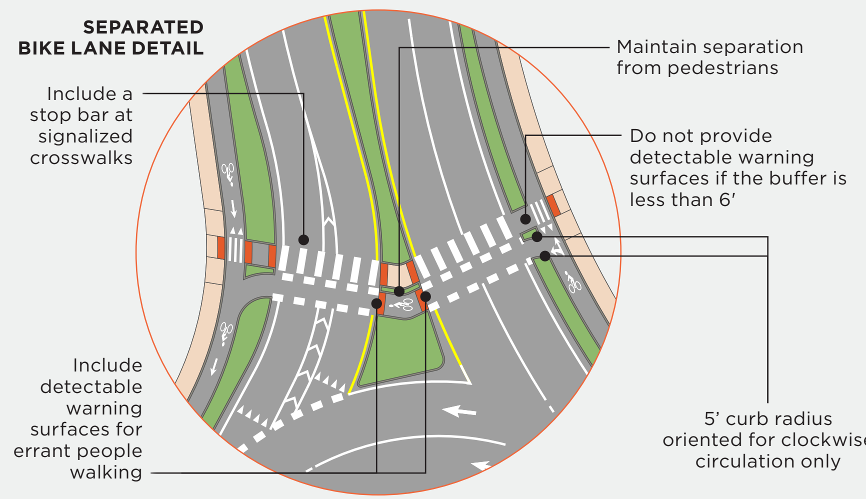


FIGURE 5-17: BICYCLE FACILITY OPTIONS AT A ROUNDABOUT

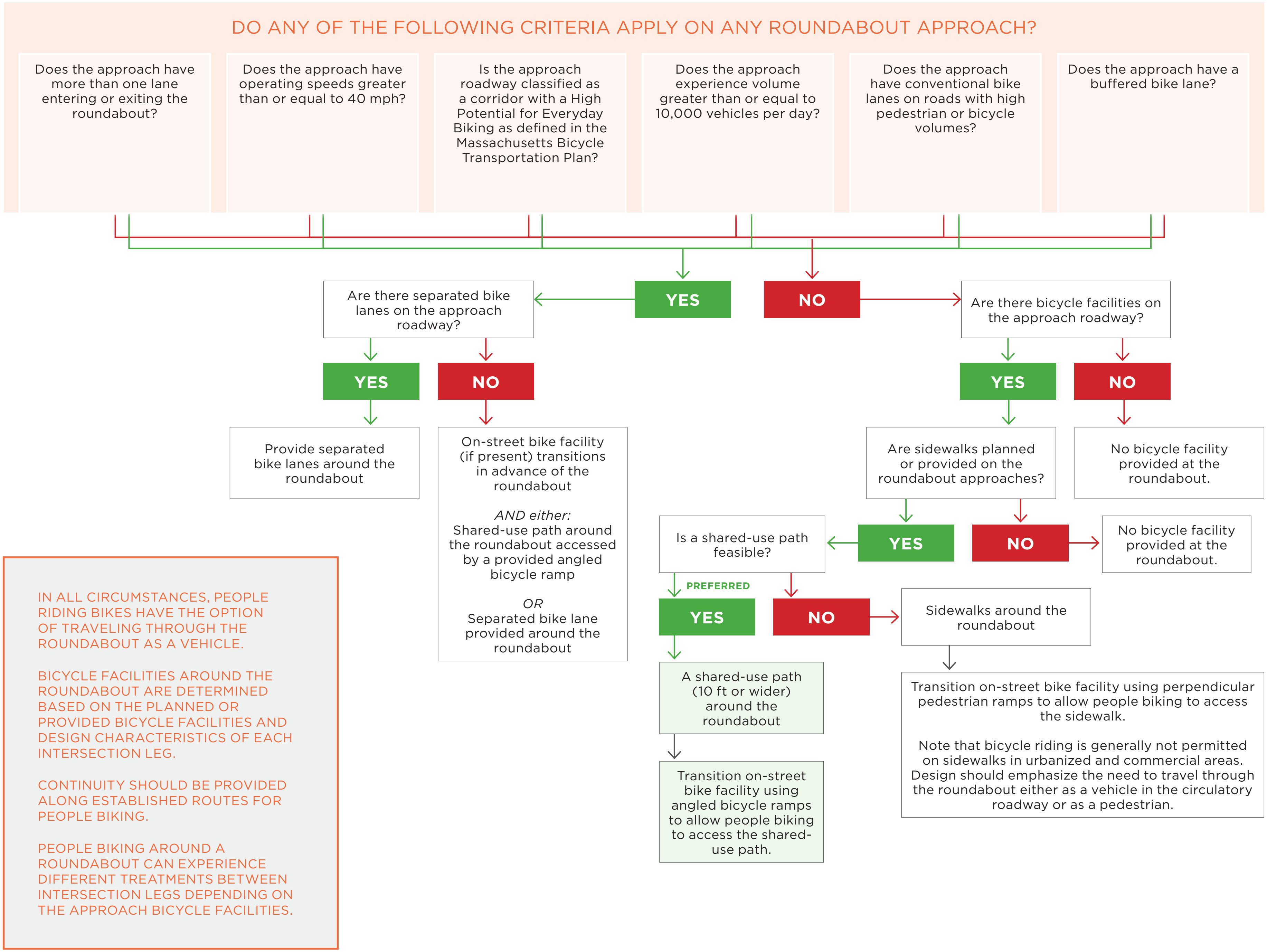
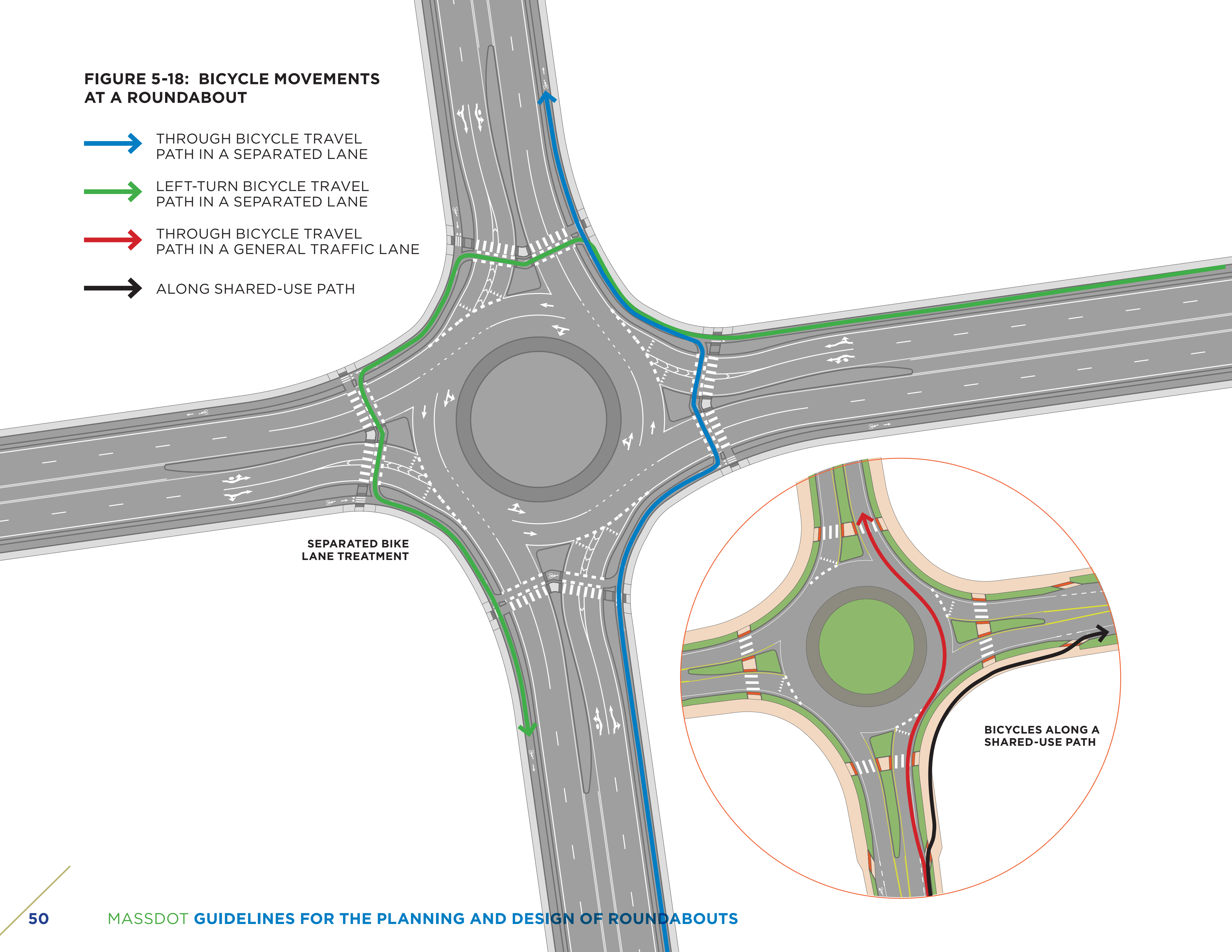


FIGURE 5-18: BICYCLE MOVEMENTS AT A ROUNDABOUT



5.5 LARGE VEHICLES

5.5.1 DESIGN VEHICLE SELECTION

State of the roundabout engineering practice is to design each approach to accommodate specific turning movements for appropriate design and control vehicles. Figure 5-19 illustrates three general categories of vehicles to consider.

DESIGN VEHICLE - The design vehicle is the largest vehicle that is expected to frequently make specific movements through an intersection. Examples include buses and single unit trucks in urban settings, WB-62 tractor trailers in rural settings, and WB-67 tractor trailers for roundabouts on the national highway system (NHS) or near freeway interchanges. Design the roundabout geometry to provide two feet (desired) or one foot of minimum clearance between the proposed curbs and design vehicle tires. Outside truck aprons may be provided to accommodate design vehicles in constrained settings or where necessary to achieve fastest path goals. For roundabouts on rolling terrain, designers should check for vertical clearance conflicts between low boy tractor trailers and circulatory roadway pavement and truck aprons.

CONTROL VEHICLE - The control vehicle is an infrequent large vehicle for which specific movements need to be accommodated through an intersection. Examples include non-articulating fire trucks in urban settings, wide farm machinery or WB-67 tractor trailers in rural settings, and oversize/overweight (OSOW) vehicles and other permitted loads on designated freight routes. Accommodating control vehicles may require hardened areas beyond the perimeter curbing, an oversized truck apron in the central island, and removable signs. Utility poles and underground vaults, light poles, pedestrian facilities, and other vertical elements should be placed outside the swept path of the control vehicle body.

PD&DG (8), Exhibit 6-2 lists the typical design vehicles at intersections based on the functional classification of the major roadway. For roundabouts, the selection of design and control vehicles is influenced by the vehicle classifications on each approach leg, surrounding land use, and planned development for near term and future design years. The selection process is crucial as design vehicle movements affect the size of the roundabout and other key design decisions. Designers should consult with MassDOT staff, local agencies, and other stakeholders early in the project development process to identify the appropriate design and control vehicles.

Through movements at roundabouts on the NHS should be designed for WB-67 trucks. Turning maneuvers may have a different design vehicle depending on the adjacent exit road type. There is trade-of between design vehicles accommodations and available speed control. The maximum speed control thresholds identified in the Section 5.3.3 shall not be relaxed to accommodate a design vehicle. If large vehicles such as WB-67 trucks use a roundabout approach rarely, they should not be used as the design vehicle. Instead, roundabout perimeter elements can be designed to accommodate this as the control vehicle. Enlarging the outside corners on entry and exit lanes to accommodate large vehicles is not recommended because it can lead to faster operating speeds for the general traffic. If additional paved space is needed on entry corners to accommodate large vehicles, this space should be built as a mountable truck apron. Section 5.5.4 discusses OSOW vehicles. Many of the strategies in that section for oversize vehicles apply to accommodating control vehicles.

FIGURE 5-19: DESIGN VEHICLE TYPES

1 Large vehicles without trailers including single-unit trucks, fire trucks without turntable ladders, transit vehicles (buses), and school buses. In general, roundabouts should be designed to allow these vehicles to navigate the roundabout without using the truck apron. An SU-30 or B-40 design vehicle serves as a good proxy for these vehicles.

2 Large vehicles with trailers including fire trucks with turntable ladders. Roundabouts should be designed to allow these vehicles' rear trailer to use the truck apron around the central island. In general, it should not be necessary or anticipated that the cab of the truck would use the truck apron. A fire truck, WB-50, or WB-67 design vehicle are generally used to test these vehicles.

WB-40 articulated trucks are appropriate for local streets that are not used by large tractor-semitrailers and for access roads to ports and train yards where container traffic may be predominant.

3 Oversize/overweight (OSOW) vehicles require special accommodations to navigate a roundabout beyond the design for the vehicles described above. Custom vehicles found in most CAD-based design software allow for OSOW vehicles to be tested. OSOW vehicles should be evaluated for both horizontal path and underside vertical clearance. Examples of OSOW vehicles include modular building transporters and windmill blade transporters.

5.5.2 DESIGN VEHICLE CHECKS

Vehicle turning path templates or CAD-based vehicle turning path simulation software should be used during the design process to establish the turning path requirements of the design vehicle. As per American Association of State Highway and Transportation Officials (AASHTO) (1) policy, the designer should provide at least one foot of shy distance between the vehicle tire tracks and curb, preferably two feet to accommodate variations in drivers. Vehicle body envelopes that include mirrors or attachments should also be included in CAD-based simulations to determine the swept path beyond the roadway edges. Signs, utility poles, or other vertical elements should not be placed within the swept path created by the test vehicle body. Control vehicle tire tracks can overlap with curb edges. The vertical clearance between the bottom of the load overhang and the top of curb or other vertical design elements should also be checked for OSOW control vehicles. Lowboy trailers are examples of such OSOW control vehicles.

Multilane roundabouts can be designed to accommodate the design vehicle path within the envelope of one lane or allow large vehicles to sweep across multiple lanes on the entry, circulating, and exiting. Figure 5-20 illustrates the path of a WB-67 truck for the following path cases:

CASE 1 TRUCKS USE MULTIPLE LANES TO ENTER AND TO CIRCULATE AT A ROUNDABOUT

CASE 2 TRUCKS REMAIN IN THEIR LANE ON ENTRY INCLUDING A STRIPED BUFFER IF IT EXISTS AND CAN TRAVEL SIDE-BY-SIDE WITH A PASSENGER CAR; HOWEVER, TRUCKS STILL USE MULTIPLE LANES TO CIRCULATE ONCE IN THE ROUNDABOUT

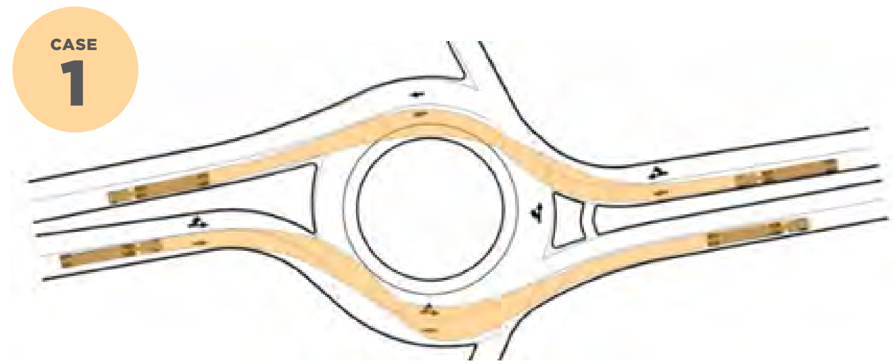
Case 2 designs often result in larger roundabouts and wider curb to curb widths, which, in turn may result in higher vehicular speeds. To address the fastest paths, designers may shift approach geometry to the left, decreasing flexibility in entry and exit design. The selection of the appropriate case is based on truck volumes and roadway type of each approach. Table 5-3 provides thresholds for truck percentages for each case.

