CITY OF BEND

ROUNDABOUT DESIGN MANUAL

City of Bend

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Prepared for:

The City of Bend

CITY OF BEND

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ACRONYMS & ABBREVIATIONS

AASHTO .... American Association of State Highway and Transportation Officials
ACP .... asphalt concrete pavement
ADA .... Americans with Disabilities Act
ADAAG .... ADA Accessibility Guidelines
ANSI/IES .... American National Standards Institute/Illuminating Engineering Society of North America
APS .... Audible Pedestrian Signal
BNSF .... Burlington Northern Santa Fe Railway
City .... City of Bend
DIAL .... Deschutes County Property Information
DSD .... decision sight distance
E .... Curb Exposure
ESALs .... equivalent single axle load
FHWA .... Federal Highway Administration
G .... Gutter Width
H .... Curb Height
HCM .... Highway Capacity Manual
HCS .... Highway Capacity Software
ICD .... inscribed circle diameter
ICE .... Intersection Control Evaluation
ISD .... intersection sight distance
Level of Service .... LOS
LTS .... Level of Traffic Stress
mph .... miles per hour
MUTCD .... Manual on Uniform Traffic Control Devices
NCHRP .... National Cooperative Highway Research Program
ODOT .... Oregon Department of Transportation
OSOW .... oversize/overweight
PCC .... Portland cement concrete
PDED .... Private Development Engineering Department
PROWAG .... Publi Rights-of-Way Accessibility Guidelines
psi .... pounds per square inch
ROW .... Right-of-Way
RRFB .... Rectangular Rapid Flashing Beacons
SSD .... Stopping Sight Distance
TCP .... traffic control plan
TDI .... tactile directional indicators
TMD .... Transportation and Mobility Director
TSAP .... Transportation Safety Action Plan
TSP .... Transportation System Plan
TWD .... tactile warning delineator
V/C .... volume to capacity
vpd .... vehicles per day

CITY OF BEND

EXECUTIVE SUMMARY

The City of Bend, Oregon has developed this Roundabout Design Manual to ensure the consistent and safe construction, design, and implementation of roundabouts within the city. This manual serves as a comprehensive guide, addressing various aspects critical to the successful integration of roundabouts into the urban infrastructure. The objectives of this manual are:

- To provide clear guidance for the construction and design of roundabouts.
- To maximize safety and efficiency of roundabouts for all types and modes of use.
- To standardize the roundabout design and implementation process to maintain consistency across projects.

This manual covers a wide range of topics essential for roundabout design and implementation. It begins with an overview of the characteristics and applications of different roundabout types, followed by guidelines for evaluating intersections using the Intersection Control Evaluation form, and planning roundabout installations. The manual also delves into user and stakeholder considerations, ensuring that the needs and concerns of various groups are addressed.

In addition, the manual outlines the requirements for planning and design documentation, providing a framework for thorough and consistent project documentation. Safety performance analysis and operational analysis are also key components, offering tools and resources to ensure that roundabouts are both safe and efficient for all users and modes of use.

The geometric design process is outlined and specifies the required performance checks. Standards for horizontal alignment, vertical design, cross sections, and facilities for people walking and biking are outlined to guide the physical design of roundabouts. Specifications for traffic control devices, such as signing, striping, and illumination, are included to ensure proper traffic management.

Furthermore, the manual offers guidance for integrating landscaping, paved surfaces, and artwork into roundabout designs, enhancing their aesthetic appeal. Detailed requirements for plan set submissions are provided to streamline the approval process. Finally, the manual includes general educational requirements and resources to inform and engage the public about the benefits and proper use of roundabouts.

This manual is an essential resource for engineers, planners, City staff, and stakeholders involved in the development of roundabouts in Bend, ensuring that each project meets or exceeds minimum standards of safety, efficiency, and aesthetic quality.

1.0 INTRODUCTION

1.1 OBJECTIVE

This manual provides guidance for the consistent design and construction of the various types of roundabouts built in Bend, Oregon. It supports construction of multi-modal roundabout designs that improve safety for all travel modes and keeps people moving. The manual applies to all construction, reconstruction, and applicable maintenance projects.

1.2 OVERVIEW

Roundabouts provide significant safety benefits over other alternative designs, including reduced speeds, increased reaction time, fewer conflict points, fewer crashes, and less severe crashes. Because of these benefits, they are an important tool used to help meet the City of Bend's (City) Vision Zero goals and Transportation System Plan (TSP) policies. Roundabouts are the first choice for intersection design instead of a traffic signal or all-way stop at major intersections (arterial and/or collector intersections).

The National Cooperative Highway Research Program (NCHRP) Research Report 1043: 2023 Guide for Roundabouts supersedes the former NHCRP Research Report 672: Roundabouts: An Informational Guide and provides national guidelines for the planning, design, and construction of roundabouts. It includes performance-based design using an Intersection Control Evaluation (ICE) to identify the most appropriate intersection form for the context and goals. This City of Bend design manual generally follows the format of NCHRP 1043. It supplements the information in NCHRP 1043, highlighting elements specific to, emphasized in, or modified for roundabouts in Bend.

Related City documents that inform standards used in roundabout designs include but are not limited to:

- Bend Development Code
- Engineering Standards and Specifications
  - This Roundabout Manual
  - Signing and Striping Manual
  - Complete Streets Manual

- Transportation Systems Plan, including Figure 4-3 Functional Class Map, Figure 5-1 Low-Stress Bicycle Network, and Figure 5-2 Primary Transit Corridors
- Transportation Safety Action Plan, safety recommendations

This City Roundabout Design Manual contains descriptions, typical applications, and guidance rather than specific standards due to the design of roundabouts varying based on so many different elements. There is no one master layout. The various design elements include items such as the context, speeds, capacity needs, user types (people walking, biking, driving, or riding transit), different vehicle types, and space available. The overall steps for designing and constructing a roundabout include:

1. Planning - Identifying location and corridor specific priorities.
2. ICE/Alternatives Analysis - Conducting an ICE to determine compatible configurations.
    a. Step 1: Project scoping/initial screening
    b. Step 2: Evaluation, operational analysis, and documentation
3. Design - Applying an iterative design process for preliminary, draft, and final design.
4. Construction – Building the roundabout and submitting final as-built drawings.

NCHRP 1043 provides detailed information on the design elements needed to move through these steps, complementing the guidance in this manual.

2.0 CHARACTERISTICS AND APPLICATIONS

Roundabouts are circular intersections where traffic travels counterclockwise around a central island and entering traffic must yield to circulating traffic. Vehicles entering a roundabout are slowed and deflected using outside (passenger side) curbing and an inside (driver side) splitter islands on the approach lanes. Each roundabout is configured specifically for its location to improve operation, safety, and how different travel modes are served for that intersection's constraints and traffic patterns.

2.1 Roundabout Types

Roundabout configurations include mini, compact, single-lane, and multi-lane configurations. These different layouts are appropriate for different street classifications, contexts, traffic volumes, Rights-of-Way (ROWs), mode priority, and other characteristics. Roundabouts in Bend include facilities to keep vehicles, pedestrians, and cyclists as separated as possible. Table 1 summarizes features of the different types of roundabouts. Appendix A contains general "do/don't do" examples from previously constructed or designed roundabouts that should be considered during design. The following sections describe some Bend-specific considerations for each type.

Table 1. Summary of Roundabout Types and Features

Feature	Mini	Compact	Single Lane	Multi - Lane
Max Design Vehicle[(1)]	SU 30/ Bus*/Emergency Response*	WB 50 for through movements	WB 50/WB 67**	BUS/WB 40/WB 50/WB 67
Max Approach Roadway Speeds[(3)] (R1)	30 miles per hour (mph)	35 mph	None	None
Target Entry Speed (R2)	15 - 20 mph	20 mph	20 - 23 mph	20 - 25 mph
Target Exit Speed (R3)	15 - 20 mph	20 mph	20 – 23 mph	20 – 25 mph
Inscribed diameter	45 - 90 feet	65 - 120 feet	90 - 180 feet	140 - 200 feet
Entry Width	14 - 15 feet	14 - 18 feet	16 - 18 feet; can Increase to 18 - 20 feet for fire if needed	18 - 25 feet
Circulating Width	14 - 18 feet	16 - 18 feet	18 - 21 feet	28 - 32 feet
Central Island	Traversable	Typically non-traversable with truck apron, may be traversable in constrained location	Non-traversable, typically includes truck apron	Non-traversable, typically includes truck apron
Splitter Islands[(2)]	Min. 20 feet long, mountable, target 6 feet min. width for pedestrian refuge – may not have room for refuge on local streets, required 6 feet min. on collector streets	Min. 50 feet long, raised, target 8 feet width for pedestrian refuge, 6 feet min. where constrained	Min. 80 feet, long Raised, 8 feet min. width for pedestrian refuge	Min. 80 feet, long Raised, 8 feet min. width for pedestrian refuge
Typical max ADT (vehicle/day)	10,000	15,000	20,000 (Rule of thumb: Sum of entering and circulating traffic at merge point should <1,500 vehicles/ hour for a single lane to be adequate)	50,000

(1) May vary based on site specific context. See Section 10. * Bus/Emergency Response at mini design vehicle only where identified as bus/emergency route. Larger vehicles to traverse central island. ** WB 67 evaluated based on corridor and movements, at minimum through movement.

(2) Islands may differ by approach; local street approaches may be traversable if right-of-way restricted or adjacent access that is inaccessible with non-traversable island cannot be relocated.

(3) Or speed limit where posted limit is lower.

2.1.1 Mini Roundabout

Mini roundabouts are small roundabouts used on low-speed corridors (20 to 25 miles per hour [mph]), most commonly residential neighborhoods or local commercial areas. They are single-lane roundabouts with inscribed circle diameters less than 90 feet (typically 45 to 90 feet) and traversable islands. The splitter islands and center island are mountable allowing larger vehicles in the traffic stream to traverse overtop to maneuver through the intersection. They are typically used at intersections between two local connector streets; streets that collect traffic from other local streets and connect to an arterial or collector street. Although small, mini roundabouts can have greater capacity and safety benefits than an all-way stop intersection. Mini roundabouts can also fulfill traffic control needs to facilitate crossings, mitigate crashes, or reduce queuing. They serve lower-volume intersections. Typically, the entering plus circulating volume for each approach is than 1,000 passenger car units per hour (for the existing and projected 20-year volumes), and approach streets typically have at least 500 vehicles per day. Figure 1 is a picture of a mini roundabout.

Mini roundabouts are different from neighborhood traffic circles in that they have traversable central islands, splitter islands on approaches, and are yield controlled on all approaches.

Figure 1. Mini roundabout in Redmond, Oregon.

2.1.2 Compact Roundabout

Compact (also called urban compact) roundabouts use all the design elements of a single-lane roundabout. The key difference from a single-lane roundabout is the smaller footprint may not allow them to serve larger vehicles. Therefore, they are located where there are alternate large vehicle routes or very low likelihood of larger vehicles on the corridor. They can serve slightly higher volumes and speeds than the mini (up to 35 mph), more like that of a single-lane roundabout. Compact roundabouts often provide more speed control than a single-lane roundabout due to the smaller inscribed circle diameter (ICD) and smaller entry radii. They may be considered on higher volume local streets or lower volume collector street intersections. Generally, they are not used on arterial streets due to the need for accommodating larger vehicles but can be applied when constraints are present if design elements, such as traversable features, are designed to accommodate larger design vehicles. Figure 2 shows a picture of a compact roundabout.

Figure 2. Compact roundabout in Dexter, Michigan.

2.1.3 Single-Lane Roundabout

Single-lane roundabouts have a single circulating lane with single entry and exit lanes, a non-traversable center island with mountable truck apron, and splitter islands on all approaches. The overall ICD is dependent on the intersection geometry, design vehicle, and number of legs and lanes. Single-lane roundabouts are the most common type of roundabout in the City of Bend. Figure 3 is an image of the Columbia Street/Colorado Avenue single-lane roundabout.

Figure 3. Single-lane roundabout at the intersection of Colorado Avenue and Columbia Street. Bend, Oregon.

2.1.4 Multi-Lane Roundabout

Multi-roundabouts have two circulating lanes on at least one approach. They may have different numbers of lanes on different approaches. The ICD of a multi-lane roundabout is more dependent on the lane configuration and lane widths, intersection geometry, and number of legs than the design vehicle movements. They can serve larger trucks in lane or by allowing trucks to use more than one lane to enter and circulate. There are several multi-lane roundabouts in Bend with varying configurations. While there has been some discussion on standardizing multi-lane roundabouts to a consistent lane configuration, the desire to minimize the roundabout’s footprint and reduce the number of lanes leads to varying configurations that are site specific. Figure 4 is a picture of the 27th Street/Butler Market multi-lane roundabout.

Figure 4. Multi-lane roundabout at the intersection of Butler Market and 27th Street Bend, Oregon.