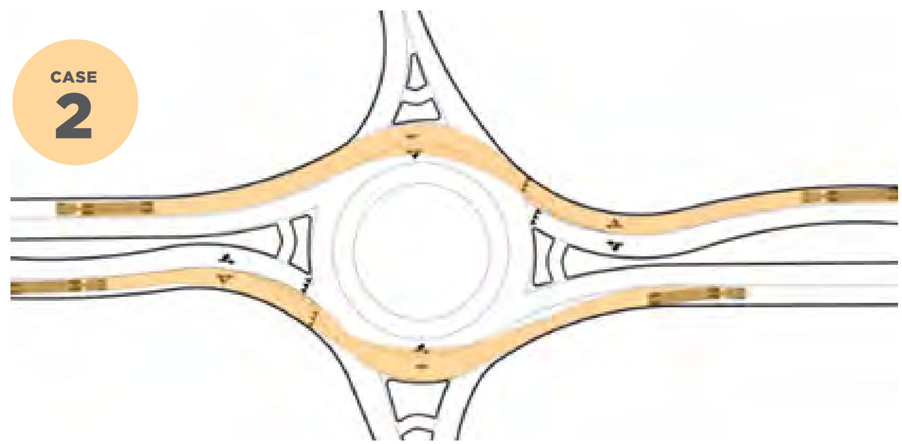
TABLE 5-3: TRUCK ACCOMMODATION CASES BASED ON FREQUENCY

TRUCKS PERCENTAGE OF APPROACH TRAFFIC	CASE
Less than 5%	1
5% or more	2

Adjacent approaches can use different truck accommodation cases. For example, major street through movements or freeway interchange terminals may be assigned Case 2, while side-street movements may be assigned Case 1.

FIGURE 5-20: MULTILANE TRUCK ACCOMMODATION CASES





5.5.3 TRUCK APRONS

Truck aprons should be sized to accommodate the largest vehicle expected to traverse the roundabout in a particular direction, including OSOW vehicles. The inside limits of the truck apron are typically established by determining the design vehicle left-turn path through the roundabout or the OSOW vehicle path for an expected movement. For example, OSOW vehicles may be accommodated for through movement only. The size of the truck apron should include one to two feet of buffer from the limits of the vehicle path checks. Snow clearance may necessitate enough width to allow a plow to fully mount the truck apron to clear snow.

Design features such as texturized and colored concrete differentiate the truck apron from the adjacent lanes. Truck aprons should be raised by two to three inches from the adjacent lanes to deter passenger vehicles from traversing them. A mountable curb or concrete lip should be used on the outside truck apron edges. The concrete finish on the aprons should not resemble the texture and color of adjacent sidewalks. Brick or stone pavers are not recommended for the truck aprons because they can break loose and are difficult to plow.

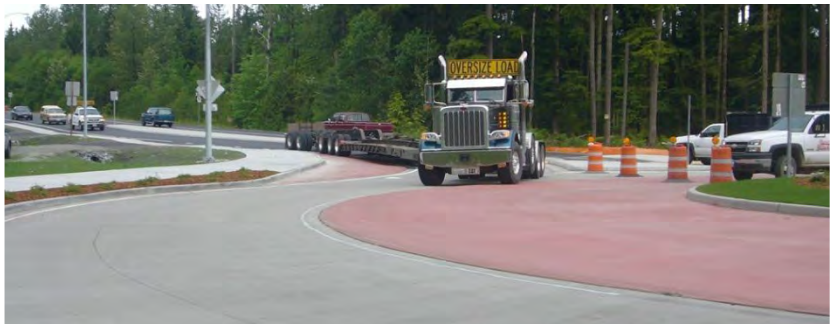
TRUCK APRON SLOPES SHOULD BE EQUAL TO OR LESS THAN 1% OF THE ADJACENT CIRCULATORY ROADWAY WHEN THE USING A CONTINUOUS OUTWARD CROSS SLOPE.

5.5.4 OVERSIZE/ OVERWEIGHT VEHICLES

Additional design vehicle checks may be necessary at roundabouts expected to serve OSOW vehicles where alternative routes are not available. Where available, designers should review three to five years of permitted load records to identify OSOW control vehicles and their respective origins and destinations. Simulations of these control vehicles can help identify the removable sign area or where an outside truck apron is required. Examples of these treatments are illustrated in Figure 5-21. Other strategies for accommodating OSOW vehicles include a larger ICD, wider circulatory roadway, mountable splitter islands, central island cut-throughs, and approach cut-through treatments. A designer should be aware of surrounding industries and perform additional OSOW design checks. Careful placement of traffic signs, roadside furniture and utility vaults and junction boxes can also reduce damage and facilitate vehicle movement. Vertical design along the OSOW alignment may require special investigation to reduce the risk of vehicles high centering as they traverse the roundabout.

FIGURE 5-21: EXAMPLES OF OSOW VEHICLE ACCOMMODATIONS

Removable Sign in Use in Washington
Courtesy of Brian Walsh, Washington State Department of Transportation



Increased Width of Central Truck Apron and Outside Truck Apron
Courtesy of Kelli Owen

AN OUTSIDE TRUCK APRON AND/OR MOUNTABLE SPLITTER ISLAND CAN BE USED IN CIRCUMSTANCES WHERE OTHER DESIGN MODIFICATIONS ARE UNABLE TO ACCOMMODATE LARGER DESIGN VEHICLES.

5.6 SIGHT DISTANCE & VIEW ANGLES

Sight distance is a fundamental consideration for intersection design. There are two types of sight distance that apply to roundabouts: stopping sight distance and intersection sight distance. Stopping sight distance must be provided for users approaching the roundabout and for users traveling through the roundabout. Intersection sight distance, sometimes called “sight triangles” must be provided for drivers entering the roundabout. The principles of intersection and stopping distance are well documented in the *AASHTO Green Book* (1) in general, and the *NCHRP Report 672* (4) describes the principles as they apply to roundabouts.

5.6.1 SIGHT DISTANCE

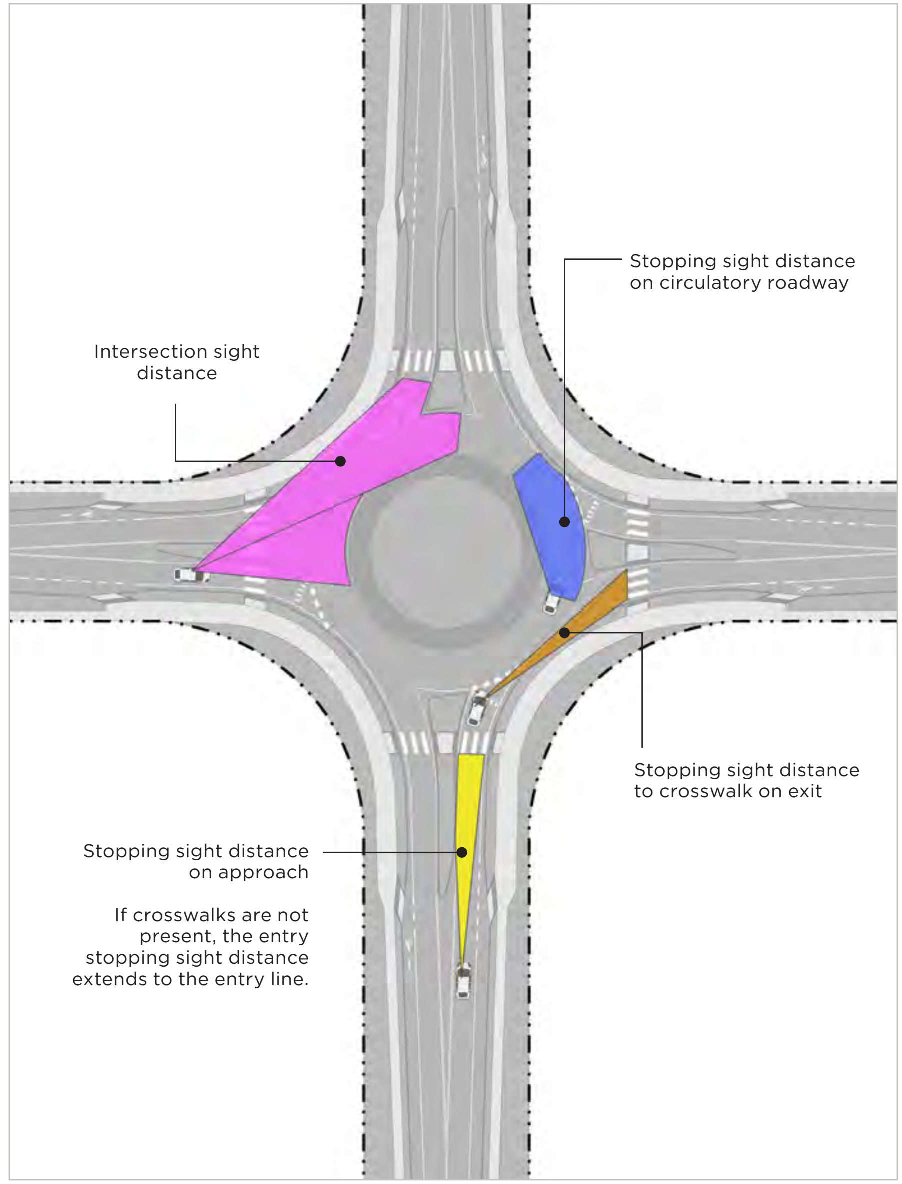
Roundabout designs should provide clear lines of sight to crosswalks on both the entry and exit, yield lines, and around the circulatory road. Sight distance is not required through the central island. Excessive sight distance on approaches can promote higher vehicle speeds.

5.6.2 SIGHT DISTANCE CHECKS

Minimum sight distance checks at roundabouts include: approach sight distance, sight distance on circulatory roadway, and sight distance to crosswalk on exit. Distances to these critical locations are measured as the stopping sight distance required based on predicted speeds at specific locations as developed for the fastest path analyses.

Intersection sight distance is measured on each entry and is based on the theoretical travel speeds (fastest paths) of potentially conflicting vehicles. Drivers looking upstream from their entry are typically concerned with circulating vehicles and vehicles entering the roundabout from the left-adjacent approach. Stopping sight distance triangles and intersection sight distances are illustrated for a single-lane roundabout in Figure 5-22. The composite sight distance diagram at a roundabout are the combination of all stopping sight distance and intersection sight distance triangles for all intersection legs. An example of a composite sight distance diagram is illustrated in Section 5.7 Landscape Considerations. Designers need to provide landscape professionals the composite sight distance diagram for a roundabout and work collaboratively to limit vertical design elements that obscure the driver's view of critical decision-making points.

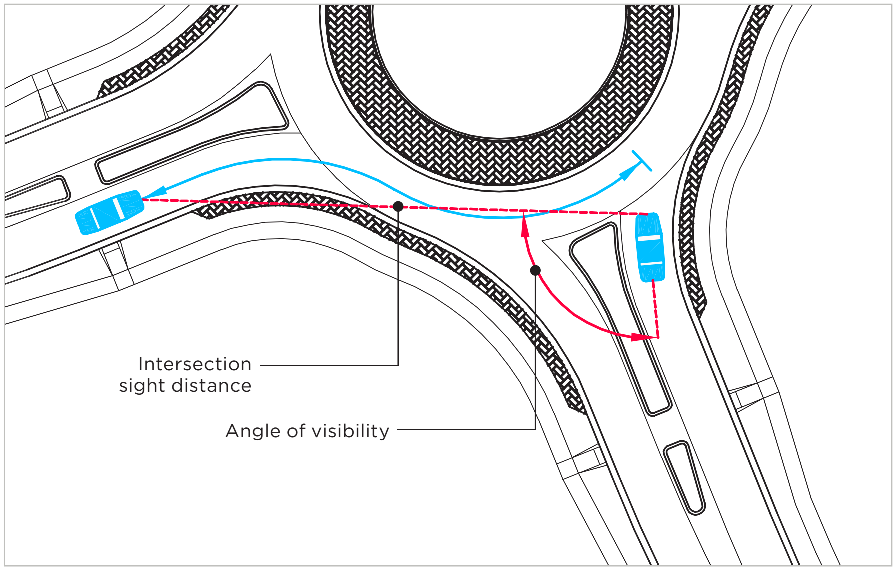
FIGURE 5-22: EXAMPLE SIGHT DISTANCE CHECKS



5.6.3 VIEWING ANGLE

The design should consider the viewing angle between the approaches. Drivers should be able to turn their heads to the left and see oncoming traffic. The viewing angle, as shown in Figure 5-23, is measured between the trajectory of the entering vehicle at the yield line and a vehicle on the left-adjacent approach placed back at the intersection sight distance. The minimum intersection viewing angle should be 75 degrees. Narrower viewing angles can occur at roundabouts with entries less than 90 degrees apart, roundabouts with more than four legs, roundabouts with consecutive entries (such as at freeway ramp terminals), and roundabouts with a very large ICD.

FIGURE 5-23: EXAMPLE ANGLE OF VISIBILITY CHECK



5.7 LANDSCAPE CONSIDERATIONS

THE DESIGN OF A ROUNDABOUT LANDSCAPE CAN PROVIDE SEVERAL BENEFITS:

Plants – along with pavement, markings, curbing, or walls – can reinforce the geometry of the intersection and enhance navigational cues for all modes, particularly for people walking.

Plantings can mitigate impacts of the large intersection pavement area, improve stormwater infiltration, reduce heat island impacts, and capture particulate matter from vehicular exhaust.

At the same time, the landscape can be an attractive focal point or entryway to integrate the roundabout into the surrounding community.

GENERAL LANDSCAPE DESIGN CONSIDERATIONS INCLUDE THE FOLLOWING:

Sight lines for drivers, people walking, and people biking will shape the landform, as well as the types and locations of plant materials. Sight lines are determined from the site-specific intersection geometry and form the basis of a Combined Sight Distance Diagram (see Section 5.6.1).

Site conditions including soil quality and landscape context will determine the types and species of plant material.

Community expectations must be balanced with maintenance considerations, including local resources for special requirements, as well as budget and site constraints. In general, a more naturalized design will require less long-term maintenance.

Use a diverse palette of native species adaptive to the context in order to maximize biodiversity and climate change resiliency.

Refer to the MassDOT PD&DG (8), Chapter 13, for more specific guidance on appropriate strategies for roundabout landscape design.

5.7.1 LANDSCAPE AREAS IN A ROUNDABOUT

From a landscape design standpoint, the intersection is composed of landscape areas, which are shown in Figure 5-24 and Figure 5-25, and briefly described below.

APPROACH LANDSCAPE BUFFER

The approach landscape buffer is an extension of the approach road buffer strip. Typically this area is turfgrass, although it can be planted with other groundcover that meets sight line requirements.

WAYFINDING BUFFER

The wayfinding buffer is intended to both separate people walking and biking from the road and to guide them to crosswalks. The material should contrast from both the road and the sidewalk or shared-use path. Turfgrass is often the most cost-effective groundcover for the buffer although it may be difficult to maintain because of snow load and similar traffic impacts. If paved, the surface should be a non-traversable surface, such a high-relief pattern concrete surface.

PERIMETER LANDSCAPE

The remaining landscape areas are collectively referred to as the perimeter landscape. Where these areas are within the right-of-way, they provide an opportunity for transition planting to aid in traffic calming, integrating the roundabout landscape into the surrounding landscape. These areas also potentially provide an attractive frontage for adjacent businesses and residents, or a minimally maintained transition to adjacent natural landscapes.

SPLITTER ISLANDS

Splitter islands can be planted, paved, or a both. However, sight lines must be maintained. Where the splitter island is paved, road and walkway pavement should contrast by color and, ideally, by texture as well.

CENTRAL ISLAND

The central island is comprised of a paved truck apron, an outer central island landscape, and an inner central island landscape. The central island should be viewed from the perimeter of the roundabout and should not attract people in. Avoid amenities that might draw people to the center island, such as paths, benches, or small signs. Limit signs to the minimum necessary for traffic control. Community welcome signs are best located in the perimeter landscape.

TRUCK APRON

The paved truck apron, which drains to the road, is typically a textured pavement that contrasts in color from the roadway and perimeter walkways.

OUTER CENTRAL ISLAND LANDSCAPE

The limit of the outer central island landscape is determined by the sight distance requirements. This zone is typically a minimum of six feet wide and planted in turfgrass, although other plants with a maximum mature height of two feet may also be used.

INNER CENTRAL ISLAND LANDSCAPE

The key function of the inner central island landscape is to alert approaching drivers to the change in roadway geometry and guide them around the roundabout intersection. It is typically, mounded and/or planted to enhance its visual prominence. Since this area supports safety in the roundabout, the landscape should provide safety functions immediately after construction. Planting can vary, including trees, shrubs, tall grasses. Low walls and other fixed elements, such as public art, should be located where they do not present a safety hazard for errant vehicles. In all cases, the landform of the inner island must address traffic function, aesthetic, and maintenance considerations. In some instances where conditions are appropriate and the island is of sufficient size, the inner central island landscape may be developed as a stormwater Best Management Practices (BMPs). For additional guidance on stormwater BMPs, refer to the MassDOT PD&DG (8) Landscape Section, as well as the MassDOT Stormwater Guide.

> LANDSCAPE CONSIDERATIONS FOR LOW VOLUME ROADS.
> The center island of mini-roundabouts are typically traversable and therefore paved and not planted. Traffic circles are subject to the same considerations for plant selection and location as roundabouts.

Small diameter roundabouts may have insufficient central island space to accommodate both an outer and inner landscape area. These cases may also feature lower central island landforms that do not block the driver's view across the island. See Figure 5-25 for a range of elevations. In these cases, plantings should be added in the available central island landscape zone to block the driver's view across the island. Plantings within six feet of the truck apron's edge cannot exceed trunk sizes considered fixed objects by the *AASHTO Roadside Design Guide* (11).

FIGURE 5-24: LANDSCAPE AREAS

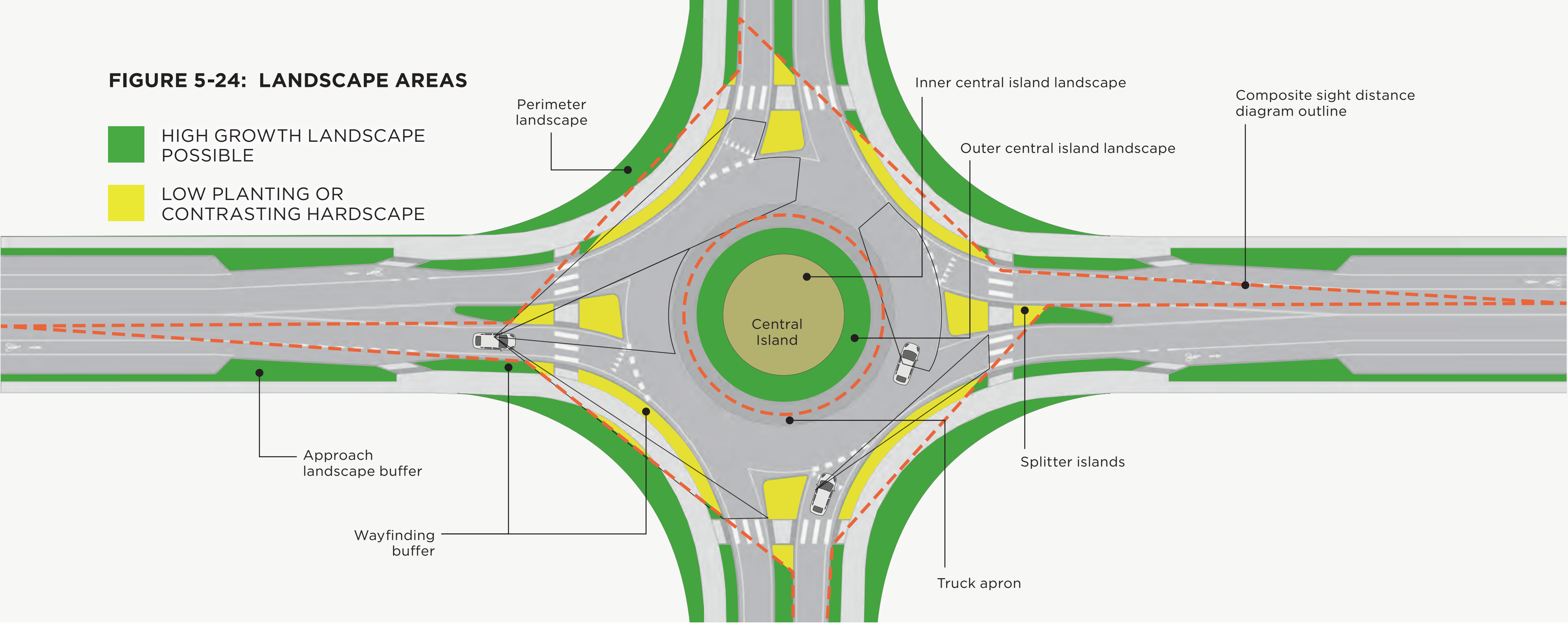
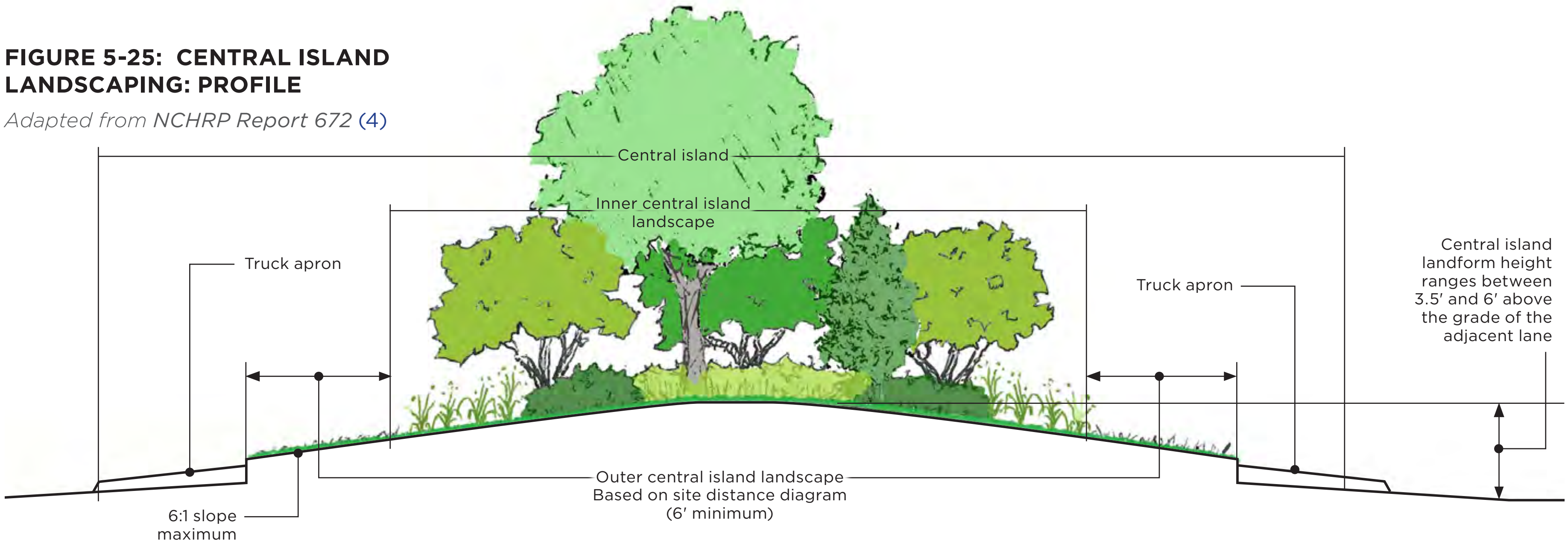


FIGURE 5-25: CENTRAL ISLAND LANDSCAPING: PROFILE

Adapted from NCHRP Report 672 (4)



5.8 PATH ALIGNMENT

Geometric elements of a multilane roundabout affect the path vehicles take circulating through the intersection. Entry geometry in particular can lead vehicles in the outside lane to drift toward the central island and obstruct the path of a vehicle in the inside lane, as illustrated in Figure 5-26.

5.8.1 PATH ALIGNMENT CHECKS

Vehicles are guided by geometric elements augmented by lane markings up to the entrance line of a roundabout. At this point, vehicles will continue along their natural trajectory into the circulatory roadway, based on their speed and orientation. If the paths of adjacent vehicles overlap, there is potential for conflict, which creates operational inefficiency and increases the potential for crashes. Figure 5-26 illustrates the potential path overlap between two entering vehicles. Figure 5-27 details how to develop and test the entry vehicles paths. Small entry radii can produce path overlap by orienting the vehicle in the outside lane toward the inside circulating lane. Overly small exit radii may result in overlapping vehicle paths when the inside circulating vehicle is oriented toward the outside exit lane.

Multilane roundabout entries and exits should be designed to align vehicles into the appropriate receiving lanes. The curvilinear design technique shown in Figure 5-27 orients entering or exiting vehicles toward their appropriate receiving lanes with a short tangent between the intersection leg geometry and the circulating lanes. The entry pavement marking between the two lanes should include at least a five-foot tangent in advance of the entry line. The result of such design is illustrated in Figure 5-27.

FIGURE 5-26: ENTRY PATH EXAMPLES AT A MULTILANE ROUNDABOUT

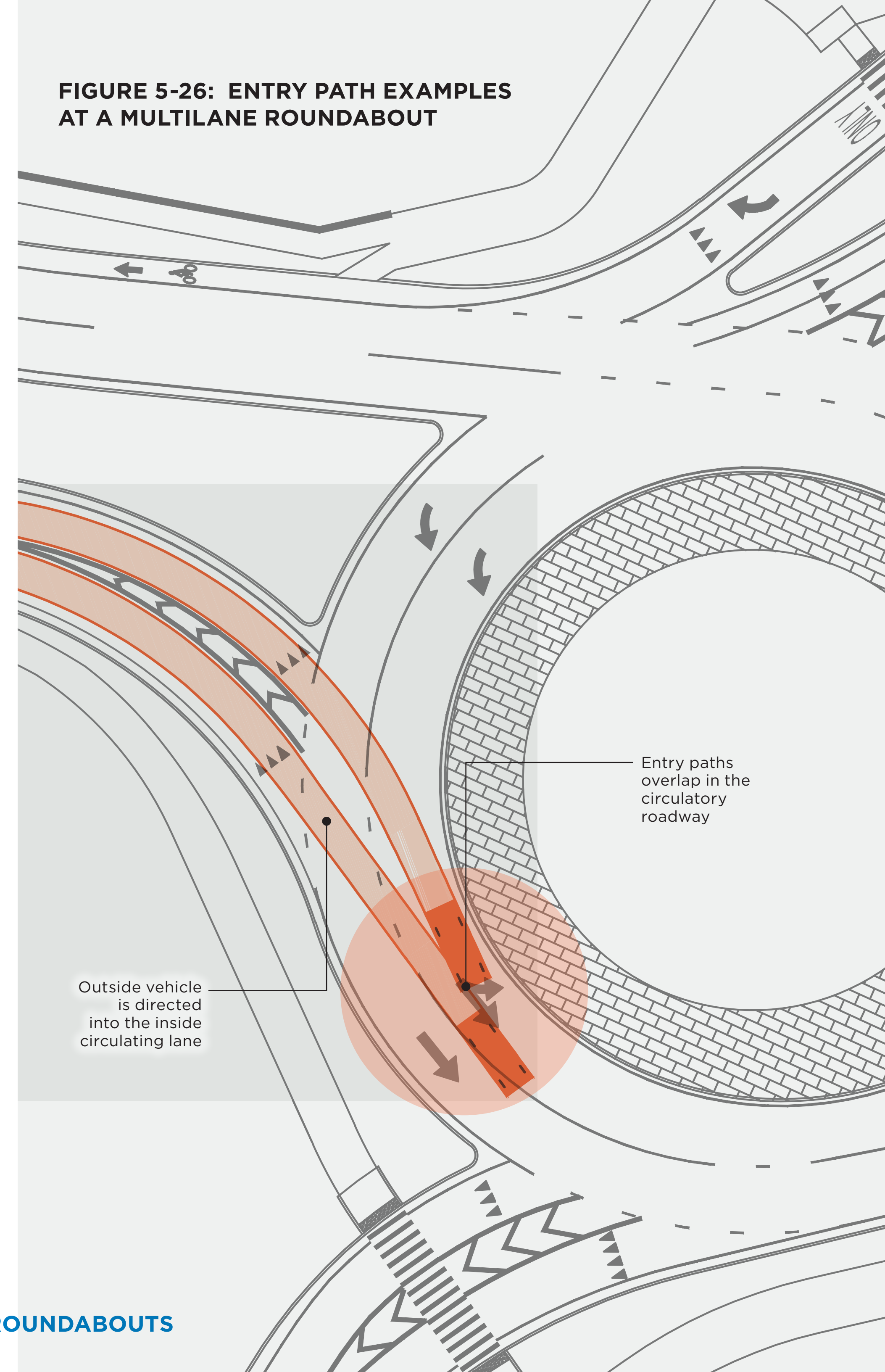
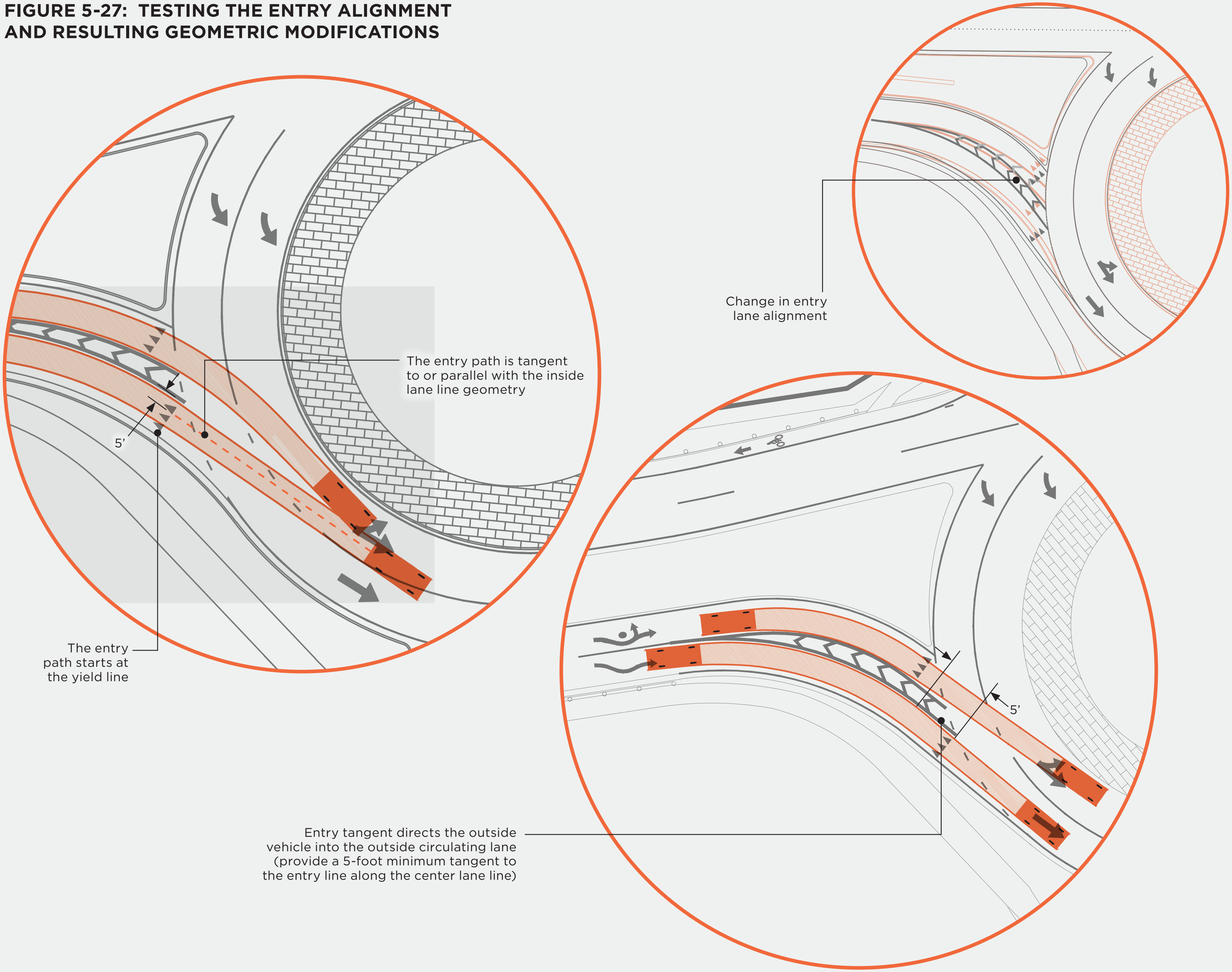


FIGURE 5-27: TESTING THE ENTRY ALIGNMENT AND RESULTING GEOMETRIC MODIFICATIONS



5.9 ALTERNATIVE FORMS & DESIGN DETAILS

5.9.1 CONSTRAINED LOCATIONS

A common constraint is the availability of right-of-way in urban areas. Mini-roundabouts with mountable central islands are an appropriate solution in these situations and often can fit within the existing intersection footprint. Figure 5-28 illustrates the components of a mini-roundabout. Figure 5-30 illustrates the layout of a mini-roundabout within the existing intersection of two residential streets. *NCHRP Report 672* (4) Section 6.6 provides design guidelines for mini-roundabouts. Mini-roundabouts are also being used on higher speed roadways suburban and rural settings but require speed reduction treatments on the approaches such as reverse curves and long.