2.1.5 Turbo Roundabout

Turbo roundabouts are a type of multi-lane roundabout that includes spiral geometry and lane divider channelization that directs vehicles to stay in the appropriate travel lane. The lane divider may be raised or flush and serves to reduce sideswipe and mild-angle crashes at exits caused by weaving to the desired lane in a multi-lane roundabout. Turbo roundabouts have similar capacity as standard multi-lane roundabouts but may see fewer crashes because of fewer conflict points. The added lane is “nested” (or starts from the central island) to reduce overall ROW impacts. Figure 5 shows a nested lane and a flush divider turbo roundabout example.

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

Figure 5. Turbo roundabout from NCHRP 1043 EX. 12.28.

2.1.6 Separated Roundabout

A separated roundabout is any type of roundabout that has a separated circulating lane for bicycles. The use of separated roundabouts is intended for corridors with high bicycle use on low-stress routes, where there are higher intersection risks to cyclists. The corridor these are located on may or may not have bike facilities that are separated from the roadway. Figure 6 is a picture of the 9th Street and Wilson Avenue separated roundabout in Bend.

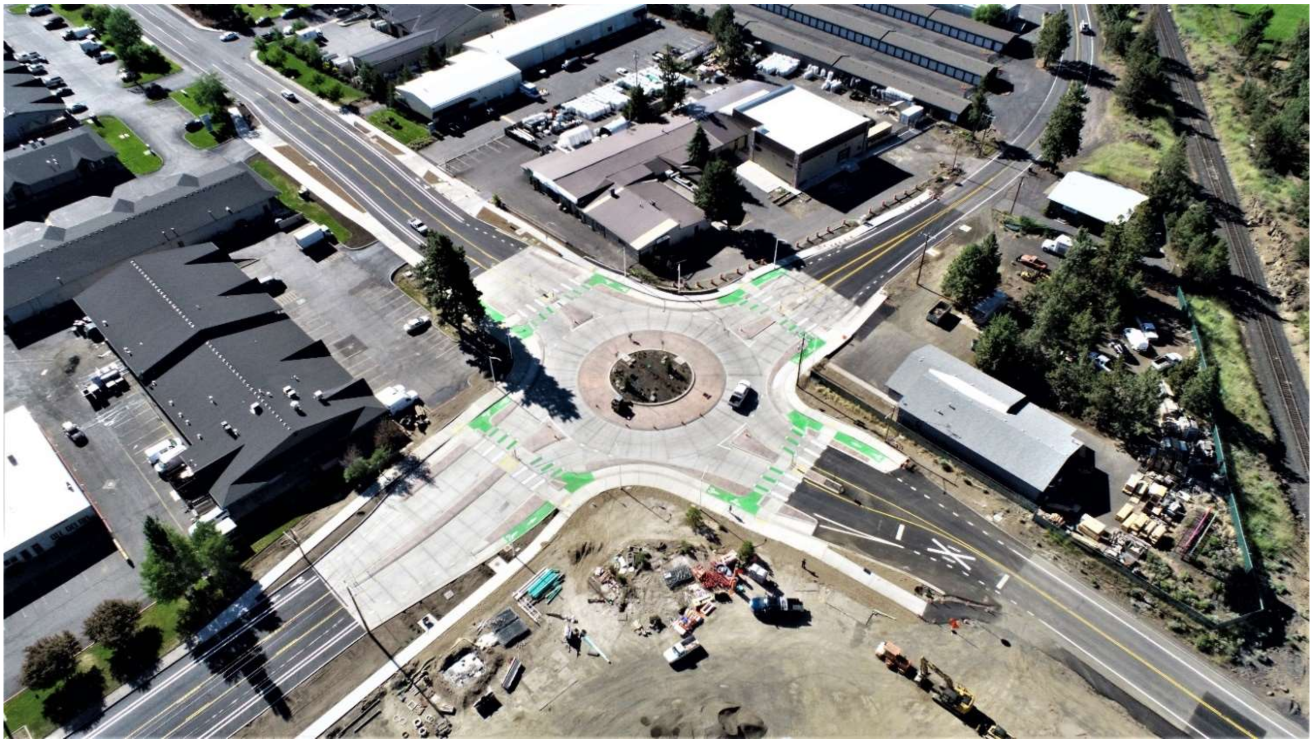


Figure 6. Separated roundabout at the intersection of 9th Street and Wilson Ave.

2.1.7 Guiding Principles

The three guiding principles for transportation system design apply to roundabout design in Bend. Designs built in alignment with these guiding principles support the goals in the City's transportation plan: design for context, design for all ages and abilities across all modes, and design to reduce crash risk.

2.1.7.1 DESIGN FOR THE CONTEXT

Bend's transportation policy supports roundabout designs that fit the context of the location and corridor. Typically, the design includes multi-modal facilities with the fewest number of travel lanes to serve design volumes at the slowest entry/exit speeds feasible. Designs should provide for throughput to keep people moving on arterial and collector streets and may emphasize traffic calming on residential collector and local streets. Designs should also consider the context of the specific site, such as schools, parks, neighborhoods, street classification, alternate crossings, and current and/or planned land use decisions. Overdesigning roundabout intersections or designing for too far in the future can have negative results due to higher potential speeds on roundabouts that are too large or have too many lanes due to lower volumes.

2.1.7.2 DESIGN FOR ALL AGES AND ABILITIES

Roundabouts should be designed for people walking, biking, and driving across all ages and abilities. Every roundabout includes facilities for people walking, biking, and driving as separated as feasible. While roundabouts will serve all users, they may be served in different ways depending on the context and location. Part of the design evaluation will identify the priority movements to inform how different modes are accommodated. Roundabouts on the Low-Stress Network (Transportation Systems Plan, Figure 5-1), will be designed with greater focus on walking and biking facilities targeting level of traffic stress 1 or 2. In addition, using the Universal Design Principles can further modify designs to accommodate a wider range of abilities across all user types.

Intersections are often the greatest barrier to walking and biking. Providing connected, separated, and intuitive facilities with slower speeds at roundabout intersections can encourage more people to try other travel options than driving for more trips. The design evaluation includes reducing conflict points and creating intuitive approaches and lane assignments that make it easy for people driving to enter, circulate, exit, and stop as needed for crossing pedestrians and cyclists.

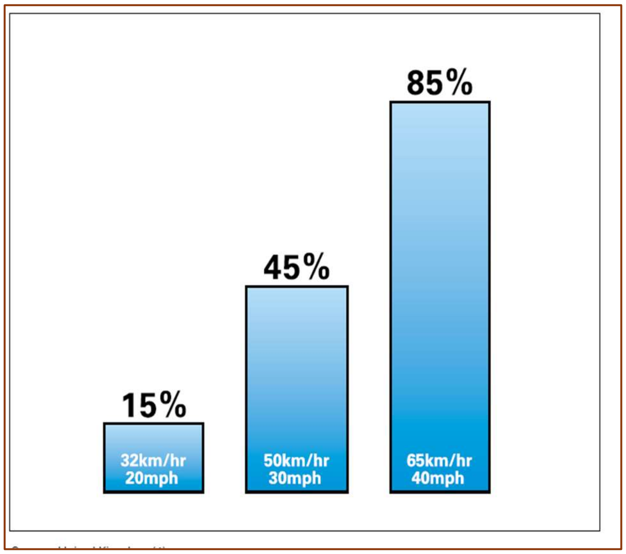
2.1.7.3 DESIGN TO REDUCE CRASH RISK

City streets are designed and built to encourage appropriate speeds for their context, aiming to reduce the number of crashes and improve crash outcomes (reducing severity) for pedestrians, cyclists, and drivers. While roundabout, by design reduce the rate and severity of crashes for people driving, additional conflict point reduction and speed management is needed to reduce the risk for people walking and biking.

These guidelines provide methods for reducing conflict points (see Section 7.0) and managing entry and exit speeds (9.3.1 Speed Management) giving all users more time to make decisions and avoid crashes.

Applying speed management is important to reduce the trend identified in the City's Transportation Safety Plan that people walking and biking are more likely to be injured, and injured more severely, in crashes due to higher speeds. Bend's Roundabout Design Manual targets the slower end of the NCHRP 1043-recommended design speed ranges to incorporate the safety, operational, and multi-modal benefits that occur at lower speeds.

Exhibit 1. Shows pedestrian's chances of death if hit by a motor vehicle at different speeds. (Image from Federal Highway Administration's (FHWA) Roundabouts: An Informational Guide.)



3.0 PLANNING AND INTERSECTION EVALUATION

3.1 Locations for a Roundabout

Under a roundabout-first policy, roundabouts are prioritized for intersections that meet signal warrants, including arterial/arterial, arterial/collector, collector/collector, and highway ramp intersections. Roundabouts may also be considered at collector/local intersections that meet or are approaching all-way stop control warrants. The mini roundabout is a tool for providing traffic calming at higher volume local/local street intersections at low-stress corridor intersections.

A roundabout may not be appropriate in the following situations:

- Highly constrained locations where the desired geometry is not achievable.
- Corridors with interconnected traffic signals or nearby signals with long queues that can back up into the proposed intersection.
- Areas with steep terrain where the roundabout footprint is larger than a signalized or stop-controlled intersection, requiring additional retaining walls or slopes.
- Intersections with imbalanced traffic volumes that create minimal gaps for traffic to enter the flow, although metering could mitigate this issue.

Roundabout locations are identified from:

a. the ICE form and every arterial-arterial, arterial-collector, and collector intersection,

b. development or master plan approval,

c. capital project planning, or

d. as directed by the City Engineer.

3.2 Project Planning

The priorities will differ for roundabout designs based on the context, user type emphasis, low-stress route function, speeds, available right -of-way or other criteria as noted in the ICE form (see Appendix B). The first step in the design should be to identify initial priority factors to help guide the design options. NCHRP 1043 provides a general discussion on developing project priorities and the NCHRP 1036 Roadway Cross-section Reallocation guide helps evaluate projects where the optimal design cannot be accommodated. Use the ICE form for roundabout planning.

4.0 USER CONSIDERATIONS

Roundabouts in Bend are designed to support the safety and comfort for users of all ages and abilities across all modes. Roundabout design features include lower speed design, separating decision points, managing viewing angles, and separating users. Specific user requirements for designs are provided in the design sections. Emphasized below are some general user considerations:

- City of Bend Engineering Standards require compliance with the *Public Rights-of-Way Accessibility Guidelines* (PROWAG, Reference 3) and the City's Complete Streets Guide encourages the use of Universal Design.
- City of Bend Engineering Standards require that facilities for people walking and biking meet Level of Traffic Stress (LTS) 1 or 2. See the standards, including the Complete Streets Guide, for more details on determining which type of facilities are required at the roundabout project location. The City recognizes that the qualitative measurements are the minimum target, and the desire is to separate people walking, biking, and driving as feasible and requires separation on key routes (TSP Figure 5-3b).
- The City supports travel options and the use of micromobility devices is increasing. Consider how people will navigate roundabouts with these different devices. This may require providing different options, such as allowing people on bicycles, including various classes of e-bikes, to use both the circulating lane and the shared-use path, or considering other alternatives.
- Designs consider and accommodate design vehicles that fit the context of nearby land use. For instance, accessibility for larger trucks (such as the WB-67) may need to be considered if a roundabout is planned along known truck routes, near businesses that require deliveries from large trucks, or in areas with land use decisions that could include future development by commercial and industrial users. Designers may only need to accommodate specific movements for these large design vehicles.
- Designs support keeping transit moving. Refer to Cascades East Transit for existing and proposed transit routes. Locate transit stops on the upstream side of the approach lanes and within the limits of the splitter islands.
- Designs accommodate Emergency Vehicles. City of Bend Emergency Services is part of the design team review and will provide input on roundabout designs and design vehicle to be used for EMS, when needed.

- Designs accommodate school buses. Bend-La Pine School District can be consulted, a standard school bus should have no issues using the same roundabout designed for WB-50 and WB-67 vehicles.
- Designs consider railroad operations in the vicinity. Where roundabouts are close to railroad crossings, additional design elements may be required to obtain approval from appropriate railroad governing entities (e.g., Oregon Department of Transportation [ODOT] Rail, Burlington Northern Santa Fe Railway [BNSF]). Engaging these stakeholders early in the design process can help prevent potential project delays during construction. Operations should be evaluated to minimize the potential of queuing across rail crossings. In cases where existing rail crossings cross a stop-controlled approach at an intersection, a roundabout may reduce the delay of the crossing approach and probability of a vehicle stopping on the tracks. Initial designs should consider the location of the roundabout and whether it is in the Stopping Sight Distance (SSD) of the rail crossing based on posted roadway speed.
- Climate Friendly Areas – (reserved for future use).

Maintenance will be considered in roundabout designs. Where feasible, include space behind the sidewalk/shared-use path or in a buffer between the circulating lane and the sidewalk/shared-use path for snow storage. Curbs along the median and bike ramps should be designed to accommodate the street sweeper.

5.0 STAKEHOLDER CONSIDERATIONS

The stakeholder process for roundabout design is part of the development review or capital projects process. Designers are encouraged to reach out to the various stakeholders early in the design process to understand their needs and incorporate as appropriate at early stages of design.

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6.0 PLANNING AND DESIGN DOCUMENTATION

The City of Bend TSP and Standards identify roundabouts as the preferred intersection treatment, and other forms (such as traffic signal and all-way stop) may be considered based on individual site characteristics. The following two-step design documentation process evaluates design options with an emphasis on determining the right type of roundabout or intersection control based on context, crash risk reduction, and multi-modal operations. The two steps are:

1. ICE scoping, and
2. ICE Documentation

6.1 Project Scoping/Initial Screening

The first step of the planning process is to identify which intersection type (mini-roundabout, compact urban roundabout, single-lane roundabout, multi-lane roundabout, protected roundabout, traffic signal, or other) should be considered for further evaluation. Complete the ICE Scoping Form (Appendix B) and submit it to the City Engineer for review and approval.

Where adequate ROW is available or can be reasonably obtained in a location that supports a roundabout, evaluating a traffic signal or all-way stop is not required. Use the scoping form (example shown in Figure 7) to determine which type of roundabout (i.e., mini, compact urban, single-lane, etc.) will be evaluated.

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Intersection Control Evaluation Scoping Form

Use this form to determine what intersection forms are REQUIRED to be evalauted as part of the City of Bend's Intersection Control Evaluation (ICE) Process and what intersection forms should be CONSIDERED as part of the ICE process. Fill out the desired information in the yellow cells.

Intersection Name:	
Analyst Name:	

Criteria		Input	Roundabout Types					Signal
			Mini-	Compact Urban	Single Lane	Multilane	Protected	
Functional Classification (Major Street/Minor Street)[A]		Arterial/Collector		Consider	**Required**	Consider		
Key Walking & Biking Route or Bicycle Low Stress		Intersection is on the LSN					Consider	
Number of Travel Lanes on Major Street		2-3 lanes			Consider			
Nearest Signalized Intersection		<500 feet						**Required**
Nearest Railroad Crossing		>1,000 feet						
Daily Entering Traffic Volumes[C]	< 20% Left Turn Traffic	N/A						
	>= 20% Left Turn Traffic	<15,000	Consider	Consider	Consider	Consider		
Intersection Forms to Evaluate Further:			Consider	Consider	**Required**	Consider	Consider	**Required**
RESULTS:			A full Intersection Control Evaluation Report is required.					

Figure 7. Example Intersection Control Evaluation Scoping Form

Include a sketch-level drawing over an aerial photo, showing ROW lines and additional details as needed to identify feasibility and significant conflicts that could impact the form or type selection.

6.2 Evaluation and Documentation

Based on the outcome from the *ICE Scoping Form*, there are two options for ICE Step 2 – Evaluation and Documentation. Both options listed below are discussed in more detail in Sections 6.2.1 and 6.2.2.

- **Roundabout Evaluation** – The intent of the simplified Roundabout Evaluation is to determine what type of roundabout (i.e., mini roundabout, compact urban, single-lane, multi-lane, protected), size (inscribed intersection diameter), and lane configuration is necessary based on the context, safety, and multi-modal operations. Section 6.2.1 describes in more detail the requirements for a Roundabout Evaluation Memorandum.
- **Intersection Control Evaluation –** A full ICE is required if the *ICE Scoping Form* indicates analysis of a signal is also required. Section 6.2.2 describes in more detail the requirements for an ICE Report.

6.2.1 Roundabout Evaluation Requirements

The intent of the simplified Roundabout Evaluation is to understand the intersection context, user needs and multi-modal operations to determine:

- The type of roundabout (i.e., mini-roundabout, compact urban, standard, multi-lane, separated)
- The required lane configurations (single-lane versus multi-lane approaches) and phasing (near-term versus planning horizon needs).

6.2.1.1 Roundabout Type

Consider the following criteria, described in more detail in Table 2, when selecting the type of roundabout between a mini, compact, standard, or separated roundabout:

- Intersection context and footprint
- Design vehicle accommodation
- Walking and biking accommodation

Additional criteria may be considered based on discussion with City staff. Conceptual design-level details and iteration during the design phase will be needed to find an appropriate balance between the above criteria and to meet the design controls for performance (see Section 9.3).

Table 2**Error! Reference source not found.** provides a high-level summary of key considerations for each of the major roundabout types related to the above criteria. Detailed descriptions of key features of the major roundabout types can be found in *NCHRP 1043, Section 2.3: Roundabout Categories* while *NCHPR 1043, Chapter 3: A Performance-Based Planning and Design Approach* contains additional detail related to key considerations when determining the appropriate type of roundabout.

Table 2. Roundabout type considerations.

Criteria	Roundabout Type			
	Mini-Roundabout	**Compact Urban**	**Standard (Single-Lane or Multi-Lane)** [A]	**Separated (Single-Lane or Multi-Lane)** [A]
Intersection context and footprint	• Generally recommended only at collector-collector or collector-local intersections • Should only be considered in right-of-way constrained locations • Best suited on lower speed roadways (i.e., 25 mph to 30 mph)	• Generally recommended only at collector-collector or collector-local intersections • Can be considered in right-of-way constrained locations	• Can be recommended for most corridor contexts	• Can be recommended for most corridor contexts • Will generally require additional right-of-way (ROW) • Additional consideration for utility locations and drainage design required
Design vehicle needs	• Should only be considered in areas where design vehicle needs, and ROW limitations would require fully traversable central islands and splitter islands	• Should be considered in areas where design vehicle needs, and ROW limitations may require some traversable elements	• Generally, can be designed to accommodate large vehicles	• Generally, can be designed to accommodate large vehicles
Walking and biking needs	• Can be considered on the bicycle low-stress network but typically not recommended for key walking and biking routes	• Can be considered on the bicycle low-stress network but typically not recommended for key walking and biking routes	• Can be considered on the bicycle low-stress network and key walking and biking routes	• Should be considered on key walking and biking routes where separated bike lanes are provided on two or more approaches[B]

[A] *See Section 6.2.1.2 to determine appropriate lane configurations for a standard roundabout.*

[B] *Unless LTS level 1 or 2 can be met.*

6.2.1.2 Roundabout Lane Configurations and Phasing

Operational performance analysis is used to size alternatives, compare performance, and determine the appropriate lane configuration. Evaluate the lane configuration based on the operational analysis and criteria listed on the approved ICE scoping form (see Section 6.2.2), including site-specific evaluation criteria (context/footprint, vehicle accommodation, and walking/biking accommodation). If a multi-lane roundabout is recommended, determine if there is an interim configuration that can address near-term operational needs while maximizing safety for all users.

To determine the appropriate lane configuration and phasing, conduct the intersection operations analysis based on the guidance in Section 9.0. The analysis may need to be conducted using various lane configurations (single lane, hybrid [partial two-lane], full two-lane, etc.) as identified in the scoping form or as determined during the evaluation to serve the volume projections for the 20-year design life. If the existing and projected 20-year design life volume-to-capacity (V/C) ratio of the entry or circulating lane is less than 0.90, single lane operation is typically acceptable. As the degree of saturation increases above 0.90, multiple lanes should be considered.

When projected traffic volumes indicate a multi-lane roundabout is required for future year conditions, designers should evaluate how long an interim configuration (e.g., single-lane roundabout) will operate acceptably before requiring additional lanes. When a single-lane roundabout provides sufficient capacity for much of its design life, designers should consider constructing and operating the roundabout in a single-lane configuration until operational performance dictates the need for ultimate expansion to a multi-lane roundabout. The City Engineer will review the recommendation to accept the higher V/C ratio during the peak period in the 20-year design life or to require additional traffic lanes based on the scenario results.

In addition, system context should be considered when determining lane configuration and phasing needs. System context can include the project’s original rationale, such as addressing capacity issues, existing crash problems, difficulty crossing the main street, or delays caused by queuing at the intersection. Context also includes consideration of anticipated users, adjacent land uses, available ROW, and design vehicle needs. For example, in areas where heavy walking and biking volumes are expected (such as Key Walking and Biking Routes), a roundabout with a single-lane exit instead of a multi-lane exit could be recommended to simplify the crossings for people walking and biking.

6.2.1.3 Documentation

Summarize the roundabout evaluation in a technical memo including:

1. **Introduction** – Including reference to traffic study general recommendations and intersection forms evaluated per the approved ICE scoping form.
2. **Context/Existing Conditions** - By mode (vehicle, walk, bike, transit, emergency, and other vehicles) and include any project catalyst for the intersection reconfiguration (Transportation Safety Action Plan [TSAP] intersection/safety improvements, key route walk/bike enhancement, separated facilities, development traffic increases, etc.). Include existing traffic counts in the appendix.
3. **Future Conditions** – By mode and include a summary of key future elements from the traffic study for the 20-year design life.
4. **Operational Analysis** – V/C, control delay, 95% queue length, etc.
5. **Alternatives Evaluation** – Complete ICE form with discussion of criteria as applicable.
6. **Summary and Recommendation** - Roundabout type and lane configuration.

6.2.2 Intersection Control Evaluation Requirements

The intent of the full ICE is to compare a traffic signal (or other intersection control) with various types of roundabouts to determine the appropriate intersection control type. Use the Tier 1 and Tier 2 selection criteria in Table 3 and Table 4, respectively. Tier 1 criteria are primary evaluation criteria required in the evaluation while Tier 2 criteria can supplement Tier 1 criteria as needed, or when the Tier 1 criteria do not provide sufficient differentiation between the intersection control types reviewed.

To provide a reasonable comparison, each intersection control type should be developed at a consistent and comparable level of detail. For roundabouts, follow Section 6.2.1 to determine the appropriate type and lane configuration and Section 8.0 for the operational analysis. For control types other than roundabouts, follow the operational analysis procedures presented in the latest edition of the Highway Capacity Manual.

Summarize the intersection control evaluation in a technical memo including:

1. **Introduction** – Including reference to traffic study general recommendations and intersection forms evaluated per the approved ICE scoping form. (include completed ICE form as appendix)
2. **Context/Existing Conditions** – By mode (vehicle, walk, bike, transit, emergency, and other vehicles) and include any project catalyst for the intersection reconfiguration (TSAP intersection/safety improvements, key route walk/bike enhancement, separated facilities, development traffic increases, etc.). Include existing traffic counts in the appendix.
3. **Future Conditions** – By mode and include a summary of key future elements from the traffic study for the 20-year design life.
4. **Operational Analysis** – V/C, control delay, 95% queue length, etc.
5. **Alternatives Evaluation** – Complete ICE form with discussion of Tier 1 and/or Tier 2 criteria as applicable
6. **Summary and Recommendation** – Control type and lane configuration.

Table 3. Tier 1 intersection control evaluation criteria

Category	Criteria	Resources/Considerations
Crash Risk		
Motor Vehicle Safety	Conflict points (exposure) Severity (speed)	• *NCHRP 1043,* Section 7.2
Pedestrian Safety	Conflict points (exposure) Severity (speed) Separation from vehicles and bikes	• *NCHRP 1043*, Section 7.3 • *Section 7.0 - this manual.*
Bicycle Safety	Conflict points (exposure) Severity (speed) Separation from vehicles and pedestrians	• *NCHRP 1043*, Section 7.3 • *Section 7.0 - this manual.*
Traffic Operations		
Peak-Hour Traffic Operations	Volume-to-capacity ratio Average delay Queue lengths (average and 95th percentile)	• Section 0 (below) • Non-roundabout intersection forms*:* Latest edition of the *Highway Capacity Manual*
All Ages and Abilities Multi-Modal Facilities		
Design Vehicle	List types of heavy vehicle accommodated (SU 30, WB 40, WB 50, WB 67, etc.) Buses (Cascades East Transit [CET] and School) Emergency vehicles Unique accommodated vehicles	• *NCHRP 1043*, Section 9.7
Pedestrians	PLTS Continuity of Walking System Limits out-of-direction travel	• Complete Streets Manual
Bicycles	BLTS Continuity of Bicycle System Direct route	• Complete Streets Manual • Provides direct connections to system at same or better LTS • Limits out of direction travel
Special User Needs	School zone Low-stress bicycle route Universal design, sight impaired Driveway access/access control	• Complete Streets Manual
System Context		
System Effects	Adjacent traffic control Railroad crossing Design consistency along the corridor	• *Highway Capacity Manual* – Upstream impacts and vehicle arrival patterns
Environmental Impact	Land use context	• Review of existing adjacent land use and planned land use
Emergency Response	Response time/qualitative impacts of control and geometric delay	• Section 0 (below) • Non-roundabout intersection forms*:* Latest edition *Highway Capacity Manual*
Context at Intersection		
Intersection Footprint	Intersection proper (physical & operational influence area) Roadway approach geometry	• Review of conceptual geometric design
Intersection Influence Area	Driveway closures or impacts	• Review of conceptual geometric design

Table 4. Tier 2 intersection control evaluation criteria.