Figure 5-29 illustrates components of a compact roundabout. A compact roundabout features minimum splitter island dimensions or uses a six-foot-wide traffic separator and generates most of the vehicle path deflection through the central island. Figure 5-29 illustrates an example of a compact roundabout with typical traffic separators as splitter islands. Both mini- and compact roundabouts need to follow the roundabout design principles outlined in Section 5.1; however, the design checks should be analyzed in the context of the adjacent roadway geometry and land uses.

FIGURE 5-28: MINI-ROUNDABOUT DESIGN ELEMENTS

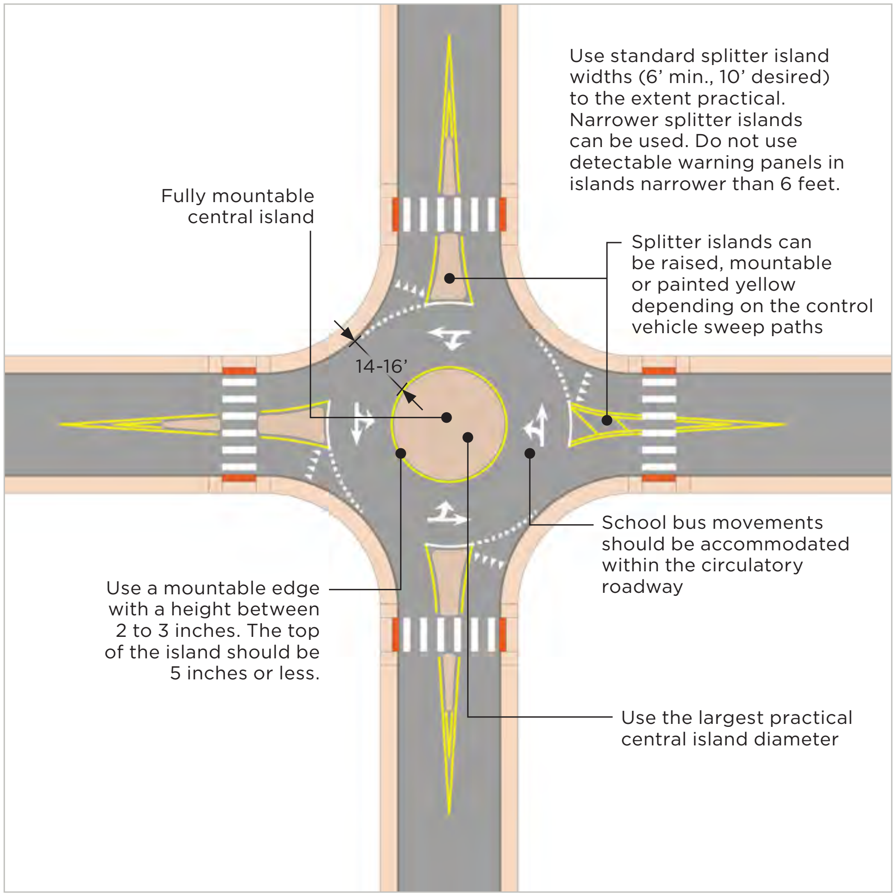


FIGURE 5-29: COMPACT ROUNDABOUT DESIGN ELEMENTS

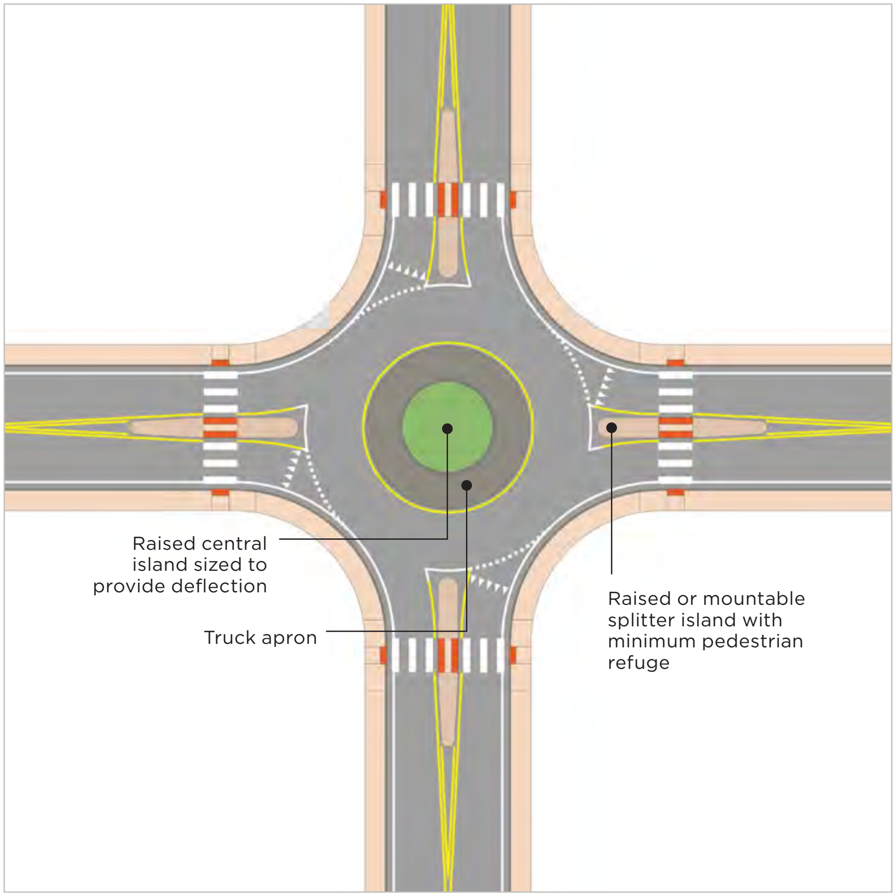
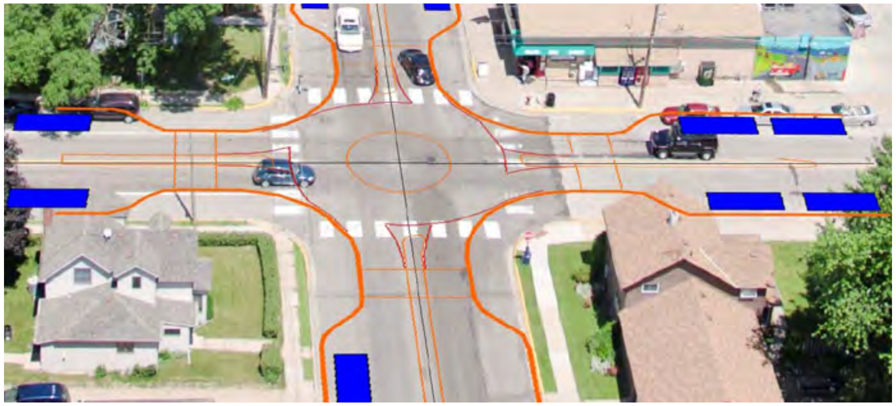


FIGURE 5-30: MINI-ROUNDABOUT CURBS OUTLINE WITH AN EXISTING INTERSECTION AREA IN STILLWATER, MN

Courtesy of Wei Zhang, PhD, PE, FHWA



5.9.2 SPECIAL CUT-THROUGH USES

Roundabouts near at-grade railroad crossings require special considerations. At-grade railroad crossings for transit or freight lines are acceptable on roundabout approaches and lines sometimes cross the roundabout itself, as illustrated in Figure 5-31. *NCHRP Report 672* (4) Section 7.6 provides guidelines for integrating at-grade railroad crossings into roundabout design.

As noted in Section 5.5.4, special lanes closed to general traffic could also be developed through the central island to accommodate OSOW vehicles.

FIGURE 5-31: LIGHT RAIL TRACKS CROSSING THROUGH A ROUNDABOUT IN SALT LAKE CITY, UT

Courtesy of Google Maps ©2017

5.9.3 CLOSELY-SPACED INTERSECTIONS

Side-by-side roundabouts can be designed if the queue between the intersections does not block the upstream circulating flow. Closely spaced roundabouts can provide a continuous flow of traffic at side-by-side T-intersections. Figure 5-32 illustrates high capacity roundabouts installed side-by-side at a frontage road intersection and at a freeway ramp terminal. Providing ample capacity minimizes the potential for queuing and allows roundabouts to be closely spaced without losing significant operational efficiency. Private access roads serving large commercial land uses that generate high traffic volumes should be treated as full side-street intersection legs. Side-by-side roundabouts should be spaced based on the queuing results obtained during the traffic operations analysis. Queues between roundabouts should not spill into the adjacent intersection.

FIGURE 5-32: SIDE-BY-SIDE ROUNDABOUTS AT US 23 & LEE ROAD, LIVINGSTON COUNTY, MI

5.9.4 OBLONG ROUNDABOUT FORMS

Roundabouts can take elliptical and interconnected circular shapes to fit the geometry between adjacent intersection legs. Oblong roundabouts have longer central islands in order to provide visibility and entry path deflection for intersections with varying width legs or centerline off-sets. Oblong roundabouts may also help to create better separation between approaches at intersections with more than four legs.

Interconnected circular shaped roundabouts (also known as a peanutabout, a dog bone, or a racetrack) are two side-by-side intersections where the central island extends between both intersections. Left-turn and U-turn movements travel around both ends of the roundabout. An example of a peanutabout is Kelley Square in Worcester illustrated in Figure 5-33.

The designer should evaluate alternative shapes for the central island that support the roundabout design principles outlined in Section 5.1.

FIGURE 5-33: KELLEY SQUARE, WORCESTER PEANUTABOUT DESIGN ILLUSTRATION

5.9.5 INTERCHANGE RAMP TERMINAL INTERSECTIONS

Roundabouts are acceptable alternatives to ramp terminal intersections. They can provide cost benefits since roundabout approaches may require fewer lanes, which can lead to narrower bridge designs compared to signalized intersections. Roundabouts also establish slower operating speeds for all approaching vehicles within the interchange area, which helps to slow drivers from the high operating speeds of freeways to lower local road speeds. Figure 5-34 illustrates the geometric layout of two roundabouts at an interchange along Route 146 in Millbury, Massachusetts. Diamond interchange terminals could also feature a pair of "teardrop" roundabouts.

CLOSE ATTENTION SHOULD BE GIVEN TO OFF-RAMP QUEUING LENGTHS AT FREEWAY RAMP INTERSECTIONS.

FIGURE 5-34: INTERCHANGE LAYOUT AT ROUTE 146 AND WEST MAIN STREET IN MILLBURY WITH ROUNDABOUTS

Adapted from Project No. 605964 Plans

5.9.6 ACCESS MANAGEMENT

Access management at roundabouts follows the same context-based principles outlined in Chapter 15 of the MassDOT PD&DG (8). Driveways are points of access to private properties and are not intersections in themselves.

Driveways within the roundabout are allowed but discouraged if other access locations exist onto a property if relocating them to the roundabout approach is reasonable. *NCHRP Report 672* (4), Section 6.11.1 discusses when driveways should be allowed within roundabouts and how they should be designed.

Access near the roundabout, especially between the entry and pedestrian crosswalk, is also discouraged. Driveways shall be located a minimum of 50 feet and desirably 75 feet away from the entry line into the roundabout. Driveways located along the splitter island on a roundabout approach will operate as right-in-right-out only and can use the roundabout itself to make a U-turn. *NCHRP Report 672* (4), Section 6.11.2 provides further detail for locating driveways or public access on a roundabout approach.

DRIVEWAYS SHALL BE LOCATED A MINIMUM OF 50 FEET AND DESIRABLY 75 FEET AWAY FROM THE ENTRY LINE INTO THE ROUNDABOUT.

5.9.7 PARKING

Parking is not allowed within the circulatory roadway. On-street parking on the approaches should not compromise the performance of the roundabout or safety of its users. On-street parking should be set back at least 20 feet from the pedestrian crosswalks.

ON-STREET PARKING SHOULD BE SET BACK AT LEAST 20 FEET FROM THE PEDESTRIAN CROSSWALKS.

5.9.8 TRANSIT

Transit stops can be located on approaches to roundabouts but never in the circulatory roadway. Bus stops in the exit lane that block traffic should be avoided because of the potential of queues into the circulatory roadway. Bus bays or turnouts should be designed integral with the roundabout geometry and should not compromise the performance of the roundabout or pedestrian safety. Turnouts are not recommended on multilane approaches because it may be more difficult for buses to re-enter traffic. Designers should review local transit agency guidelines to determine the need for turnouts.

NCHRP Report 672 (4), Section 6.8.4 provides details on locating bus stops at roundabouts.

5.9.9 HIGH-SPEED APPROACHES

Roundabouts in rural settings or on high speed facilities need to be introduced to drivers well in advance of the intersection. Roundabout approach geometry should be designed to make the central island and shape of the roundabout visible to the driver early.

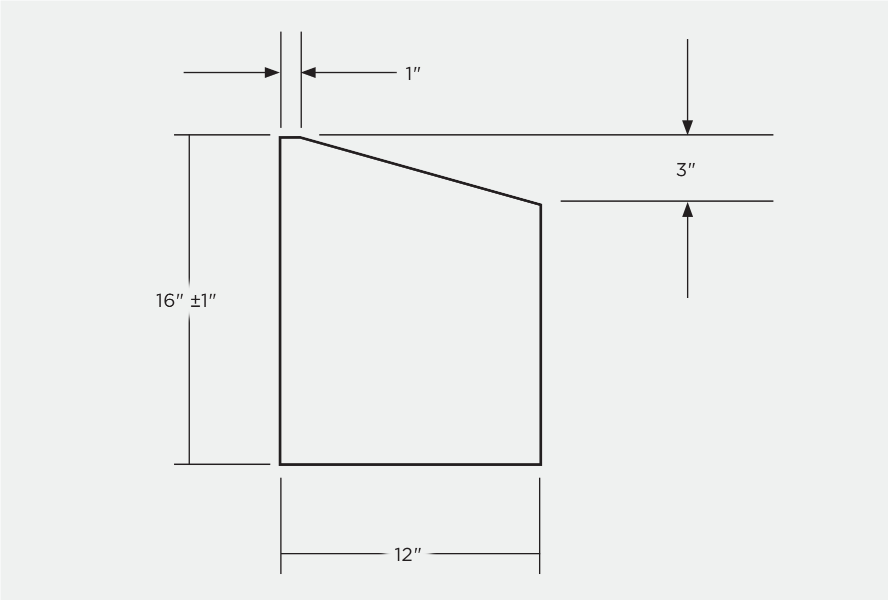
Splitter islands with additional curvature that deflects the through vehicle path can increase driver awareness of an approaching roundabout and start the deceleration process. Figure 5-7 provides design details for splitter islands on high-speed roads. *NCHRP Report 672* (4), Section 6.8.5 discusses treatments for high-speed approaches in more detail.

5.9.10 CURB TYPES

Roundabouts require two main types of curbs: mountable around truck aprons and vertical for all other elements. Mountable curbs around the truck apron discourage smaller vehicles from driving onto the apron but allow truck trailers to climb over. Figure 5-35 illustrates the preferred mountable granite curb details. Other mountable curbs with three inch reveals are also acceptable. Mountable curbs with reveals higher than three inches should be avoided because they can destabilize truck trailers and lead to roll-overs.

Vertical curbs are preferred on splitter islands, as they provide clear visual cues to drivers. Non-traversable central islands could also be separated from truck aprons with vertical curbs; however, curb types should be consistent with the intersection plan to accommodate OSOW vehicles.

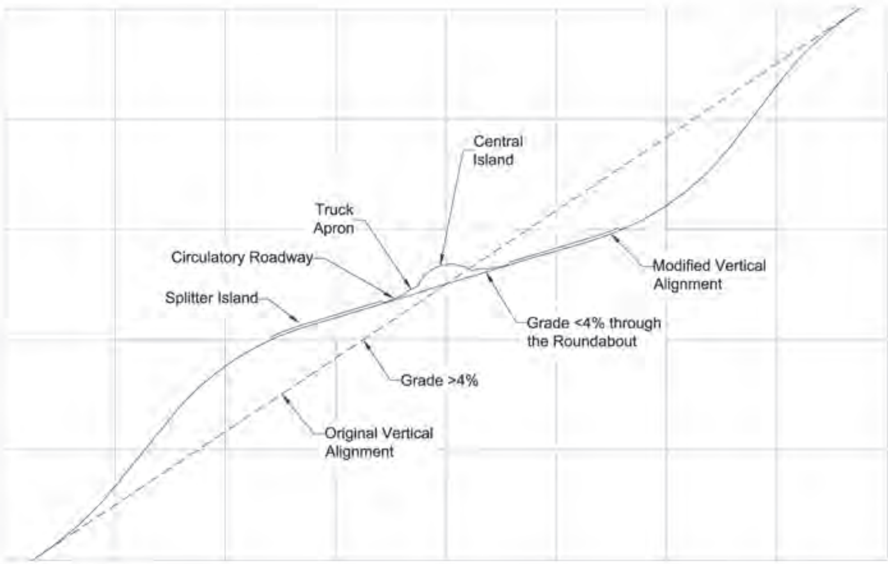
FIGURE 5-35: MOUNTABLE CURB DETAIL



5.9.11 VERTICAL CONSIDERATIONS

Section 6.8.7 of *NCHRP Report 672* (4) provides design guidance on profiles, superelevation, approach grades, and drainage. Roundabouts can be constructed at a mix of topographic locations; however, approach grades should be designed in conjunction with the circulatory cross-section or intersection plane to reduce acute grade changes on entries and exits. The intersecting roadway profiles through the intersections should be adjusted to 4% (uphill or downhill) or less. Steep grades affect the deceleration and acceleration rates, especially for trucks. Figure 5-36 illustrates a vertical grade transition through the approach geometry to 4%. The circulatory roadway in the example is built on a plane sloping from the right to the left.