Category	Criteria	Resources
Crash Risk		
Motor Vehicle Safety	Crash Prediction	• American Association of State Highway and Transportation Officials (*AASHTO) Highway Safety Manual* • *NCHRP 1043 Chapter 7*
Traffic Operations		
Peak Hour Traffic Operations	Sensitivity to changes in volumes/travel patterns	• Section 8.0 (below) • Non-roundabout intersection forms*:* Latest edition *Highway Capacity Manual*
24-Hour Traffic Operations	Qualitative Discussion of Off-peak Average Delay	
All Ages and Abilities Multi-modal Users		
Pedestrians	Crossing distances	NCHRP 1043, Section 4.2
Bicyclists and Micromobility Users	Adjacent bike facilities Intersection specific considerations	NCHRP 1043, Section 4.3
Transit Users	Transit Stops	
System Context		
Environmental Impact	Estimated fuel consumption/emissions output	
Access Management	Facilitates access management Median and U-turn opportunities Driveway connections	• Review of conceptual geometric design
Emergency Response	Evaluating likely emergency response routes	
Context at Intersection		
Environmental Impact	Impervious surface area Aesthetics Stormwater Facilities	• Review of conceptual geometric design
System Effects	Local Street Traffic Calming	• Ability of design to discourage cut thru and/or slow down traffic on local street approaches
Intersection Influence Area	Approach and segment cross-section	
Benefit/Cost Ratio		
Benefits	Crash reduction Reduced fuel consumption/emissions Reduced delay (15-min delay, 24-hour delay) Level of Traffic Stress for pedestrians Level of Traffic Stress for Bicyclists	• *AASHTO Highway Safety Manual* • Section 8.0 (below) • Non-roundabout intersection forms*:* Latest edition *Highway Capacity Manual*
Costs	Design/Engineering Costs Construction costs including ROW acquisition Operations/maintenance costs (includes energy costs for signals and roundabout lighting)	• Life-Cycle Cost Estimation Tool (2016)

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7.0 SAFETY PERFORMANCE ANALYSIS

By design, roundabouts reduce the number and severity of crashes compared to other intersection types. Even so, safety can often be further enhanced with a conflict reduction analysis. The ICE memo and subsequent design iteration process includes steps to reduce the number and severity of conflicts as feasible with extra focus on reducing conflicts for the more vulnerable users: pedestrians and bicyclists.

In general, perform the following safety performance analyses and provide exhibits with the roundabout memo for City review where applicable:

- Perform a sight-line analysis per NCHRP 1043, section 9.5. Consider sight obstructions such as fences, planned landscaping, and franchise utility facilities for elimination or relocation. Where applicable, non-standard crossings, bike ramps, and other roundabout features may need to be considered to provide increased safety for vulnerable users.

- Perform a sight distance analysis including SSD, intersection sight distance (ISD), decision sight distance (DSD), and view angle. The Green Book section 9.0 and NCHRP 1043 section 9.5 provides guidance on determining SSD, ISD, and DSD. As feasible, provide clear vision areas on the approaches inside of the SSD triangles. Refer to NCHRP 1043 section 9.5 for more detailed information.

Also consider:

- For bikers and pedestrians: minimize exposure to conflicts, reduce speed at conflict points using geometry (such as increasing bike ramp angles), define potential conflict areas, separate modes where feasible, clearly communicate right-of-way priority for different modes, provide simple alignments, provide adequate sight distance for drivers to conflict points, provide comfortable spaces for waiting and decision making including the splitter islands.

- Vertical designs will consider safe stopping distance and provide K-values on centerline profiles that align with City design standards and approach speeds.

- Consider the location of the roundabout in relation to other potential vertical or horizontal obstructions. Areas shaded during winter may be a poor candidate for roundabouts as they remain iced over for extended periods. Areas where the approaches are excessively steep may create hazards for drivers stopping and difficulty with traction in the winter.

- Provide properly installed tactile directional indicators (TDI) including truncated domes at Americans with Disabilities Act (ADA) crossings and longitudinal directional indicators at bike ramps.

8.0 OPERATIONAL ANALYSIS GUIDANCE

8.1 General Analysis Requirements

Operational performance analysis is used to size alternatives and compare performance. Different levels of analysis are required for planning studies, ICE Step 1 and ICE Step 2.

Traffic Analysis requirements are listed in Chapter 4.7 of the Bend Development Code. Conduct the operational analysis using the latest version of the *Highway Capacity Manual* (HCM), with local calibration factors. For planning-level evaluation, you may also reference *NCHRP Report 1043: Guide for Roundabouts*, or its current version. Include the following four measures of effectiveness to evaluate intersection operations to compare across alternatives and to the criteria in the Bend Development Code 4.7.500B6:

- Volume-to-capacity ratio (V/C)
- 95^{th} percentile queue
- Level of Service (LOS)
- Control Delay

Deterministic software, such as Synchro, Vistro, Highway Capacity Software (HCS), or Sidra, may be used to develop the measures of effectiveness. Microsimulation, such as Vissim, may be required where the HCM methodology has limitations, such as with three-lane roundabouts or when dynamic conditions exist, such as with rail crossings and nearby traffic signals, or at the discretion of the City Engineer.

The analysis should minimally evaluate p.m. peak hour operations. Other time periods, such as a.m. peak hour, off-peak hours or multiple hours may be required at the discretion of the City Engineer based on adjacent land use generators (e.g., schools) or heavily congested locations.

8.2 HCM and Calibration Factors

The HCM uses Equation 1 for capacity at a roundabout.

$$C_{pce} = A \cdot e^{(-B \cdot v_{c,pce})} \quad \text{(Equation 1)}$$

where,

C_{pce} = lane capacity, adjusted for heavy vehicles, (pc/h)
$A = 3600/t_f$
$B = (t_c - t_f/2)/3600$
t_c = critical headway (s)
t_f = follow-up headway (s)
$v_{c,\ pce}$ = conflicting circulating flow rate, adjusted for heavy vehicles, (pc/h)

To better reflect Bend-specific conditions, Bend-specific calibration factors were developed based on observations at single-lane roundabouts in 2009. No separate local calibration factors have been developed for multi-lane roundabouts. Apply the City-specific calibration factors in Table 5. Use a peak hour factor of 1.0 for future years, unless otherwise approved.

Table 5. City of Bend specific HCM calibration factors.

Variable	Local Calibration Factors
Critical Headway (tc)	4.1s
Follow-up Headway (tf)	2.7s
A	1333
B	-0.0008

8.3 Volume-to-Capacity Ratio

V/C ratios are one of the primary measures of effectiveness. Calculate V/C ratios for roundabouts 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 multi-lane roundabouts. Aggregate the approach V/Cs into a single V/C for the intersection when comparing to a traffic signal. Use a volume weighted averaging of approach or critical lane V/Cs.

If the existing and projected 20-year design life V/C ratio of the entry lane is less than 0.90, single lane operation is typically acceptable. As the degree of saturation (i.e., V/C ratio) increases above 0.90, multiple lanes may be required. Where analysis shows a roundabout is approaching capacity (V/C greater than 0.90) under projected future operations, include a discussion of how realistic the future projected traffic volume growth is. Conduct a sensitivity analysis to determine when additional lanes or configuration changes are needed to serve future traffic volumes. For a mini roundabout, if the V/C ratio of a roundabout leg is greater than 0.85 using HCM methodology, consider using a methodology that takes into consideration the impacts of geometry on capacity (e.g. Sidra method or a calibrated microsimulation model) or consider a standard roundabout instead.

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9.0 GEOMETRIC DESIGN PROCESS AND PERFORMANCE CHECKS

9.1 Design Process and Memo

As shown in the below chart (Figure 8), designing roundabouts is an iterative process. The process begins with the information from the approved ICE that determined the number of lanes and type of roundabout. It then moves through various iterations until a preferred design is identified meeting as many of the target criteria as feasible for the project location. Table 6 summarizes a list of outcomes that should be identified through the iterative design development process. The results are summarized in a Design Memo and submit to the City Engineer for approval prior to or with the 30% construction plans. For roundabouts designed with The City of Bend Private Development Engineering Department (PDED), PDED should be engaged early in the design process and may be able to review overall concepts. However, since there is no 30% design submittal for private development, the design memo is due with the initial plan set submittal.

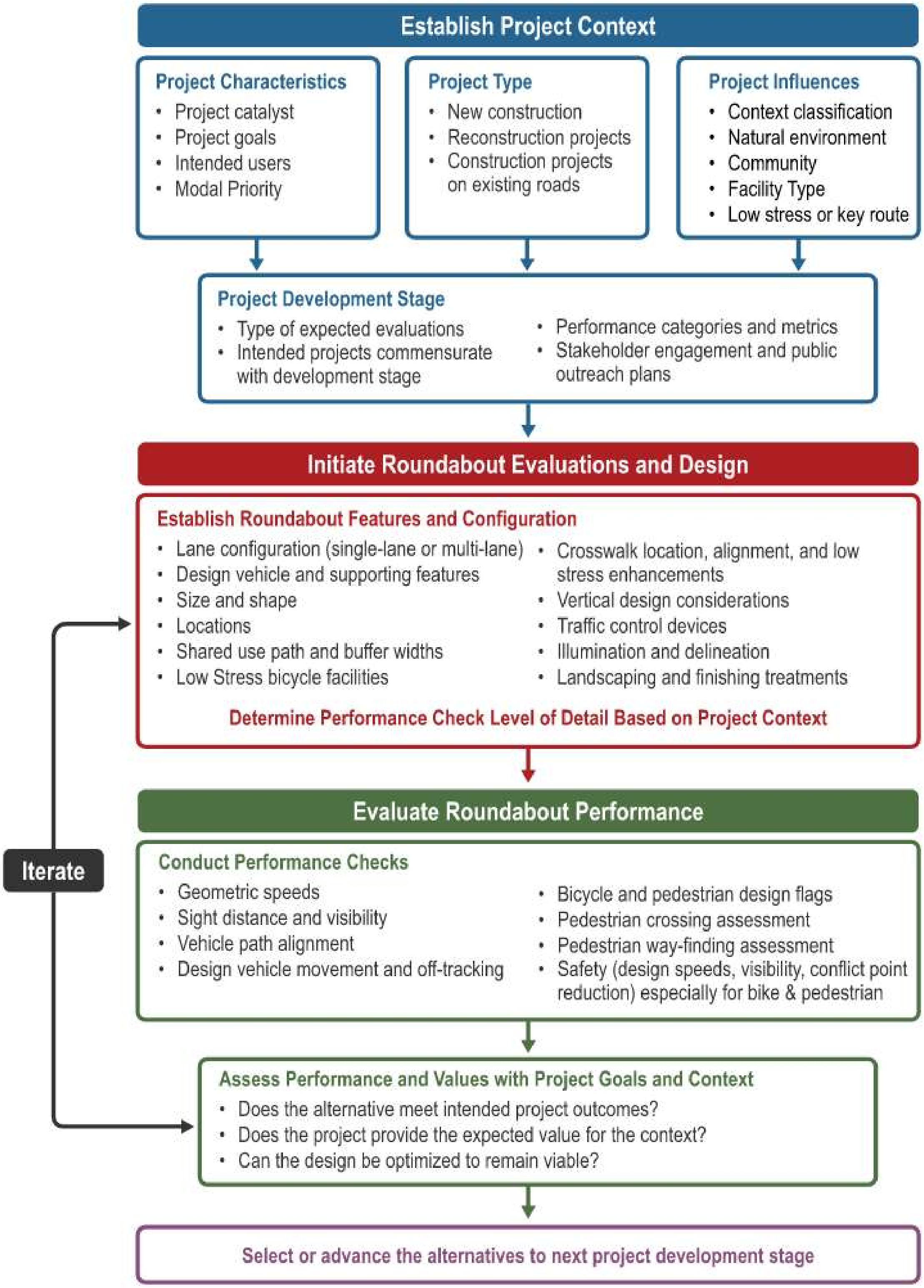

Figure 8. Chart illustrating the iterative roundabout design process based on NCHRP 1043 Exhibit 9-1, with City of Bend-specific elements added.