FIGURE 5-36: ROADWAY PROFILES AT A ROUNDABOUT



5.9.12 DRAINAGE

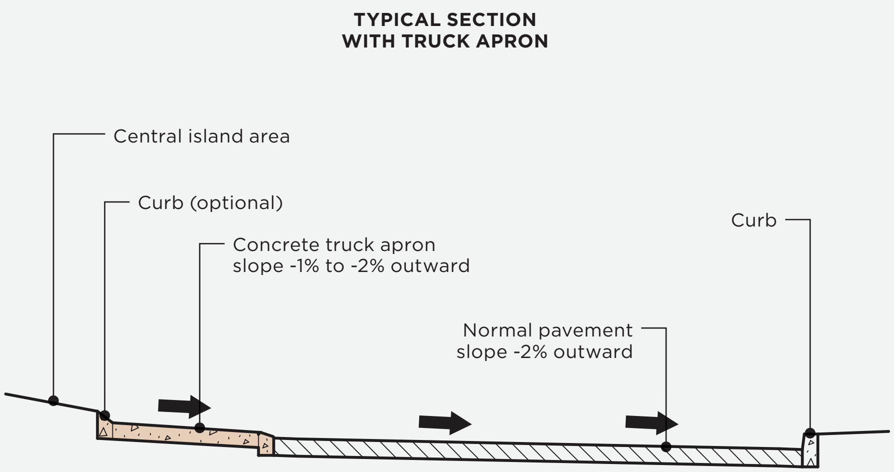
Pavement drainage follows the cross-section and profile of the circulatory roadway and will typically flow toward the outer curb of the roundabout. In situations where the circulatory roadway is crowned or the entire roundabout is sloped as one plane, drainage may flow toward the central island along the truck apron curb line. Drainage inlets should be placed upstream of pedestrian crossing areas at both the entries and exits. Roundabout pavement drainage design follows the same requirements listed in the PD&DG (8), Section 8.4 for MassDOT facilities.

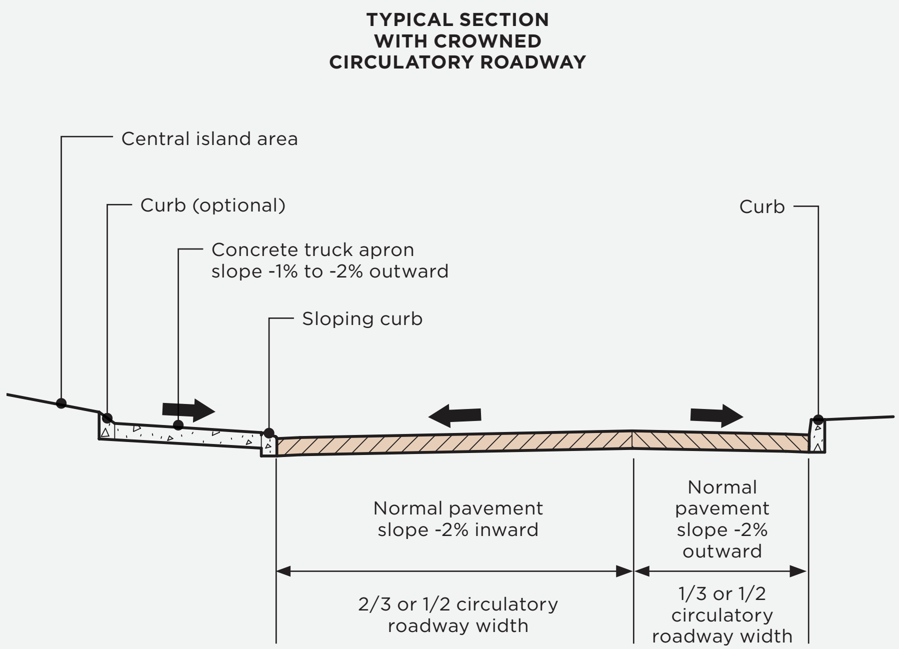
5.9.13 CIRCULATORY ROADWAY CROSS-SECTION

Circulatory roadways are generally built with an outward slope of 2% away from the central island. This technique is recommended for single-lane roundabouts located in flat terrain. It increases the visibility of the central island and it promotes slower circulating speeds. In hilly terrain, cross slopes can vary around the central island in order to better match the approaching roadway profiles. This technique is called tilted plane or folding plane and allows the circulatory roadway to be warped and sloped inward or outward from the central island to match the roadway profile and existing intersection topography. Multilane circulatory roadways can be built with an outward slope or crowned as illustrated in Figure 5-37. Crowning the circulatory roadway reduces the slope experienced by the rear wheels of tractor-trailers as they straddle the truck apron and adjacent lane. This may reduce the likelihood of load shifting and provide more stable turn maneuvers for semi-trailer trucks. This grading technique is recommended at locations with high truck volumes. Section 6.8.7.3 of the *NCHRP Report 672* (4), provides additional details and other vertical design options.

FIGURE 5-37: CIRCULATORY ROADWAY CROSS-SECTION OPTIONS

Adapted from NCHRP Report 672 (4), Exhibits 6-76 and 6-77





5.10 SIGNING

Signage at roundabouts should "enhance and support driver expectations" (4). Signs should be visible to drivers without obstructing other users (i.e. pedestrians or bicyclists). Chapter 2 of the *MUTCD* (2) provides guidance on the size and placement of roundabout signs. Figure 5-39 provides MassDOT-specific guidance on appropriate roundabout signing.

5.10.1 REGULATORY SIGNS

Section 2B.45 of the *MUTCD* (2) provides examples of roundabout signing. MassDOT-specific recommendations not found in the *MUTCD* (2) include:

- An additional yield (R1-2) sign should be placed in the splitter island on the left-hand side of an entry wider than 18 feet or if sight distance to the right-hand Yield sign is obstructed.
- Directional arrow (R6-4, R6-4a, and R6-4b) signs may be mounted at a four-foot height from the truck apron elevation.
- Lane control (R3-8) signs with fish-hook arrows should be used in advance of multilane roundabouts. Use a circle with the arrow for the inside lane closest to the roundabout central island.

5.10.2 WARNING SIGNS AND OBJECT MARKERS

Circular intersection (W2-6) symbol signs should be installed in advance of a roundabout if space permits. This sign assembly can be omitted on approaches to roundabouts in dense urban environments or locations where directional or regulatory signs create clutter. Auxiliary advisory speed plaque (W13-1P) is not recommended for roundabouts. Auxiliary Roundabout (W16-17P) plaque is optional but should be omitted to reduce sign clutter.

5.10.3 SUPPLEMENTAL TREATMENTS

Text warning signs could be used on constrained approaches that use Case 1 to accommodate large vehicles. "Do not drive next to trucks" or a similar warning signs could be used to alert drivers of potential truck encroachment on adjacent lanes. Designers should consult MassDOT staff before using non-standard signs.

Drivers could be warned if a roundabout exit was not designed for a large truck. Such signs could prohibit trucks from turning right or could advise them to make a 270-degree right turn around the truck apron, as illustrated in Figure 5-38.

FIGURE 5-38: TRACTOR-TRAILER TRUCK RIGHT-TURN ADVISORY SIGN

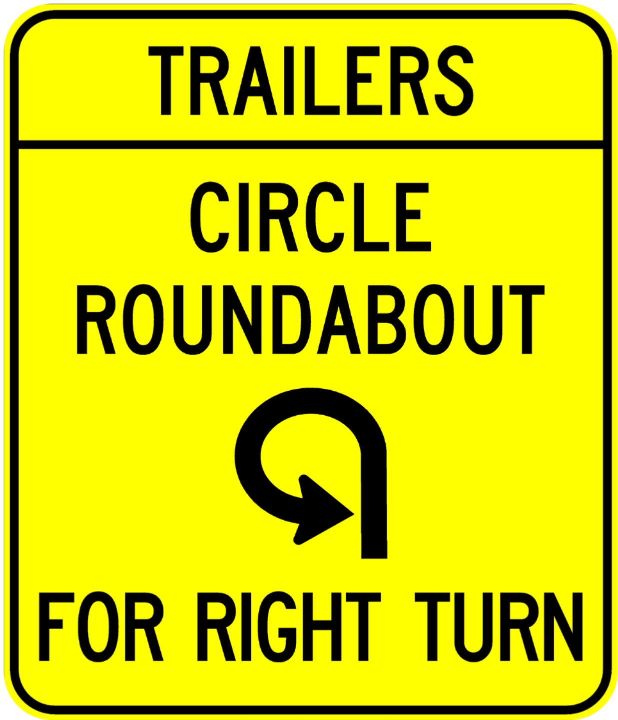
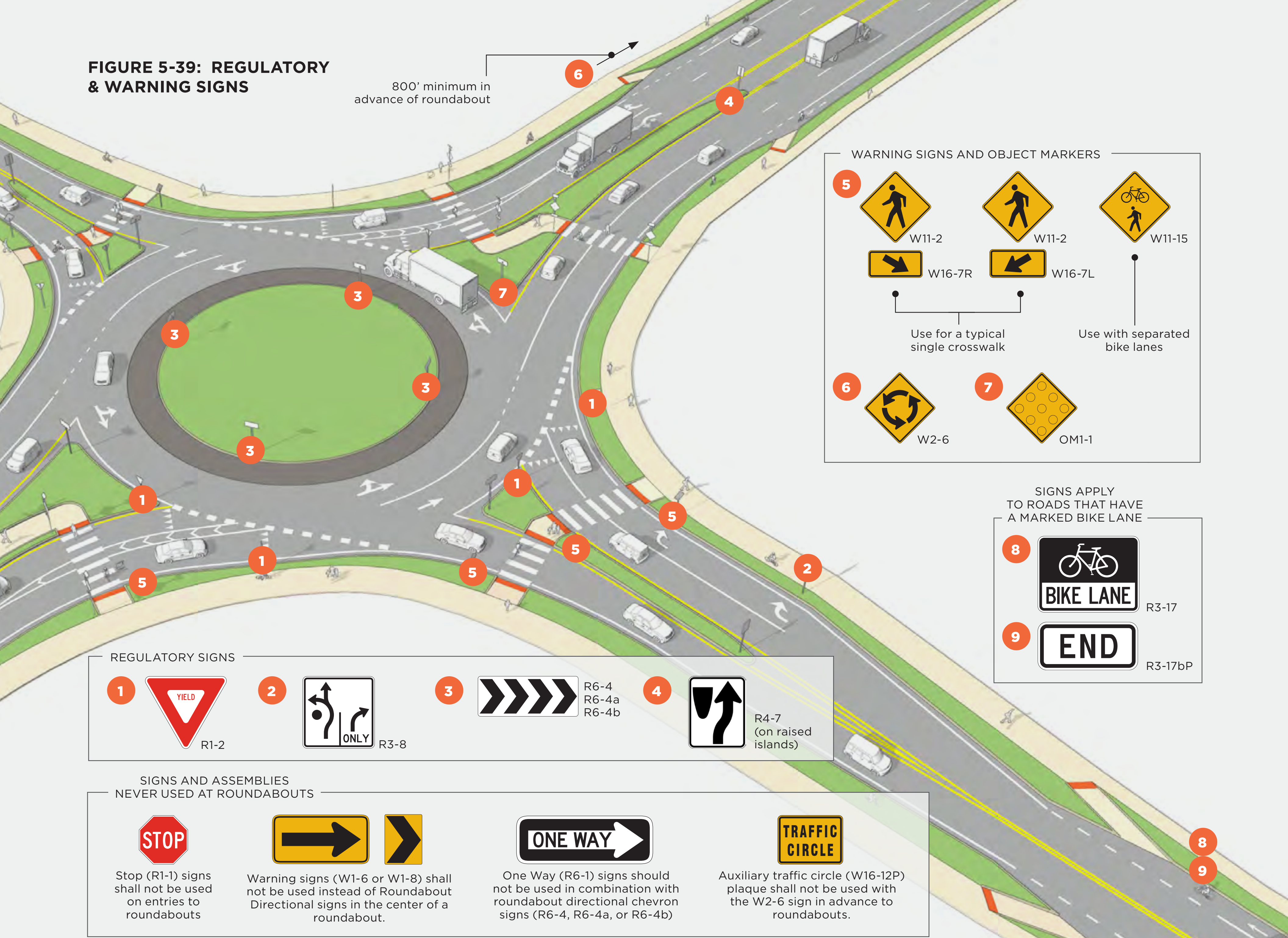


FIGURE 5-39: REGULATORY & WARNING SIGNS



Stop (R1-1) signs shall not be used on entries to roundabouts

Warning signs (W1-6 or W1-8) shall not be used instead of Roundabout Directional signs in the center of a roundabout.

One Way (R6-1) signs should not be used in combination with roundabout directional chevron signs (R6-4, R6-4a, or R6-4b)

Auxiliary traffic circle (W16-12P) plaque shall not be used with the W2-6 sign in advance to roundabouts.

5.10.4 GUIDE SIGNS

Guide signs provide route and destination information ahead of a roundabout and prepare drivers to select an entry lane and the appropriate exit. The placement of destination signs at circular intersections is discussed in Section 2D.38 of the *MUTCD* (2). The following are Massachusetts-specific guidelines for selecting destination sign assemblies.

Diagrammatic (D1-5) signs are useful if a numbered route changes direction through a roundabout or there are multiple routes intersecting. Diagrammatic signs should be used on freeway off-ramps and may be used at rural roundabouts with sufficient right-of-way. Diagrammatic signs may also be appropriate at an urban intersection with any of the following conditions:

- Sufficient right-of-way is available to locate the sign without intruding on pedestrian spaces.
- The intersection is the junction of two or more numbered routes.
- A numbered route makes a turn though the roundabout.
- The intersection layout or signed route configuration is potentially confusing to unfamiliar drivers.
- The sign can be located so it does not significantly add to sign clutter.

Routing and destination information can be presented on smaller sign panels (D1-3d) when diagrammatic signs are not practical or desired. *NCHRP Report 672* (4), Exhibit 7.25 provides guidelines for the advanced placement of routing and destination signs.

Confirmation signs should be installed on the exit nose of splitter islands. A modified version of MassDOT sign MA-D1-5 can typically be used to serve this purpose. These signs confirm for drivers the destination served by each roundabout exit. Refer to the *MassDOT Standard Sign Book* for layout details and dimensions.