The Design Memo includes the following sections:

1. Introduction – Summarize the traffic study general recommendations and approved ICE form. (include approved ICE in memo).
2. Context/Existing Conditions – Summarize existing conditions by mode (vehicle, walk, bike, transit) from the traffic analysis; include any project catalyst for the intersection reconfiguration (TSAP intersection/safety improvements, key route walk/bike enhancement, separated facilities, development traffic increases, etc.).
3. Future Conditions – Summarize future conditions by mode from the traffic analysis.
4. Operational Analysis (V/C, 95% queue length, control delay, etc.) – Detail the operational analysis and results.
5. Horizontal Geometry – Design Criteria and Resultant Design: Present a summary of design criteria from the ICE and the proposed dimension, including design vehicle, inscribed circle diameter, entry/exit width, circulating road width, crosswalk offset and width/refuge width, splitter island length, bike ramp location and width, and the method of addressing PROWAG requirements for blind/visually limited people if the shared-use path/sidewalk is attached.
6. Performance Checks – Summarize the results of the analysis.
   a. Fastest Path Analysis
   b. Sight Distance Analysis
   c. Truck Turning Analysis
7. Signing and Striping – Note any exceptions or deviations to standard signing and striping.
8. Vertical Design Elements – Summarize the vertical design providing typical sections, confirming drainage plan concepts, and general grading plan.
   d. Typical sections
   e. Grading plan
9. Construction Staging/Multi-Lane Roundabout Phasing – A summary discussion of how traffic will be staged during construction with figures as applicable. (This is not a detailed traffic control plan (TCP), but instead a general summary of the methods to check feasibility of construction plan and impact on traffic.)
10. Landscaping Concepts – Show any areas where landscaping must be restricted for visibility and note restrictions (location, height, etc.).

11. Illumination – Document illumination design standards, equipment, and performance metrics to be used in design. The design horizontal/vertical light levels and uniformity for the roundabout and marked crosswalks should be summarized in a table. Document information on illumination including light fixture type, fixture distribution, fixture wattage, fixture color temperature, pole type, arm length, luminaire mounting height, maintenance, and ownership.

Table 6. Roundabout design elements and outcomes.

Horizontal Geometry (Providing Design Criteria and Resultant Design)
Design Vehicle
Roundabout Size
Approach Alignments
Entry and Exit Lane Widths
Circulating Roadway Width (Lane Widths for Multi-Lane)
Crosswalk Location, Widths, Splitter Island Width, Geometry
Splitter Island Information
Pedestrian and Bicycle Accommodations
Performance Checks
Fastest Path Analysis
Speed Consistency
Sight Distance Analysis
Design Vehicle Movement Analysis
Signing And Striping
Basis of Design and Design Standards
Special Signing and Striping Needs
Illumination
Basis of Design and Design Standards
Special Illumination Needs
Preliminary Illumination Pole Location Outside Restricted Area
Vertical Design Elements
Evaluation of Existing and Proposed Roadway Profiles
Identification of Typical Section Elements
Review of Drainage Considerations
Verification of Ability to Comply with ADA Guidelines
Construction Staging
Review and Discussion of Construction Staging Requirements
Landscaping
Basis of Design Standards Recognition of Low Growth Areas

9.2 Design Principles

The following design principles support the general transportation guiding principles of designing for the context, all ages and abilities across all modes, and to reduce the number and severity of crashes. The overall principles for roundabout design are generally defined in Exhibit 9.2 of the NCHRP 1043 and shown in Figure 9. These overarching principles are generally common to all roundabouts, with slight variations based on the design differences of each type.

Overarching Principles
• Design for target vehicular speeds (e.g., 15 mph to 25 mph [25 km/h to 40 km/h]) throughout the roundabout, with maximum entering design speeds of 25 mph to 30 mph (40 km/h to 48 km/h), depending on lane configuration.
• Design specifically to meet the needs of pedestrians, bicyclists, and micromobility users.
• Establish appropriate lane numbers and lane assignments to achieve balanced performance to best serve the combined needs of each user.
• Design for and accommodate identified design vehicles.
• Provide channelization that is intuitive to drivers and results in vehicles naturally using the intended lanes, with signing and pavement marking to complement good geometrics.
• Provide sight distance (stopping, intersection, and decision) and visibility sufficient for users to recognize the intersection and observe other users.

Figure 9. Overarching principles of roundabout design. Taken from NCHRP 1043 Ex. 9.2.

9.3 Performance Checks

Performance checks for speed, visibility, vehicle path, and walking and biking are completed at various points in the iterative design process to see how the design meets the project goals and objectives and how alternatives compare.

9.3.1 Speed Management

The operating speed of a roundabout is one of most critical factors for safe performance. Crash frequency, severity, and crosswalk yielding are directly tied to operating speed. The design iterations adjust overall size, approach and exit geometry to control entering, circulating and exiting design speeds. The most critical design objective is to maintain low and consistent speeds at the entry and through the roundabout to minimize the crash rate between conflicting streams of vehicles and maximize driver yielding at crosswalks. Target design speeds are identified on the ICE, typically and shown in Table 7. The fastest path analysis is used to identify the design elements needed to meet or exceed (by encouraging slower speeds) the target.

Complete the fastest path analysis and calculations per the NCHRP Report 1043, Section 9.4, Geometric Speeds. Fastest path speeds consider the theoretical maximum speed a vehicle can traverse the roundabout based on the geometrics, which serves a surrogate for safety performance. Use the curbing and fastest path, assuming drivers do not adhere to lane markings on the entry.

Table 7. Standard turning movements in roundabouts.

	Movement	Description
R1	Entry Radius	Minimum radius on the entry path as measured NCHRP Report 1043, Exhibits 9.7 and 9.8
R2	Circulating Radius	Minimum radius on the circulating path as measured NCHRP Report 1043, Exhibits 9.7 and 9.8
R3	Exit Radius	Minimum radius on the exit path as measured NCHRP Report 1043, Exhibits 9.7 and 9.8
R4	Left Turn Radius	Minimum radius on the left turn path as measured NCHRP Report 1043, Exhibits 9.7 and 9.8
R5	Right Turn Radius	Minimum radius on the right turn path as measured NCHRP Report 1043, Exhibits 9.7 and 9.8

9.3.2 Visibility

Complete the sight distance analysis for the intersection based upon NCHRP Report 1043, Section 9.5 Sight Distance and Visibility for the stopping sight distance, intersection sight distance, decision sight distance, and view angle. Use the approach roadway design speed and fastest path calculations completed above. Additional analysis may be required for specialty roundabout designs.

9.3.3 Design Vehicles and Path Alignment

Conduct performance checks for vehicle path to confirm the desired vehicles are tracking within the lanes. Roundabout geometry is developed based on a) designs for and b) accommodates vehicles sizes based upon the type of roundabout, the type of corridor, the type and frequency of vehicles, and the type of user. A description of these cases is:

- **Design for:** When designing for a vehicle, the cab of the vehicle remains on the travel surface while the trailer may offtrack onto mountable truck aprons. At no point shall either the cab or the trailer offtrack over vertical curbing.
- **Accommodate for:** When accommodating for a vehicle, both the cab of the vehicle and the trailer can utilize the mountable truck aprons. At no point shall either the cab or the trailer offtrack over vertical curbing. For multi-lane roundabouts larger trucks (accommodate for) can use both circulating lanes.

Table 8 shows the specific design accommodations for vehicles at a roundabout. Additionally, all roundabouts, except for mini roundabouts, must be designed to accommodate fire trucks, school buses, and Cascades East Transit (CET) buses.

Table 8. Roundabout classification and required design vehicles.

	Vehicle Design	Vehicle Accommodation
Mini Roundabout	SU-30	WB-50
Single-Lane Roundabout	WB-50	WB-67*
Multi-lane Roundabout	WB-67*	WB-67*

*The City PM may consider a reduction in the WB-67 to a modified WB-67 or WB-62 as the traditional WB-67 has become less common.

In addition, do not include reverse curves in the vehicle path as it can adversely impact the ability for approaching motorists to gage oncoming vehicle movement and gaps. Figure 10 shows an example of this at the Reed Market Road/Bond Street roundabout. The oversized ICD, designed for future expansion, causes higher circulating speeds. Combined with the reverse curve, it makes eastbound and westbound entry difficult for drivers to identify gaps in traffic or accelerate into those gaps.

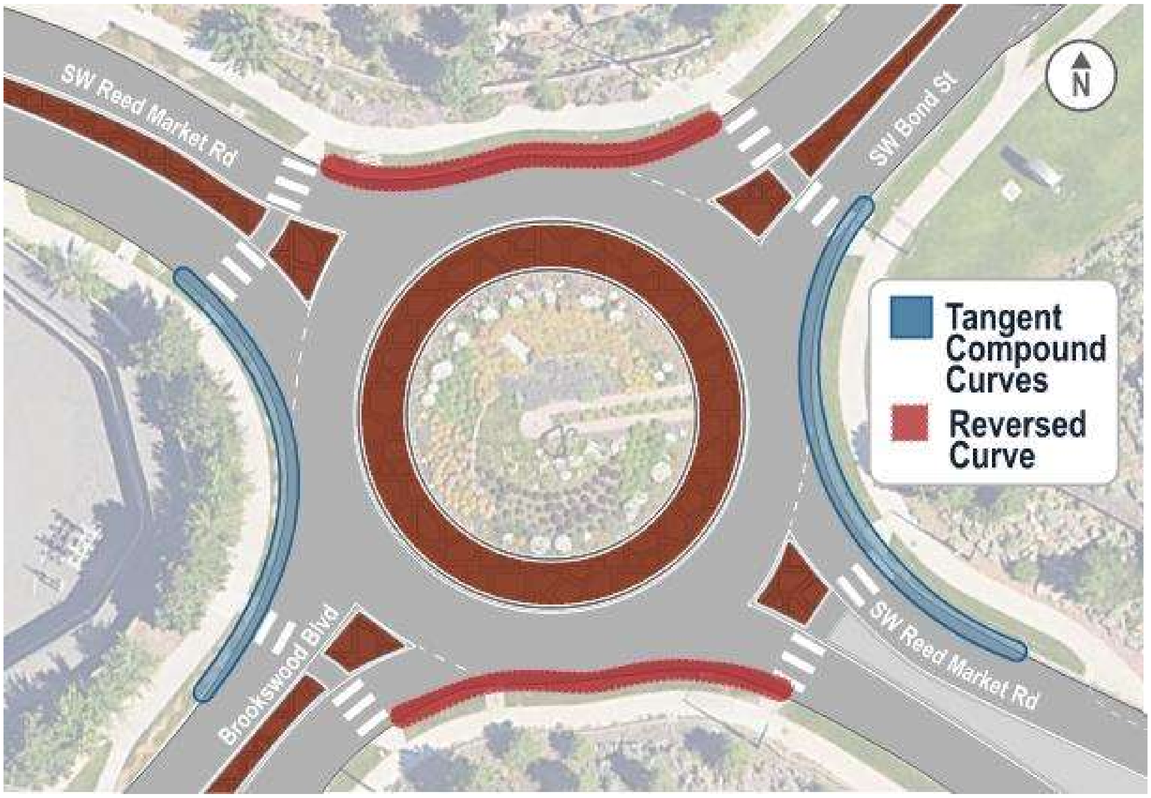

Figure 10. Reed Market and Bond Street reversed curves between entry and exit legs.

9.3.3.1 Oversize/Overweight Vehicle Accommodation

Roundabouts, other than those on state highways, typically do not accommodate oversize/overweight (OSOW) vehicles due to the type of land uses and street cross-sections. During the ICE, the City Engineer will identify if oversize and overweight vehicles need to be accommodated and work with the permitting agency, typically Deschutes County or Oregon Department of Transportation, to determine which vehicle will be used. Recent examples are the roundabouts designed and built on SE 27th Street south of US 20, including both the Wilderness Way and 27th Street intersection and the 27th Street and 15th Street/Tekampe Road intersections.

Where OSOW vehicles will be accommodated, specialized truck aprons may be used to identify a particular path of travel. Truck apron overall heights of 2 inches or less should be considered on these paths of travel to accommodate vehicle clearance needs for low-boy freight in the category of oversize and overweight vehicles in conjunction with the vertical design of the circulatory. Figure 11 shows the use of mountable curb and aprons to accommodate larger trucks, while still maintaining standard curb to curb widths. Figure 12 shows the use of outside mountable curbs and truck aprons that maintain a smaller radius along the curbs to keep speeds lower for passenger cars while allowing the trailer of larger trucks to over track without mounting or crossing standard height curbs. Figure 13 and Figure 14 show examples of accommodating OSOW vehicles by allowing them to track along specific paths through the roundabouts.

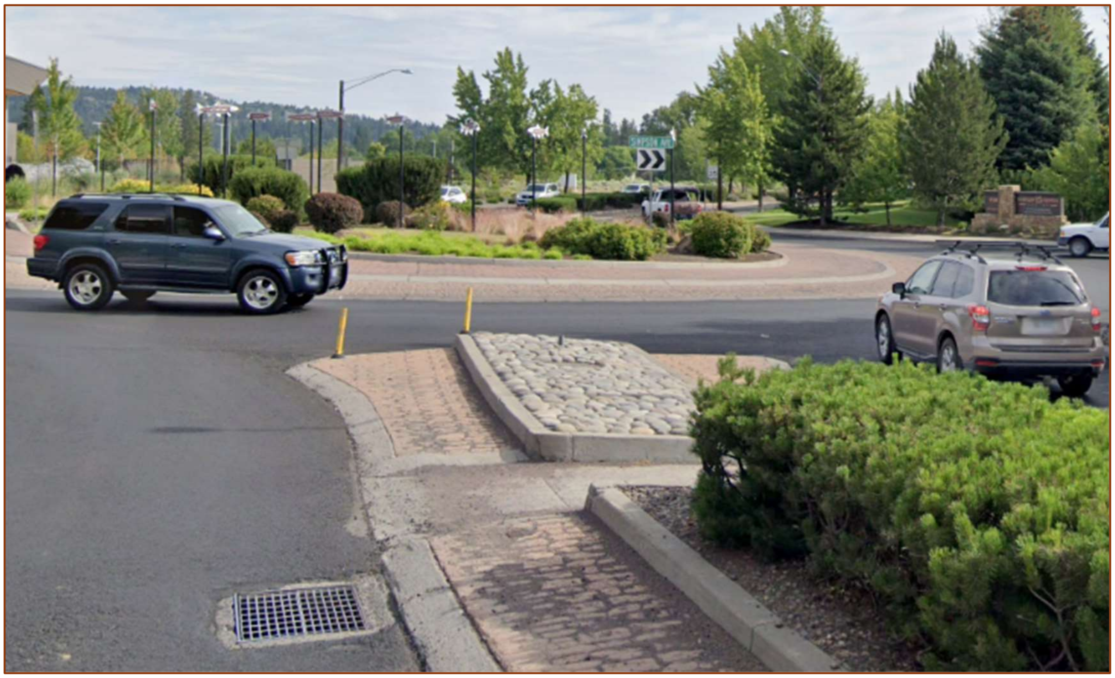

Figure 11. Double central truck aprons and stacked mountable/standard curbs allow for OSOW movements while maintaining a compact footprint. Intersection of Colorado Ave. and Simpson Ave.

Figure 12. Curb-return mountable truck apron at the intersection of 15th St. and Wilson Ave. This treatment allows for larger trucks to navigate a smaller ICD roundabout while maintaining speeds for everyday users.

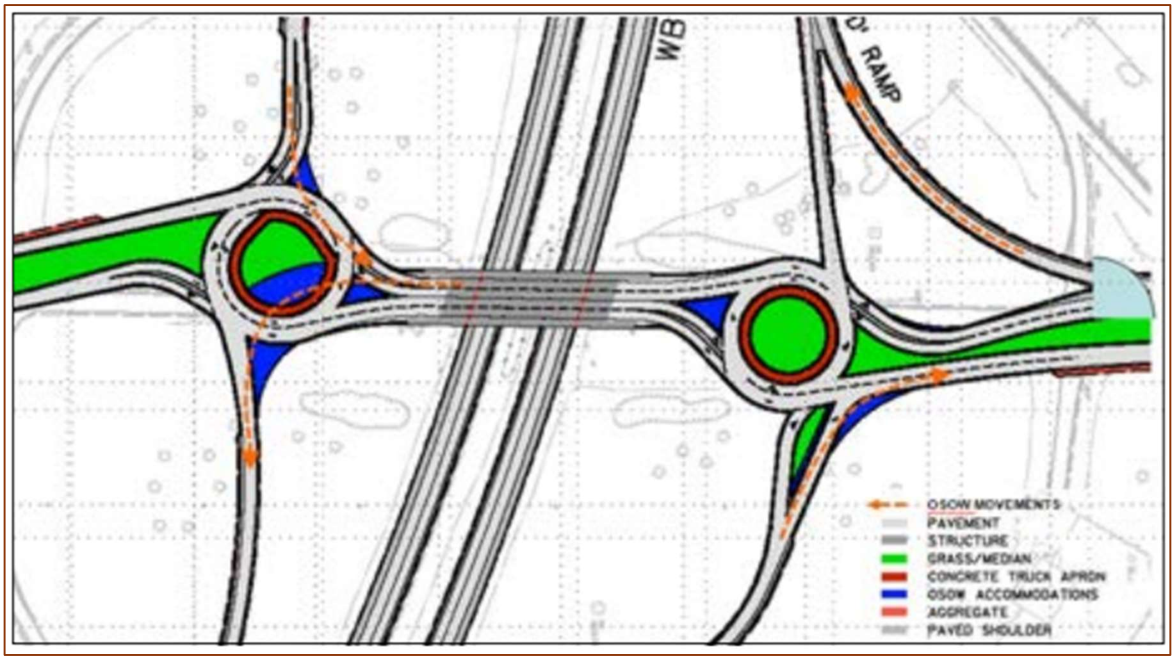

Figure 13. Accommodation for OSOW without overbuilding or reducing critical speed management features. Graphic by Josh Stratke, Strand Associates. The blue color shows mountable islands and truck aprons that serve the occasional OSOW freight truck while the red apron serves the everyday user.

Figure 14. The roundabout on US 20/Barclay Drive in Sisters, Oregon, uses a separate path of travel for oversize freight. The shared-use path has been widened and strengthened to allow oversize/overweight freight to approach the roundabout on a tangent approach, while everyday users approach on a curvilinear path to manage entry speeds.

9.3.4 Wayfinding and Crossing Assessment for Walking and Biking

NCHRP 1043 Section 9.8 provides guidance on performance checks using design flags for different criteria to iterate and improve the roundabout design for people walking and biking across all ages and abilities. This helps designers select configurations that better meet the targets to reduce risk for these more vulnerable users and facilitate easy navigation. Some examples are:

- Separating people walking, biking, and driving as much as feasible.
- Separating decision points.
- Reducing conflict points for people walking and riding bicycles.
- Aligning the crosswalk (preferred no zigzag or jog at the splitter island unless there are site-specific constraints).
- Direct and intuitive routing for walking and biking around and crossing the roundabout.

Restricting driveways near the intersection.

10.0 HORIZONTAL ALIGNMENT AND DESIGN

10.1 Optimal Design for Project Context and Multi-modal Users

Roundabout safety and operations depend on designs that reduce vehicle speeds and create smooth transitions for people moving between geometric elements entering, circulating, and exiting the roundabout. City of Bend roundabouts vary in the type of vehicles served (see section 9.3.3) and all must serve people walking, biking, and driving. This section provides more information on the desired overall operations and safety performance. It also recognizes that, due to constraints, not all may be achievable; however, a modified design can still provide enhanced performance over existing conditions or other types of intersection controls.

Roundabout size and shape develop from balancing tradeoffs within the range of possible sizes for the context and design element targets. They should be sized to provide the smallest inscribed circle diameter that accommodates traffic operations/traffic volumes, design vehicles, preferred approach angles, separates users, reduces conflict points, and other identified project location needs. Smaller footprints better support smaller right of way, slower speeds, minimize crossing distances, and other City goals. The use of in-lane and overlapping lane truck movements, mountable aprons, access management, nested-spiral lanes, and other techniques may help to meet safety and operational requirements with a smaller size.

The City of Bend standard design is a circle centered in the intersection with an ICD as shown in Table 1, Section 2.1.

Site-specific conditions may require inscribed-circle diameters that are outside these standard ranges, elliptical shapes, or offset centers. In those cases, in the design memo identify benefits and tradeoffs for the size and shape differences.

10.2 Number of Lanes

See Section 6.2 to determine the number of lanes for each approach, circulatory roadway, and exit. Use the least number of lanes necessary and phase multi-lane configurations.

10.3 Approach Designs

10.3.1 Approach Alignment

The design of the approach alignment is a balance of controlling vehicle speeds, providing sight distance, accommodating design vehicles, and multi-modal user routing. There are three general alignments to consider with designing; centered, offset left, and offset right. Each approach alignment has trade-offs, as discussed in Exhibit 10.13 of the NCHRP Report 1043.

Design roundabout approaches to be as near 90-degrees as possible and tangential in a curvilinear manner to facilitate desirable slow entry speeds and consistent speeds. Align the approach for traversable center islands to direct vehicles at entry around versus over the center island. Designs may allow vehicles classified as *accommodate* to traverse over the center island to maintain smaller geometry.

10.3.2 Exit Alignment

Design the exit alignment considering the same factors as the approach alignment. Generally, curvilinear tangential exits are used to continue speed management for the exit leg crosswalk. Tangential, non-curvilinear exits may be considered if design speeds and predicted operating speed requirements are met, and other benefits can be demonstrated.

10.3.3 Entry Lanes, Exit Lanes, and Truck Aprons

The standard entry width is 18 feet with mountable median, established to accommodate design for vehicles, buses, and emergency service vehicles while keeping speeds slow. Depending on the geometry, design vehicle accommodation, bike accommodation, and target speeds, this width may be reduced to 14 to 18 feet, or in limited cases may need to be widened. When wider lanes and throats are needed for design vehicle or geometric reasons to keep speeds lower and lane assignment clear use design tools such as:

1. Use layout striping and/or mountable exterior islands to reduce the appearance of the wide flared areas.
2. Providing a wider shy distance to the splitter island.
3. Use mountable truck aprons and mountable splitter islands to serve the “accommodate” vehicles.

Configure the curbing and design the striping layout to smoothly guide users into their entry or exit from the roundabout (Figure 15). See Section 13.0 Curbing and Pavement Details for more details on truck apron material and curb types. Truck aprons use different color materials to help differentiate the mountable surfaces for oversize vehicles versus the standard street surface for passenger cars. However, it is the shape of the apron and not the color that most effectively discourages passenger car drivers from using the truck aprons.

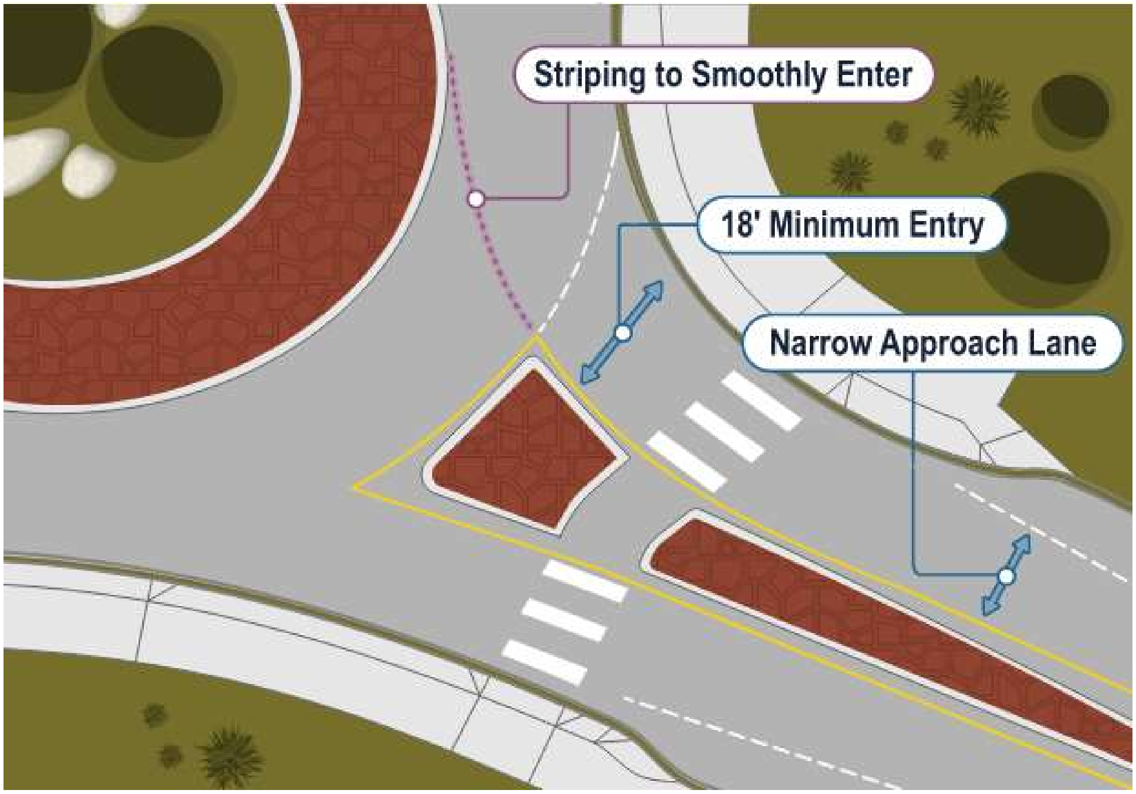

Figure 15. Single-Lane Roundabout Entry Widths using entry flare accommodates the added width of turning vehicles and striping to smoothly aim drivers on their entry/exit from the roundabout.