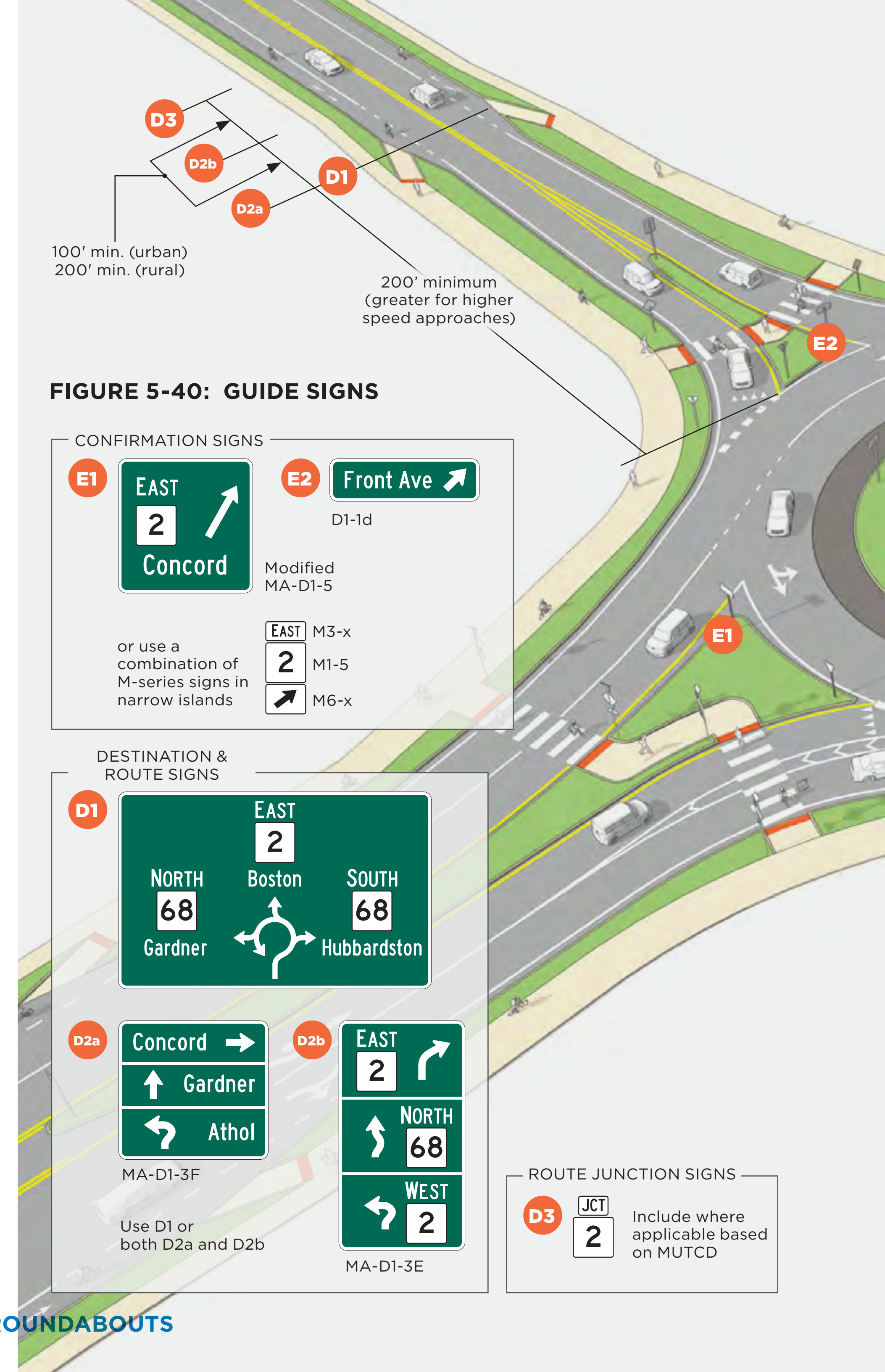


FIGURE 5-40: GUIDE SIGNS

5.11 MARKINGS

MassDOT pavement marking plans at roundabouts should follow the guidance provided in Chapter 3C of the *MUTCD* (2). This section provides Massachusetts-specific preferences and marking details for implementing *MUTCD* (2) guidelines.

5.11.1 APPROACH PAVEMENT MARKINGS

NCHRP Report 672 (4), Section 7.3.1 describes in detail the approach and departure pavement markings at a roundabout. Figure 5-41 illustrates an example of typical markings at a roundabout. In Massachusetts, yield lines (see *MUTCD* (2), Section 3B.16) should be included across all entry lanes into a roundabout. They are placed perpendicular to the direction of traffic. The virtual left-hand starting point of the yield line should align with the intersection between the solid yellow edge line and the circulatory solid white edge line. The virtual left-hand start of the yield line in the outside lane on multilane entrances should start at the intersection between the solid white lane line and the circulatory roadway dotted white entry line.

Pavement markings should be compatible with the approach signing and provide consistent directions. Fish-hook lane-use arrows should be used to designate the appropriate movements through a multilane roundabout. Pavement symbols used on the inside lane should feature a dot to illustrate the central island.

5.11.2 CIRCULATORY ROADWAY PAVEMENT MARKINGS

Multilane roundabouts should have solid white lane line markings within the circulatory roadway to channelize traffic to the appropriate exit lane. Lane use arrows can also be used in the circulating lanes. A dotted white lane line extension (DWLEx) should be provided at locations where entering vehicles cross a circulatory roadway lane line. The entrance into the circulatory roadway is marked with a 12-inch wide dotted white line (DWREL).

5.11.3 BICYCLE MARKINGS

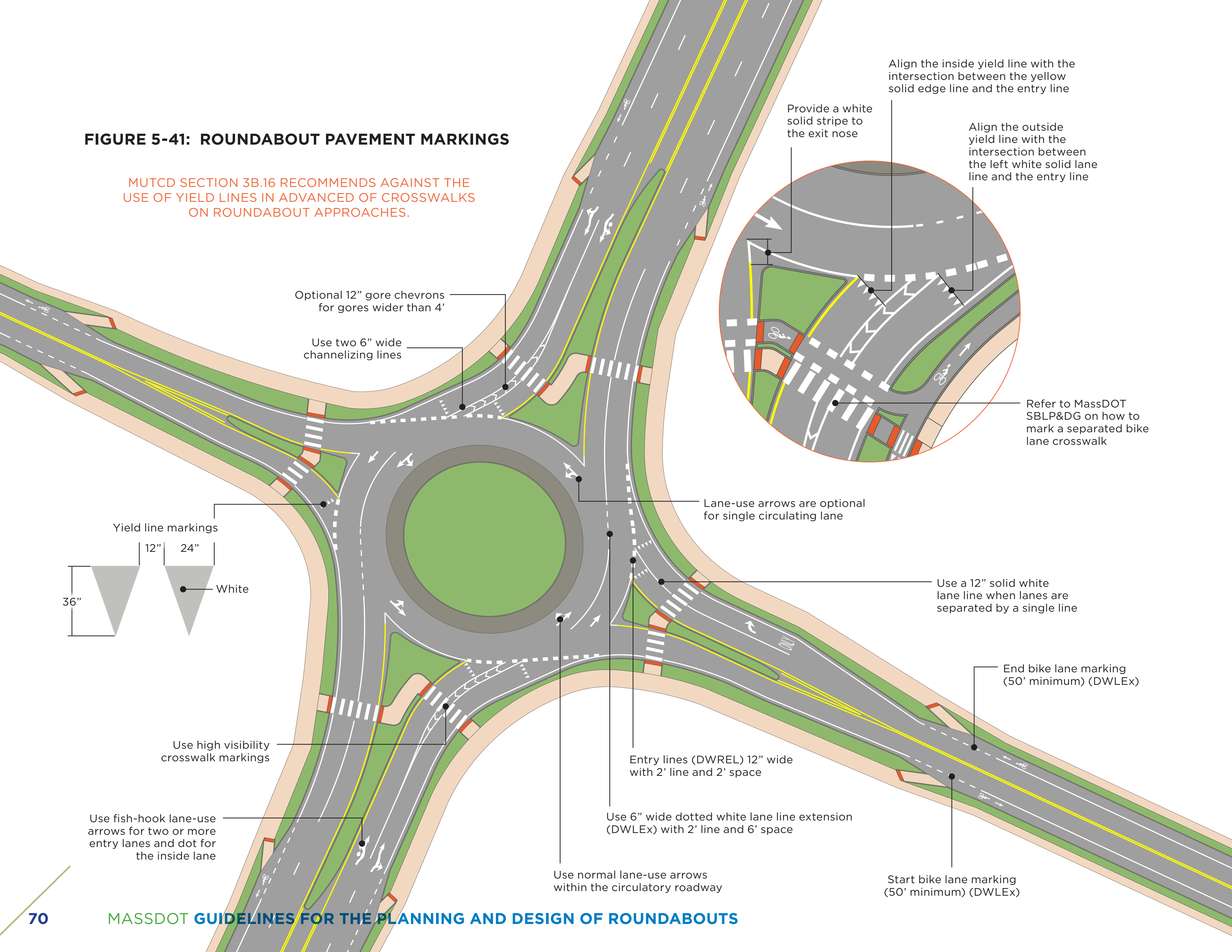
Bicycle lanes should not be marked within roundabouts as they are prohibited by the *MUTCD* (2). Bicycle lanes should be dropped on the approaches to a roundabout and reintroduced beyond the pedestrian crosswalk on the exits.

5.11.4 MINI-ROUNDABOUT PAVEMENT MARKINGS

Mini-roundabouts are fully mountable and in some cases only use pavement markings to delineate the splitter islands or even the central island. Section 7.3.3 of *NCHRP Report 672* (4) provides details on how pavement markings are different at mini-roundabouts.

FIGURE 5-41: ROUNDABOUT PAVEMENT MARKINGS

MUTCD SECTION 3B.16 RECOMMENDS AGAINST THE USE OF YIELD LINES IN ADVANCED OF CROSSWALKS ON ROUNDABOUT APPROACHES.



5.12 LIGHTING

Roundabout illumination is discussed in Chapter 8 of *NCHRP Report 672* (4) and is based on the *Design Guide for Roundabout Lighting*, published by the Illuminating Engineering Society (IES). The AASHTO publication *Roadway Lighting Design Guide* also provides guidance on roundabout lighting.

Roundabouts introduce geometry and channelization that drivers might not expect; therefore, illuminating these geometric features at night is particularly important for roundabouts. In addition, vehicular headlights are less effective at illuminating all roundabout features due to the constrained curve radius. MassDOT requires lighting at all roundabouts under MassDOT jurisdiction.

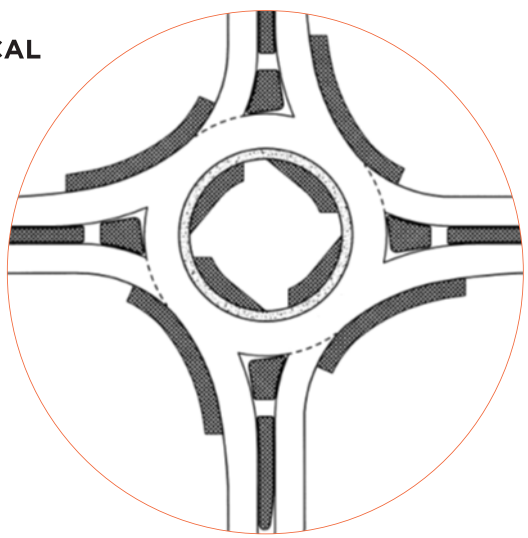
5.12.1 LUMINAIRE LOCATION

Section 8.4 Equipment Type and Location of *NCHRP Report 672* (4) provides guidance on lighting equipment and pole locations. Pole locations and equipment type should be determined based on a photometric analysis.

Poles should be set back from the curbs or roadway shoulders as far back as practical so they are clear of truck turning overhang or out of the run-off-the-road conflict area. Figure 5-42 illustrates the most likely run-off-the-road areas within a roundabout. Light poles and utility poles should be placed outside the areas illustrated.

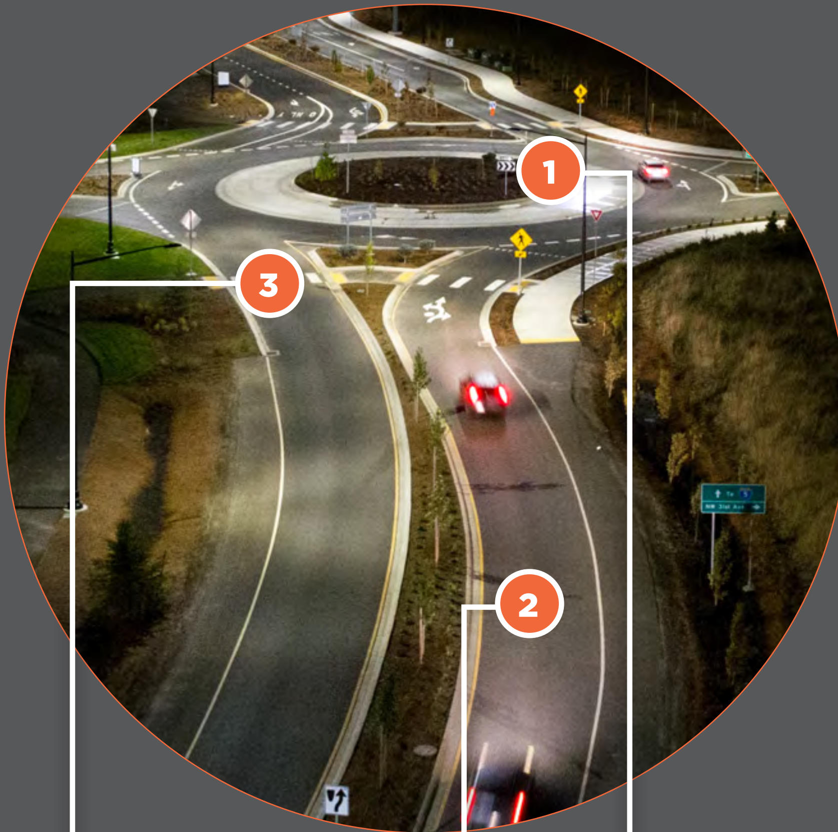
FIGURE 5-42: CRITICAL CONFLICT AREAS AFFECTING POLE PLACEMENT

Courtesy of Kansas Department of Transportation



AREAS OF POTENTIAL CONFLICT

5.12.2 LIGHTING LEVELS

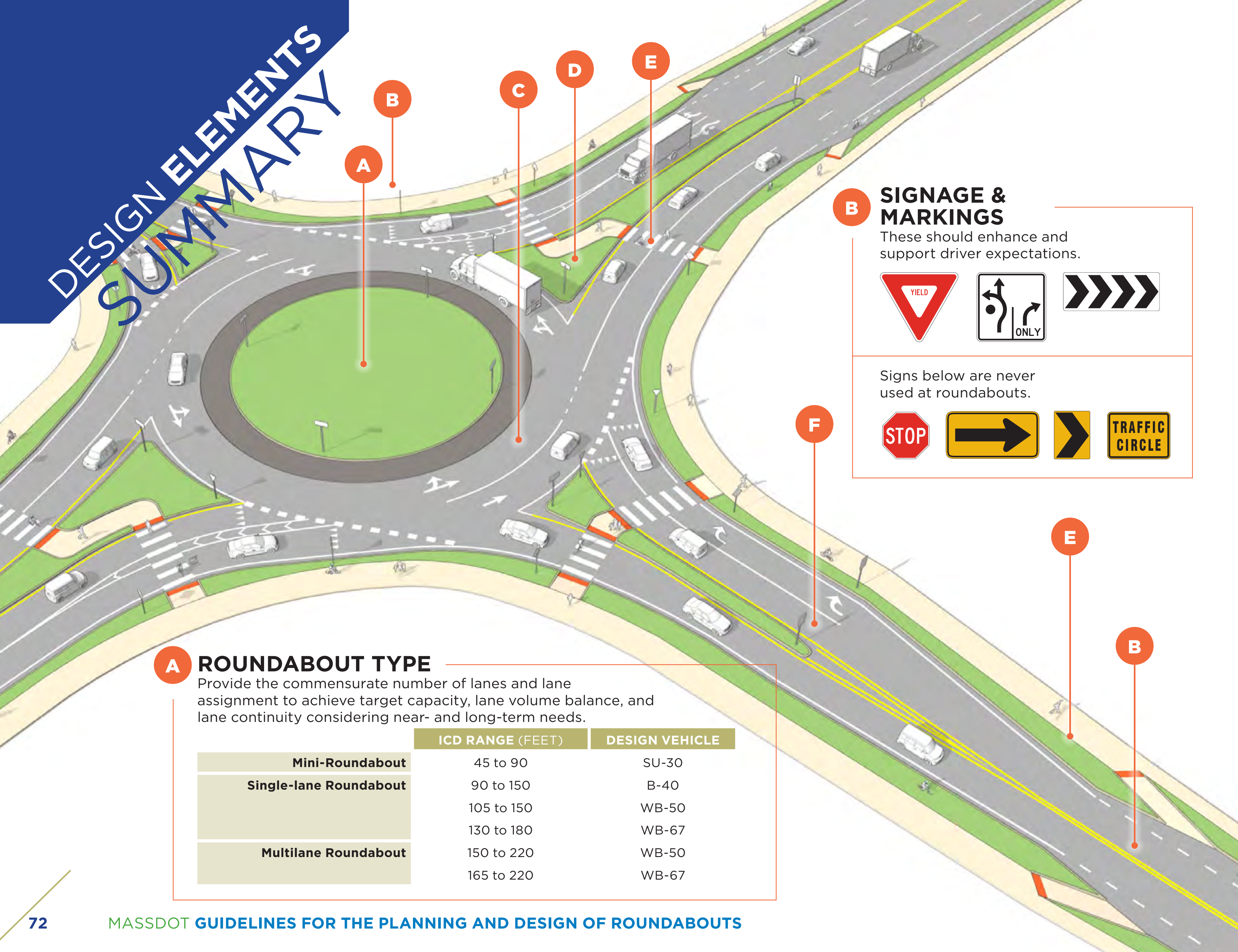


1: The roundabout itself should provide average maintained horizontal illuminance levels of 2.0 foot-candles with a uniform ratio of 4:1 or better, regardless of functional class.

2: On approaches and departures to roundabouts with no lighting, transition lighting should be provided. Regardless of functional class, transition lighting should provide average maintained horizontal illiminance levels of 1.0 foot-candles with a uniform ratio of 3:1 or better. It is preferable that transition lighting areas are 300 feet in length, 150 feet at a minimum.

3: At crosswalks, vertical illuminance levels of 4.0 foot-candles with a uniform ratio of 3:1 should be provided. The vertical illuminance level should be measured 5 feet above the roadway surface at a series of points spaced at 3 feet along the center of the crosswalk across each travel direction. Light poles for crosswalks are recommended to be located upstream from the crosswalk at a distance equal to one half of the height of the pole. This puts people walking in positive contrast from the view point of an approaching vehicle.

DESIGN ELEMENTS SUMMARY



B SIGNAGE & MARKINGS

These should enhance and support driver expectations.

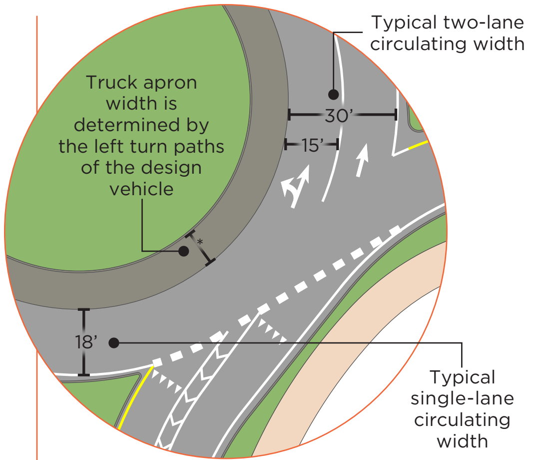
Signs below are never used at roundabouts.

A ROUNDABOUT TYPE

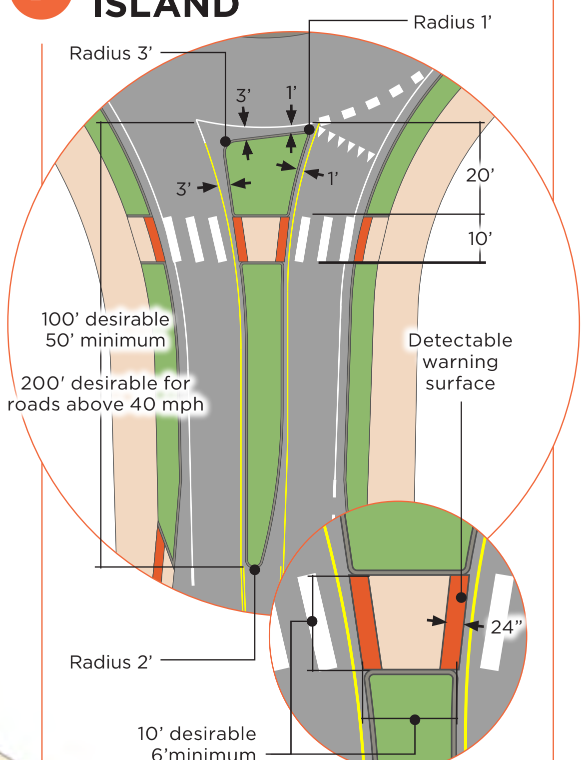
Provide the commensurate number of lanes and lane assignment to achieve target capacity, lane volume balance, and lane continuity considering near- and long-term needs.

	ICD RANGE (FEET)	DESIGN VEHICLE
Mini-Roundabout	45 to 90	SU-30
Single-lane Roundabout	90 to 150	B-40
	105 to 150	WB-50
	130 to 180	WB-67
Multilane Roundabout	150 to 220	WB-50
	165 to 220	WB-67

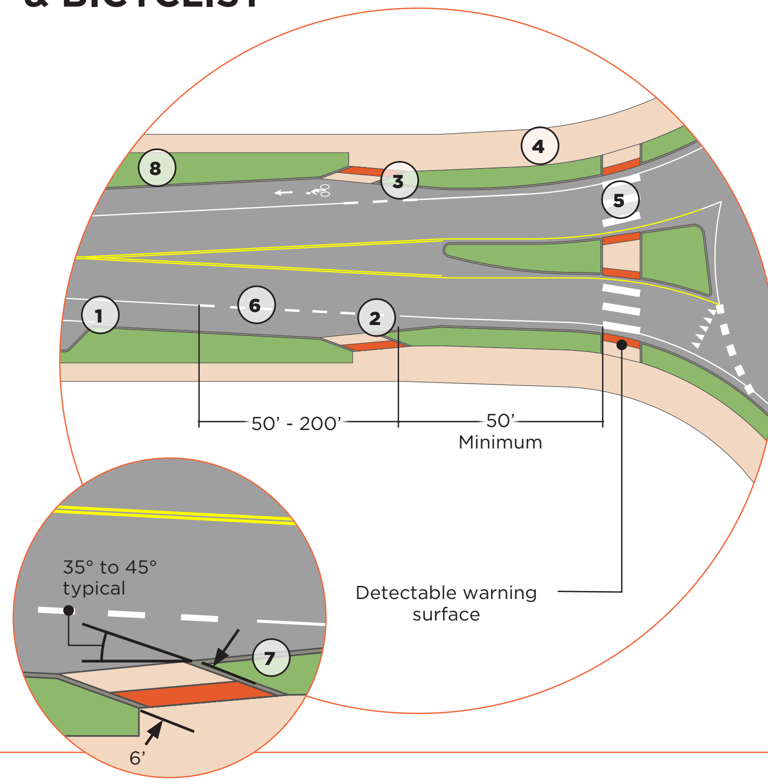
C CIRCULATORY ROADWAY



D SPLITTER ISLAND

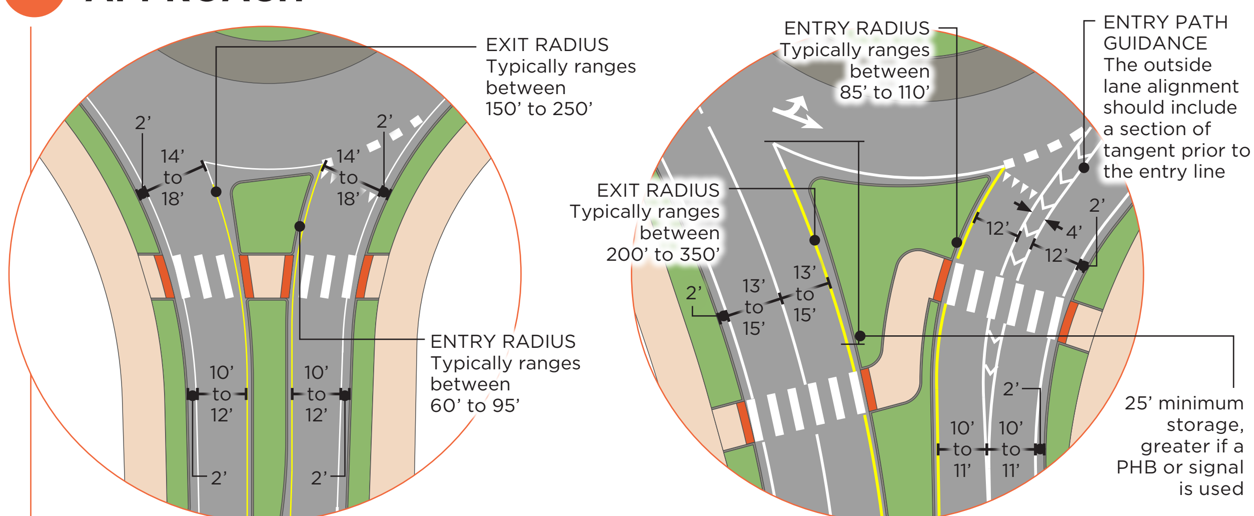


E PEDESTRIAN & BICYCLIST



1. Bike Lane
2. Ramp Up for Bicycles
3. Ramp Down for Bicycles
4. Shared-Use Path
5. Crosswalk
6. DWLEx marking allows people biking to use the travel lane
7. Maximum Taper Rate 7:1
8. Landscape Strip

F APPROACH



SECTION 6

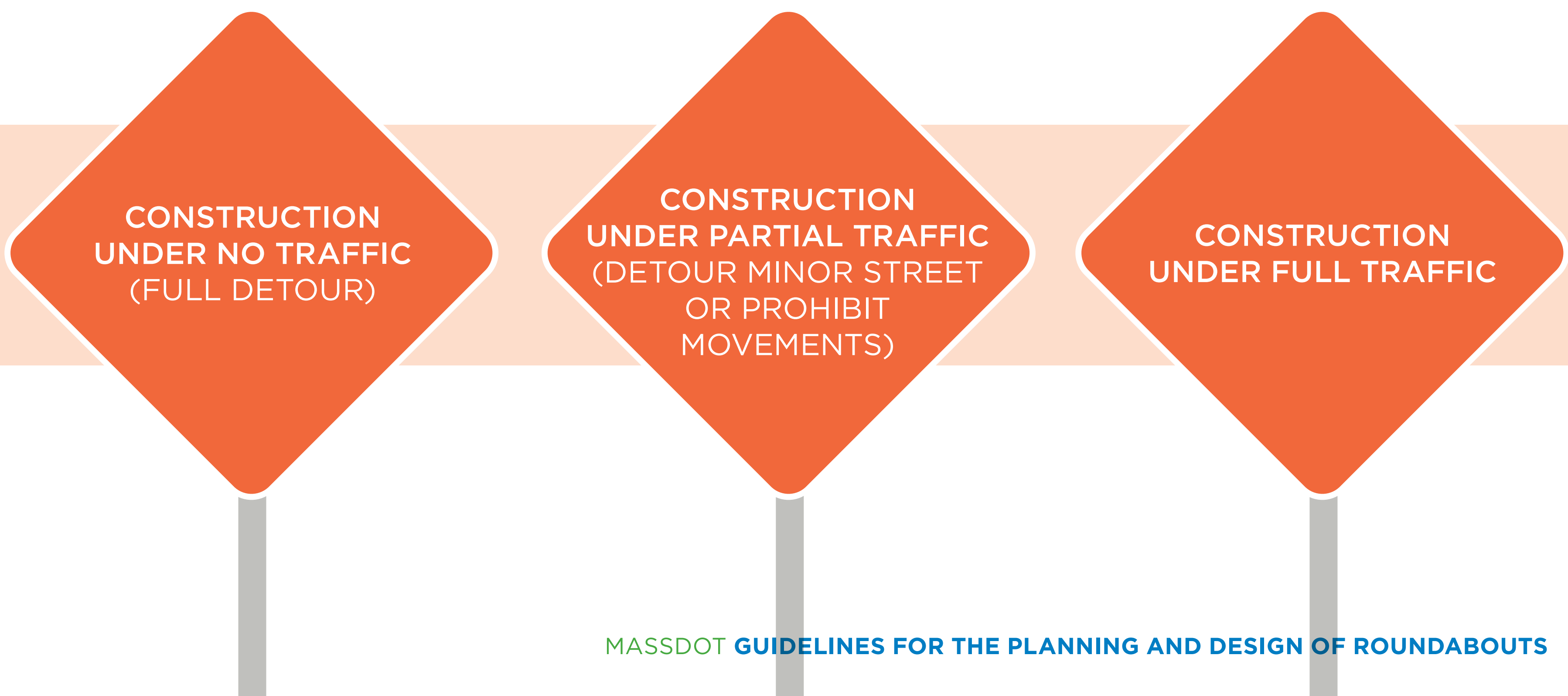
CONSTRUCTION AND OPERATIONS

6 CONSTRUCTION AND OPERATIONS

6.1 CONSTRUCTION STAGING

Roundabout construction and associated temporary traffic control plans vary based on the surrounding intersection and roadway context. In general for retrofit projects, construction and staging is easiest when large portions of the roundabout construction site can be made available by detouring or diverting traffic. Minimizing staging increases the construction quality, reduces construction time and cost, and minimizes driver confusion. Selecting a roundabout ICD location away from the existing roadway footprint could reduce construction staging and should be considered in the planning stages. In some projects, the final ICD location could be influenced by construction staging needs. Section 10.3 of *NCHRP Report 672* (4) outlines the following three types of construction conditions.

TYPES OF CONSTRUCTION CONDITIONS



6.1.1 NO TRAFFIC

Constructing a roundabout with no active traffic can be achieved by detouring traffic on all approaches, constructing a temporary roadway, or locating the new intersection off the existing roadway footprint; or a combination of these conditions. Figure 6-1 illustrates a roundabout being constructed on the side of the existing roadway with one leg of the intersection being closed. Using one temporary detour condition is less confusing to the public than a multi-stage traffic control plan that involves multiple lane changes and/or detour routes. A major challenge to closing a portion of the intersection to traffic is maintaining access to adjacent businesses and residences. If suitable detours are not available, this is not the preferred option.

FIGURE 6-1: ROUNDABOUT CONSTRUCTION ADJACENT TO ROADWAY

Courtesy the Community of Verboort, OR

6.1.2 SOME TRAFFIC DIVERTED

Illustrated in Figure 6-2 is another example in which the side-street through movements are diverted along the main roadway to create the necessary space in the middle of the intersection to construct the central island. This design approach allows all intersection approaches to stay open. The mainline left turns are displaced to the median openings on either side of the roundabout where they become U-turns. The side-street through and left-turn traffic is diverted to the same median openings where they U-turn to complete their journey.

Sometimes, temporary roadways cannot be configured to accommodate large trucks due to site or cost constraints. Detour truck routes should be signed on the adjacent roadway network in addition to the approaches to the roundabout construction site. Exhibit 10-3 of *NCHRP Report 672* (4) provides an example of roundabout construction under partial traffic that maintained traffic flow on the major roadway with the use of temporary roadways.