10.3.4 Splitter Island Design

The splitter islands provide several benefits, including physically separating entering and exiting lanes for the roundabout, providing refuge at the cross walk, and controlling user speeds. Design features include:

- Material and Type: Raised, patterned concrete splitter islands are standard on all multi- lane, single lane, and compact roundabouts. Either raised or painted splitter islands are used on mini roundabouts depending on the geometric tradeoffs and space available. Mountable sections or fully mountable splitter islands may be required for varying lengths to accommodate truck turning movements (Figure 16). Depending on emergency service requirements, widths narrower than 19 feet require mountable splitter islands up to the crosswalk where vertical curbing is typically required. See Section 13.0 Curbing and Pavement Details for more details on material and curb types.
- Length: Extend splitter islands beyond the bike ramps, at a minimum. Longer splitter islands may be required on high-speed entrances or for access control near the intersection.
- Width: The minimum crossing width equals the approaching required sidewalk/path width. Additionally, to reach LTS 1. a minimum of 10-feet-wide splitter island is required. The minimum 6 feet island is rated as LTS 2. Where narrower splitter islands are provided, consider the tradeoffs between angling the crossing to fit a bicycle and the detectability challenges of an offset crossing for people walking, especially those with visual impairments.

Configuration: The splitter island can be used to help slow speeds on the entry by using consecutively tighter radii or adding horizontal curvature to an approach. For splitter island design see Section 13.0 for curb, pavement, pattern requirements, and refer to COB Standard Drawings R-24 and R-25 for concrete and median end details.

Figure 16. Mountable curbing on the splitter island corners adjacent to the circulatory roadway facilitate plowing and accommodates occasional oversize vehicles.

10.4 Facilities for People Walking and Biking

Roundabouts in Bend are designed for people of all ages and abilities and provide intuitive, connected, and separated (as feasible) facilities for walking and biking. Section 10.4 of the NCHRP Report 1043 provides guidance on walking and biking facilities with City specific requirements and recommendations in the following sections.

10.4.1 General Design Elements

Typical applications:

- City of Bend Standards reference both *ADA Accessibility Guidelines* (ADAAG, Reference 15.2) and the best practices described in the *Public Rights-of-Way Accessibility Guidelines* (PROWAG, Reference 3). Follow ADA guidelines where private facilities connect into the public ROW, otherwise follow PROWAG guidelines.
  - Use rectangular rapid flashing beacons with Audible Pedestrian Signal (APS) and locator tones on multi-lane roundabout approaches, whether there are multi-lanes on an entry, exit or both.
    - Advance Rectangular Rapid Flashing Beacons (RRFBs) and “stop here” stop bar and sign not used at roundabouts.
    - Use one double sided, dual button signpost on the splitter island.
    - Locate RRFB push buttons within the reach of people walking and biking.
  - Use a 2-feet, non-turf landscaping or other non-prepared surface, typically a longitudinal detectable warning strip, large diameter (6 inches+) rock mulch, or other approved treatment where shared-use paths/sidewalks are curb tight adjacent to the circulating lane. TDI may also be appropriate to be used. Refer to NCHRP 1043; Section 10.4.5, and City of Bend Specials to the Oregon Standards and Specifications 0759.50(f). Provide TDI that are wet set. No surface mounted applications are acceptable. Fences are not used.
  - If bicycle and pedestrian facilities are separate and abut one another, either vertical separation (2.5 inches or a beveled mountable curb 3 to 6 inches) or a tactile warning delineator (TWD) that is 0.75 inches high and trapezoidal in cross-section is used.
  - Use a 12-inch yellow TDI, longitudinal detectable warnings, along shared-use path at bike ramp intersection to provide guidance to blind/low vision users to continue along the shared-use path.
  - Where feasible lower the sidewalk/shared-use path at the ramp landing to make it easier for blind/low vision people to locate the crosswalk (Figure 17)
  - Build the splitter island crossing width to the approaching sidewalk/path width required by standards. (Confirm width with City Engineer where existing widths are substandard).

- Design the facilities including splitter island and crossings to meet LTS 1 or 2 as required by the Development Code and Engineering Standards, or at any other intersection as feasible.
- Where shared-use paths around the perimeter of the roundabout are designed to serve both people walking and bicycling, build the circulating path a minimum of 10 feet wide.

Provide low-stress options for people biking that intuitively guide them in the proper direction and space. For on-street bike lanes this means providing a dashed merge stripe allowing a merge to the entry lane and a ramp to exit to the shared-use path.

Use a 6- to 8-foot separation from the sidewalk/shared-use path to the curb ramp and from for the bike ramp/path to allow vehicles to discern when people are leaving the sidewalk/shared-use path to cross and to improve the angle for people walking and biking to turn and see oncoming vehicle traffic (Figure 17).

Figure 17. Longer crosswalk approach to the detectable warnings facilitates longer bikes waiting out of the shared use path and allows people driving to see that people are turning to cross the street. Northbound Columbia at Simpson. This design provides ~15feet between the domes and path.

10.4.2 Crosswalk Design

Crosswalks are designed to meet PROWAG requirements and the following additional considerations:

- Target a 25 feet (one car length) crosswalk setback from the circulating roadway to separate conflict points for people driving, reduce the crossing width, and not create extended out of direction travel for people walking.
    - Consider additional offset for crosswalks (40 to 60 feet) on multi-lane approaches to provide additional reaction time for people driving as they move from the circulating lane into the exit lane while considering increased exit speeds and for vision impaired people to distinguish between circulating and exiting traffic.
- Provide straight-aligned crosswalk, not alignments that “z” or shift at the splitter island/median.
    - Where the direction changes within the splitter island, the change of direction or angle must be well defined using curbing and truncated domes to align people on the splitter island with the receiving curb ramp. With mountable splitter islands perpendicular alignments are recommended because providing detectable angle points in the splitter island can be difficult.
- Use raised crosswalks on local street legs (setback one car length) at roundabouts where the other legs are arterial or collector streets to encourage slower speeds on the local street.

See Figure 18 for an example target design for crosswalks.

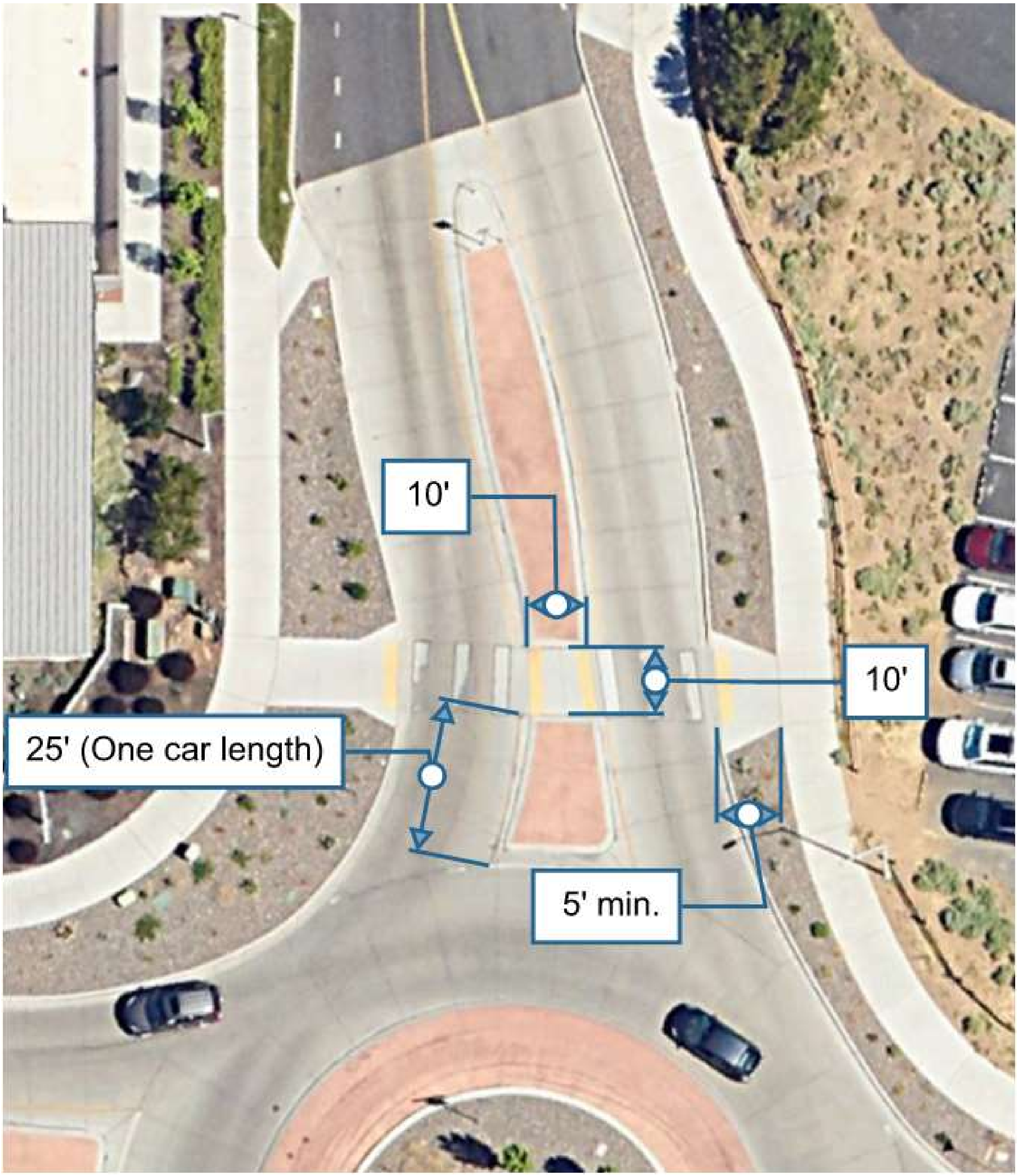

Figure 18. Target crosswalk design providing storage for one vehicle, straight crossing, preferred splitter island width, and minimum approach length each side.

10.4.3 Bike Ramp Design

Bike ramps run between the street and shared-use path or separated bike lane so a person riding can move between the different facilities or access the facilities. Provide bike ramps on all roundabout approaches where circulating shared-use paths and on-street bike lanes are provided and include the following elements:

- Target a 100 feet bike ramp setback from the circulating roadway to separate conflict points for people driving, with a minimum 50 feet offset from the crosswalk (Figure 19)
- Design the bike lane drop (dashed striping) preceding the bike ramp per Standard Drawing R-44B.
- Use 15-foot minimum radius curves along the curb line so maintenance equipment can run adjacent to the curb.
- Design the bike ramp so it is a spur to the shared-use path with an approach long enough (6 to 8 feet) so people driving can observe that people riding are leaving the shared-use path to enter the travel lane. This also cues people walking, particularly those with vision disabilities, to stay on the path and not enter the bike ramp (Figure 19).
- Angle the bike entrance and exit ramps so people riding bicycles can see approaching vehicles. Target 20 to 40 degrees with a maximum of 45 degrees so that people riding enter the bike lane on a natural path that does not overlap the travel lane paths so people driving and riding stay in their respective lanes (Figure 19).
- Design the bike ramp to a target a slope range of 10 to 20 percent max, typically steeper than an ADA ramp to provide a detectable grade difference for people with low/no vision. If this range is unable to be met, consider adjusting location or other elements to keep ramp under 20 percent.
- Design the curb line to clearly indicate the bike lane is ending, and the bike rider needs to make a choice to exit or merge into the travel lane (Figure 20 and Figure 21).

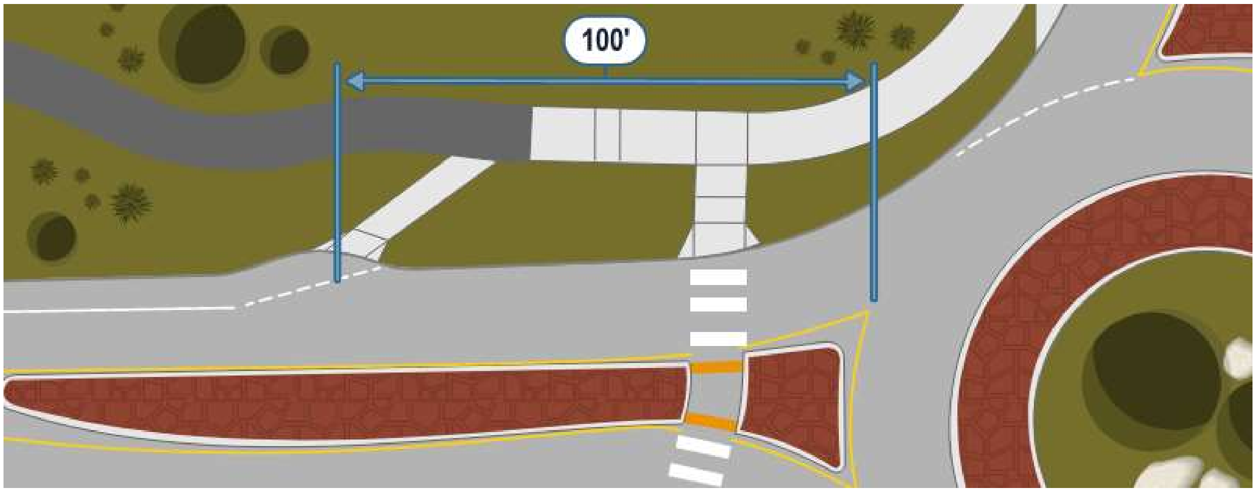

Figure 19. Example of good separation provided between bike and crosswalk ramps and the bike ramp as a spur to the shares use path.