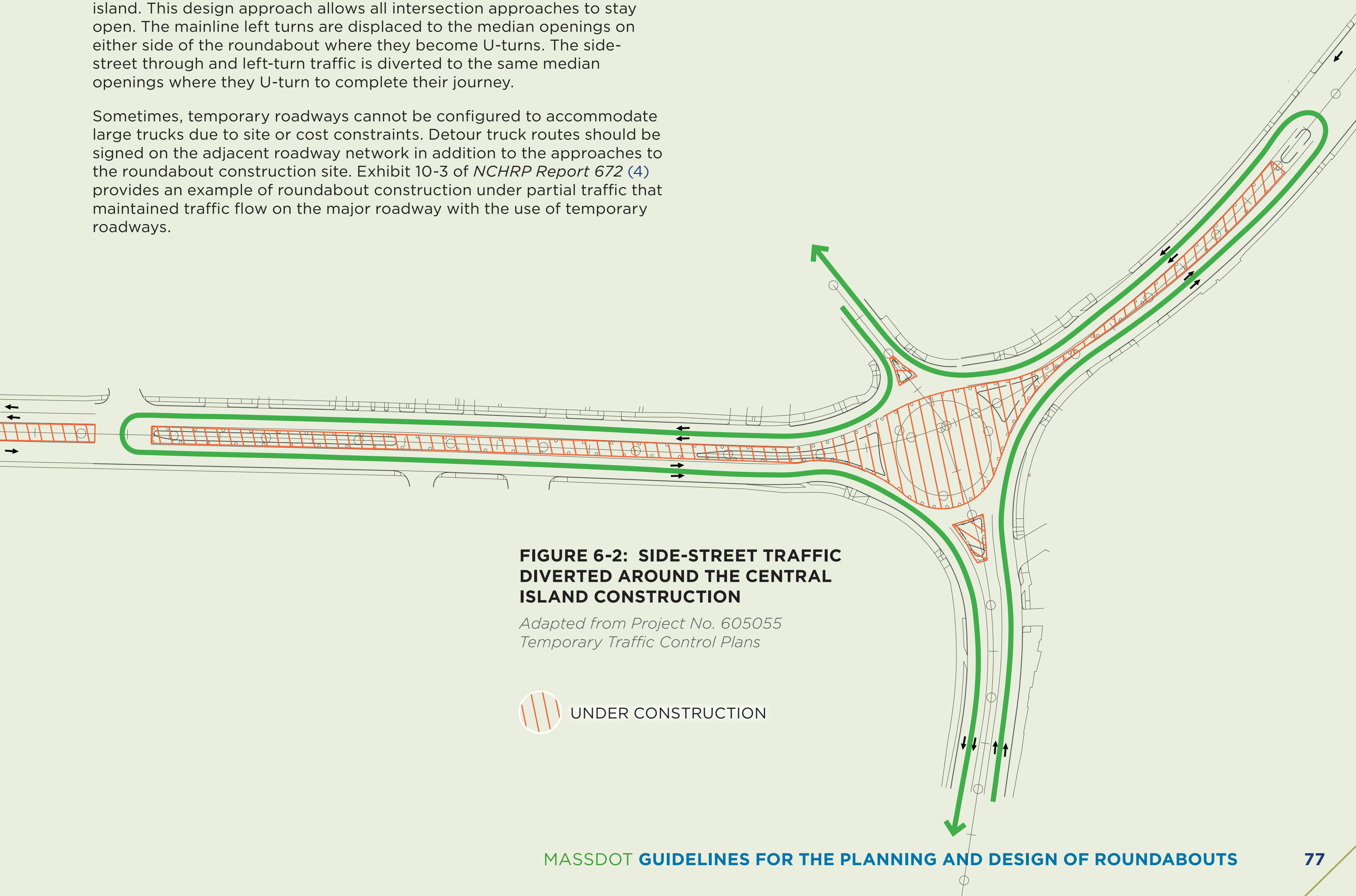


FIGURE 6-2: SIDE-STREET TRAFFIC DIVERTED AROUND THE CENTRAL ISLAND CONSTRUCTION

Adapted from Project No. 605055 Temporary Traffic Control Plans

6.1.3 FULL TRAFFIC (NO DIVERSION)

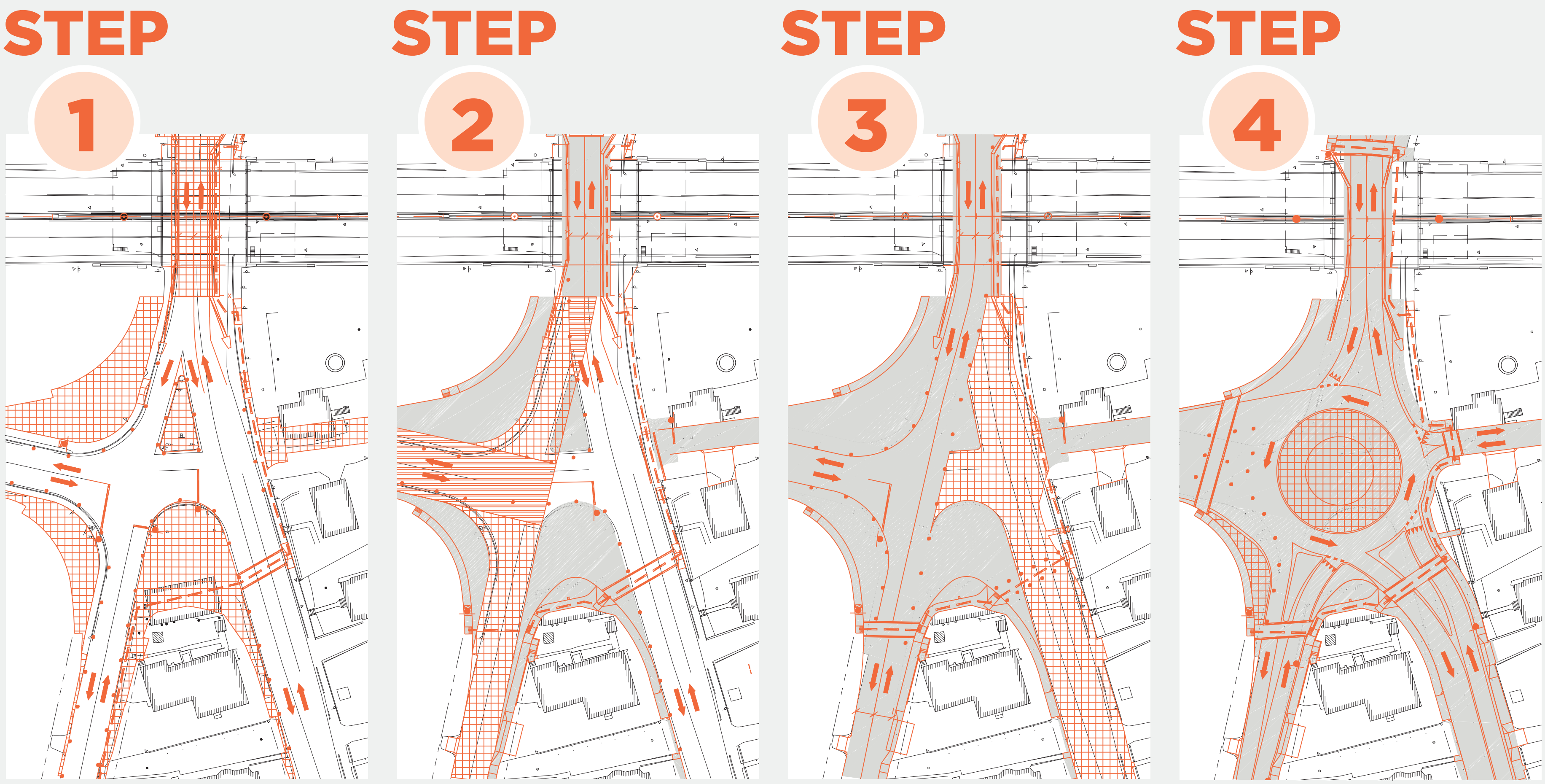
Constructing a roundabout while maintaining all traffic movements will require police detail, flagging, or other control to mitigate intersection conflicts. Nighttime traffic operations minimize construction during typically higher daytime volumes and may require special plans when police details or flaggers are not available. Truck detours may be necessary even if light vehicle movement is not restricted during construction due to constrained geometry. Figure 6-3 illustrates the progression of temporary traffic patterns through a roundabout construction site. Section 6.2 provides specific traffic control considerations for roundabout construction.

FIGURE 6-3: SEQUENTIAL TEMPORARY TRAFFIC CONTROL PHASES AT A ROUNDABOUT CONSTRUCTION SITE

Adapted from Project No. 605964 Temporary Traffic Control Plans

UNDER CONSTRUCTION

COMPLETED



6.2 WORK ZONE TRAFFIC CONTROL

Section 10.4 of *NCHRP Report 672* (4) outlines specific considerations for roundabout work zone traffic control. The following items summarize these considerations:

- Temporary pavement markings should depict intersection features as conventionally as possible. Channelizing devices (e.g., cones or drums) may be used to supplement the temporary pavement markings or establish the travel path when pavement markings are not practical.

- To the extent possible, temporary roadway and non-motorized facilities should include the same dimensions as final installation.

- Permanent roundabout signing should be installed as early as practical or located on temporary supports in the proposed location.

- Permanent lighting should be installed in advance of roundabout construction if practical. Temporary lighting should be provided if permanent installation is not practical.

6.3 CONSTRUCTION COORDINATION

Close coordination between the designer, utility companies, resident engineers, landscape architects, field engineers, and contractors enables roundabouts to be built as intended. Pre-construction coordination meetings and design review of roundabout-specific features may help initiate a project and prevent issues later in construction. Geometric details such as truck apron edging curbs and splitter island pavement markings affect the intended operation of the roundabout. The installation of these details should be closely supervised or inspected in a timely fashion. Deviation from the plans should be discussed with the designer and understood before completion.

6.4 OPERATIONS & MAINTENANCE

6.4.1 LANDSCAPE

Landscape features should be selected based on the ability of local or MassDOT maintenance forces to upkeep. As suggested in *NCHRP Report 672* (4), "where there is no interest in maintaining the proposed enhancements, the landscape design should consist of simple plant materials or hardscape items that require little or no maintenance" (4). Native plant use should be encouraged. A landscape maintenance plan is critical when plant material is located within the intersection sight distance areas outlined in Section 5.6.

6.4.2 SNOW REMOVAL

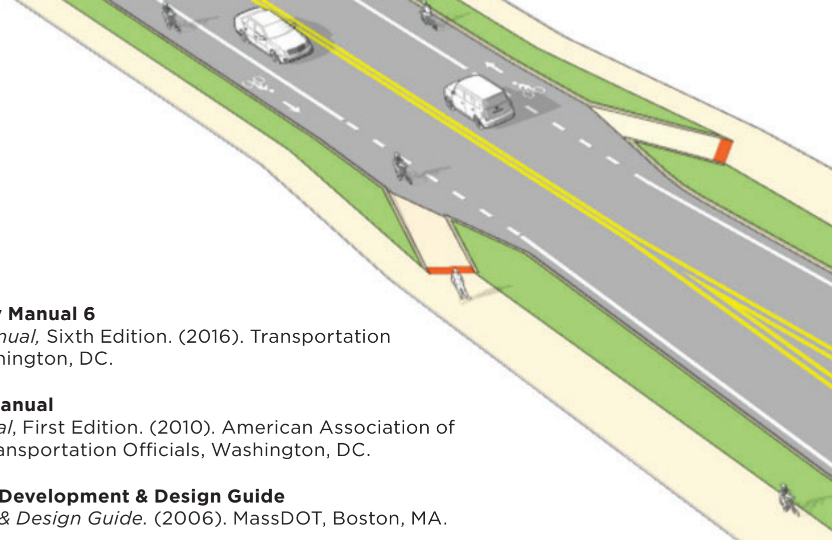
Snow must be removed from the roundabout truck apron and circulatory roadway. Locating the raised truck apron and other curbed features can cause difficulties for equipment operators removing snow at roundabouts. A common method for snow removal is for one truck to start on the truck apron and plow around the roundabout to the outside while a second truck plows each entry and exit, pushing snow to the outside and down each approach. Snow should not be stored on splitter islands or other roundabout areas where it obstructs the driver's sight on the approaches or affects pedestrian access. Storing snow on splitter islands or the truck apron can lead to refreeze.

6.4.3 PAVEMENT MAINTENANCE AND REHABILITATION

Pavement maintenance and rehabilitation should be conducted under as little traffic as possible. Temporary control plans similar to a new construction project can be used if maintenance is completed under traffic. Exhibit 10-9 of *NCHRP Report 672* (4) provides an example with four flaggers, one on each approach of a roundabout that allows maintenance work on one quadrant of the intersection. Police details are generally used instead of flaggers on MassDOT projects. Similar traffic control plans can be used to reapply pavement markings (yield lines, entry lines, and crosswalks) on the roundabout entry and exits.

6.4.4 PAVEMENT MARKINGS

Critical pavement markings such as multilane roundabout channelization entry and exit lane lines, circulating lane lines, crosswalks, and lane assignment arrows should be recessed to prolong their life. Refreshing pavement markings should be planned on a regular basis since they are integral to the guidance of traffic and therefore safe and efficient operation of the roundabout.



REFERENCES

(1) **AASHTO Green Book**
A Policy on Geometric Design of Highways and Streets, Seventh Edition. (2018). American Association of State Highway and Transportation Officials, Washington, DC.

(2) **MUTCD**
Manual on Uniform Traffic Control Devices for Streets and Highways, with Revision Numbers 1 and 2 incoporated. (2012). US Department of Transportation, Federal Highway Administration, Washington, DC.

(3) **PROWAG**
Proposed Guidelines for Pedestrian Facilities in the Public Right-of-Way. (2011). United States Access Board, https://www.access-board.gov/guidelines-and-standards/streets-sidewalks/public-rights-of-way/proposed-rights-of-way-guidelines (accessed June 25, 2019).

(4) **NCHRP Report 672**
NCHRP Report 672, Roundabouts: An Informational Guide, Second Edition. (2010). Transportation Research Board, Washington, DC. https://doi.org/10.17226/22914 (accessed June 25, 2019).

(5) **NCHRP Report 834**
NCHRP Report 834, Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities: A Guidebook. (2017). Transportation Research Board, Washington, DC. https://doi.org/10.17226/24678 (accessed June 25, 2019).

(6) **Highway Capacity Manual 6**
Highway Capacity Manual, Sixth Edition. (2016). Transportation Research Board, Washington, DC.

(7) **Highway Safety Manual**
Highway Safety Manual, First Edition. (2010). American Association of State Highway and Transportation Officials, Washington, DC.

(8) **MassDOT Project Development & Design Guide**
Project Development & Design Guide. (2006). MassDOT, Boston, MA.

(9) **MassDOT Traffic and Safety Engineering 25% Design Submission Guidelines**
Traffic and Safety Engineering 25% Design Submission Guidelines. (2011). MassDOT, Boston, MA. https://www.mass.gov/files/documents/2018/02/16/FunctionalDesignReportGuidelines_0.pdf (accessed June 25, 2019).

(10) **MassDOT Separated Bike Lane Planning and Design Guide**
Separated Bike Lane Planning and Design Guide. (2015). MassDOT, Boston, MA.

(11) **AASHTO Roadside Design Guide**
AASHTO Roadside Design Guide 4th Edition. (2011). American Association of State Highway and Transportation Officials, Washington, DC.

ACRONYMS

AADT – Annual average daily traffic

AASHTO – American Association of State Highway and Transportation Officials
ADA – Americans with Disabilities Act

BMP – Best Management Practices

CAP–X – Capacity Analysis for Planning of Junctions

CMF – Crash modification factors

FHWA – Federal Highway Administration

HCM 6 – *Highway Capacity Manual,* Sixth Edition

HCS – Highway Capacity Software

HSM – *Highway Safety Manual,* First Edition

ICD – Inscribed circle diameter

ICE –Intersection control evaluation

IES – Illuminating Engineering Society

MUTCD – *Manual onUniformTrafficControl Devices*for Streets and Highways

NCHRP – National Cooperative Highway Research Program

NHS – National Highway System

OSOW – Oversize/Overweight vehicle

PD&DG – MassDOT Project Development & Design Guide

PHB – Pedestrian hybrid beacon

PROWAG – Proposed Guidelines for Pedestrian Facilities in the Public Right–of–Way

RCW – Raised crosswalk

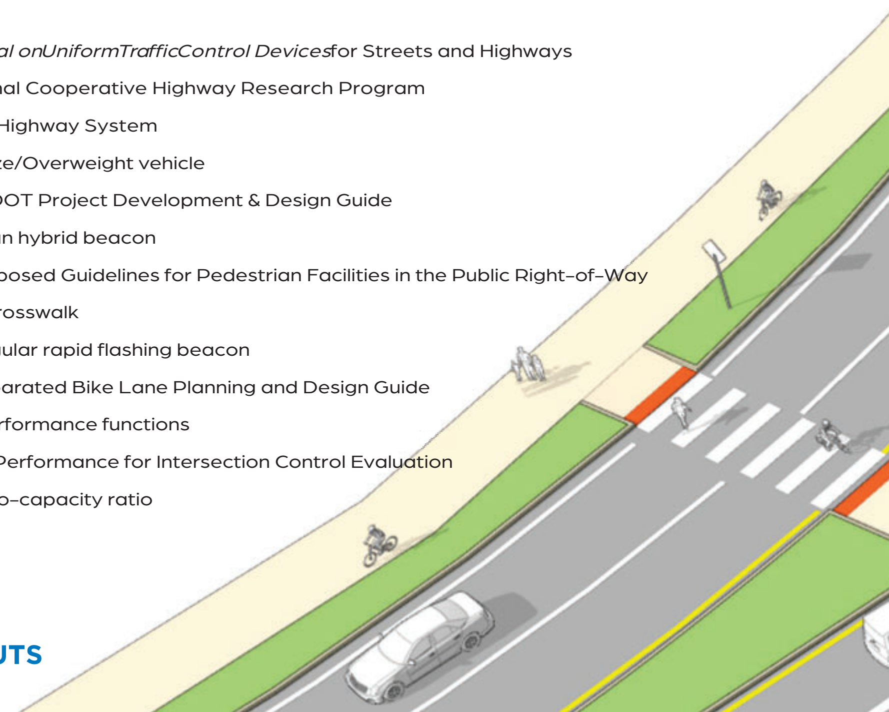
RRFB – Rectangular rapid flashing beacon

SBLP&DG – Separated Bike Lane Planning and Design Guide

SPF – Safety performance functions

SPICE – Safety Performance for Intersection Control Evaluation

V/C – Volulme–to–capacity ratio



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