Figure 20. The curb in this photo is a great example of how to ensure decisive decision making by the bike rider. The curb clearly indicates that the lane is ending, and a choice must be made. (Southbound Columbia at Colorado)

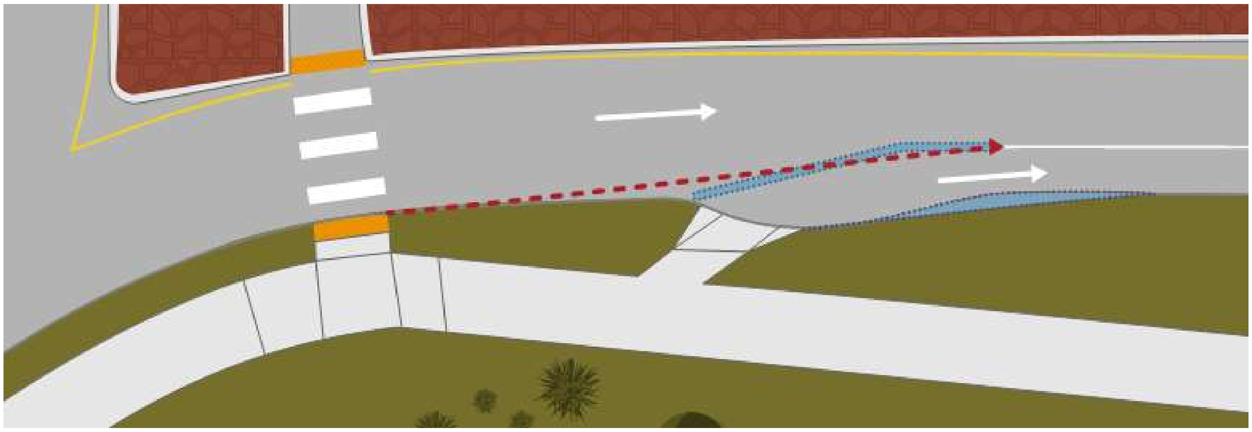

Figure 21. Design so that the ramp to bike lane transition keeps bicyclists and drivers following their lanes.

10.4.4 Separated Bike Lanes

Separated bike lane roundabouts provide bike lanes that are physically separated from the vehicle lane and are distinct from the sidewalk/shared-use path. They may be at street level, raised to the level of the sidewalk/shared-use path, or at a grade in between. Their use is targeted on designated low-stress routes with separated bike lanes along the corridor. Typical application:

- Use directional bike lanes.
- During design coordinate with the Transportation and Mobility Director (TMD) to develop an approved seasonal maintenance plan (snow management, snow storage, sweeping etc.).
- Design the radius and offset at the bike crosswalk balancing the desire for easy bicycle turning movements with the need to slow bicycle speeds and allow people driving to detect riders turning to cross.

Adjust the sight distance parameters to include visibility for people using the separated bike lane to people driving and walking.

10.5 Mini Roundabout Design

The following are some City specific design requirements for mini roundabout designs:

Use mountable splitter and center islands.

- See section 9.3.3 for design vehicle. Depending on the overall diameter and approach road angles, several infrequent large vehicle types may need to traverse the central island such as shuttle buses, larger fire trucks, and delivery vehicles as well as passenger pick-up trucks towing boats and trailers, etc. Where on a school bus or transit route, those vehicles are accommodated in the circulating lane.
- Use a low-profile mountable curb per Standard Drawing R-3 with fully traversable raised central truck apron to allow use and to discourage drivers of automobiles and other small vehicles from trying to traverse the central island or splitter island. No signs are placed in the traversable center island or on mountable splitter islands.

Design the typical entry width per Section 2.1.

- Where retrofitting in an existing area, the ADA ramps and crosswalk may need to be modified so the crossing is out of the circulating lane.

Mini roundabouts may include bike ramps to cross a collector street leg on higher volume approaches (above 1,500 vehicles per day [vpd]) where there are shared-use paths or designated greenways. Bike ramps are not typically used at local/local street intersections.

10.5.1 Mini Roundabout Examples

Figure 22. Mini roundabout, Redmond, Oregon.

Redmond, Oregon installed a mini roundabout (Figure 22), which opened to traffic in late 2020. Features include a mountable splitter island and bike ramps on each approach and a mountable central island, shared sidewalk, and external truck aprons.

Features that are included for the Redmond mini roundabout that are not standard for Bend mini roundabouts include: placement of street name signs on the splitter island, use of pavement left-through arrows, and crosswalk signage.

Figure 23. Mini roundabout in Shakopee, Minnesota.

Figure 23 is an example mini roundabout from Minnesota that displays similar features for Bend mini roundabouts with a few exceptions. City of Bend mini roundabouts do not include the pedestrian crosswalk signs and will use a yield sign/street name combination sign - not the roundabout arrow sign.

10.6 Compact Roundabout Design

Compact roundabouts are fairly similar to single-lane roundabouts; however, they typically serve roadway with lower approach speeds, have a smaller ICD, and are found on lower classification roadways to accommodate narrower approach typical sections. Refer to Table 1 for more specific information (Table 1. Summary of Roundabout Types and Features).

10.7 Single-Lane Roundabout Design

Single-lane roundabouts are the most commonly used roundabout in the City of Bend. They can serve a wide range of speeds, approach geometry, design vehicles, and provide an efficient footprint to reduce ROW takes and project costs versus a multi-lane configuration. Refer to Table 1 for more specific information.

10.8 Multi-Lane Roundabout Design

10.8.1 Multi-Lane Risk Reduction

Multiple lanes at a roundabout facilitate traffic volumes and turning movements and while they provide an overall reduction in conflicts and severity over signalized intersections, they can increase conflicts over single-lane roundabouts, especially failure to yield and improper lane use. Consider the following design adjustments for multi-lane configurations:

- Modified configuration or enhanced signing and striping to provide clear lane assignment on approach.
- Reduce speeds below the minimum required speeds.
- Reduce lanes where possible.

Use truck apron for spiral instead of striping.

- Phase in multiple lanes by starting with a single-lane roundabout and converting when the additional capacity is needed.
- Nest a lane addition into the central island (Figure 24).
- Install the OR4-22 “Do not drive beside trucks” sign required by ORS819.247.
- Consider using bypass lanes to reduce the need for multiple circulating lanes.
- Consider a turbo roundabout configuration using flush lane channelization. (Raised elements in the circulating lane are not permitted.)

Figure 24. An example of a nested lane addition in Springfield, Oregon on US26 and Franklin Boulevard. This can improve lane discipline without the use of a spiral and reduce the size of the roundabout.

10.8.2 Phase Multi-Lane Design

Constructing multiple roundabout lanes before traffic volumes are realized can increase risk due to the wider lanes fostering higher vehicular speeds and additional conflict points. Design and build phased multilane roundabouts where traffic analysis shows a single-lane roundabout will provide sufficient capacity for much of its design life (see discussion in Section 6.2). Use one of the methods for future lane expansion identified in the NCHRP Report 1043, inside expansion, outside expansion, or pavement marking.

10.8.2.1 Inside Expansion

When designing for inside expansion, the outside curbs, shared-use paths, drainage, and illumination are built to the ultimate configuration. The traffic lanes are added by reducing the splitter island widths and truck apron. Locate the concrete jointing to plan for this future expansion. Additional information can be found in the NCHRP Report 1043 section 10.8.1. Figure 25 is an example of future expansion at the Murphy and 15th roundabout. Consider striping or painting temporary paved surfaces to further delineate the non-traveled way.

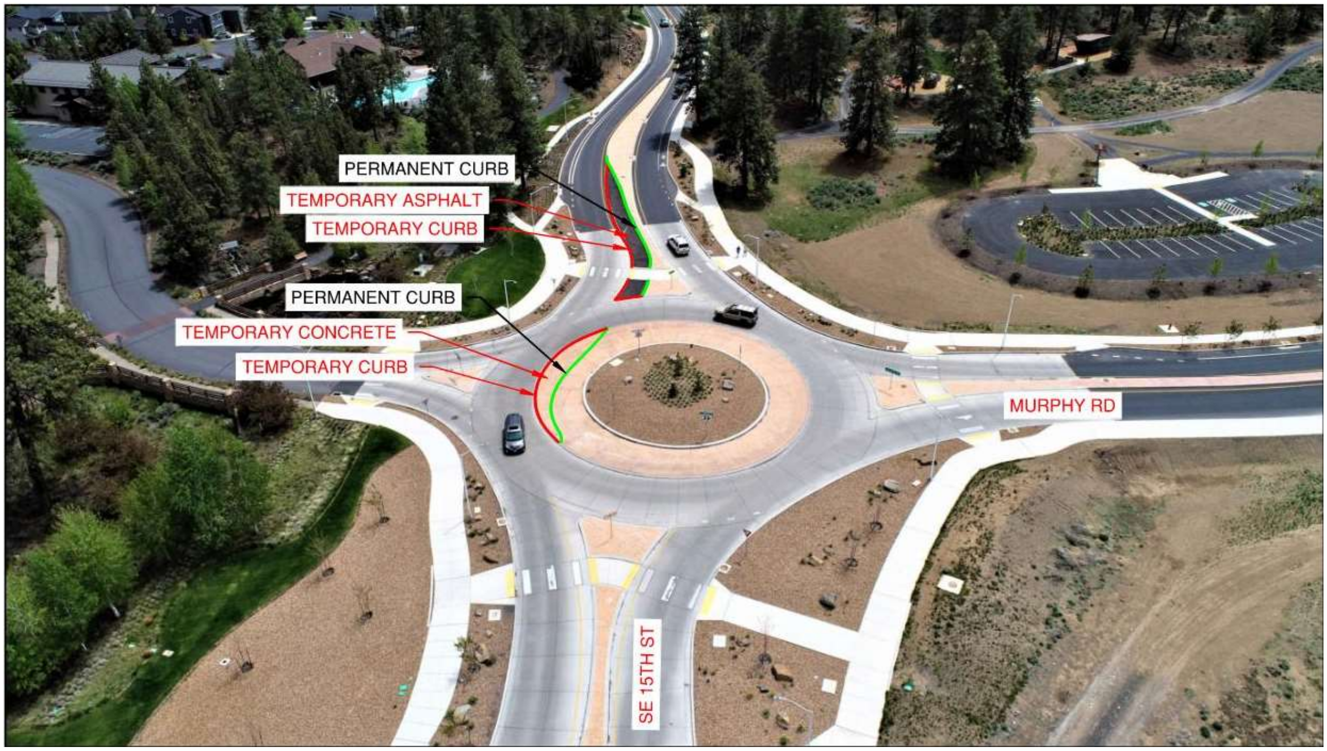

Figure 25. Temporary and permanent elements for future inside expansion at the intersection of SE Murphy Road and SE 15th Street.

10.8.2.2 Outside Expansion

With this method of expansion there is generally less impact on traffic during widening. It may also have lower up-front costs. The splitter islands and truck aprons are built to the ultimate configuration with the original design and expansion is made to the outside. If ROW is available during the original construction, utilities, shared-use path, and illumination can be designed to the ultimate location to minimize the infrastructure that needs to be rebuild with expansion. Design storm drainage systems to allow phasing and easy retrofitting or expansion for the full design.

10.8.2.3 Full Build with Pavement Marking

Figure 26 shows an example that uses temporary pavement marking to phase the design. Initially striping the gore areas creates a single lane exit operation that can be removed and restriped when the volumes justify the multi-lane exit. Phasing with pavement marking may not provide the lower speeds that can be achieved with phasing the curb, raised splitter, and central islands and is typically not used in Bend on the approaches.

Figure 26. A phased-in multi-lane roundabout in Wisconsin Rapids, Wisconsin.

10.8.3 Spiral Transitions

A spiral transition is circulating lane alignment that can facilitate vehicles staying in the correct lane. It uses a spiral radius on a portion of the center island that varies from the circulating radius as shown in red on Figure 27. Spirals may be beneficial when:

- One or more entries require exclusive left-turn lanes.
- A combination of entering and exiting lanes requires a spiral to maintain lane continuity.
- Where a circulating driver must shift to the outside lane when transitioning from single to multi-lane portions of the roadway (15th/Reed Market eastbound to northbound is an example of this).
- At a 2 x 1 multi-lane design or similar configuration to improve the likelihood of entering drivers in the outside lane yielding at entry.

Shape the central island spiral using the curbing/apron and not striping to present the spiral geometry. Striping, even if inlaid as required in a roundabout, wears out and does not provide as good an indicator of the travel path.

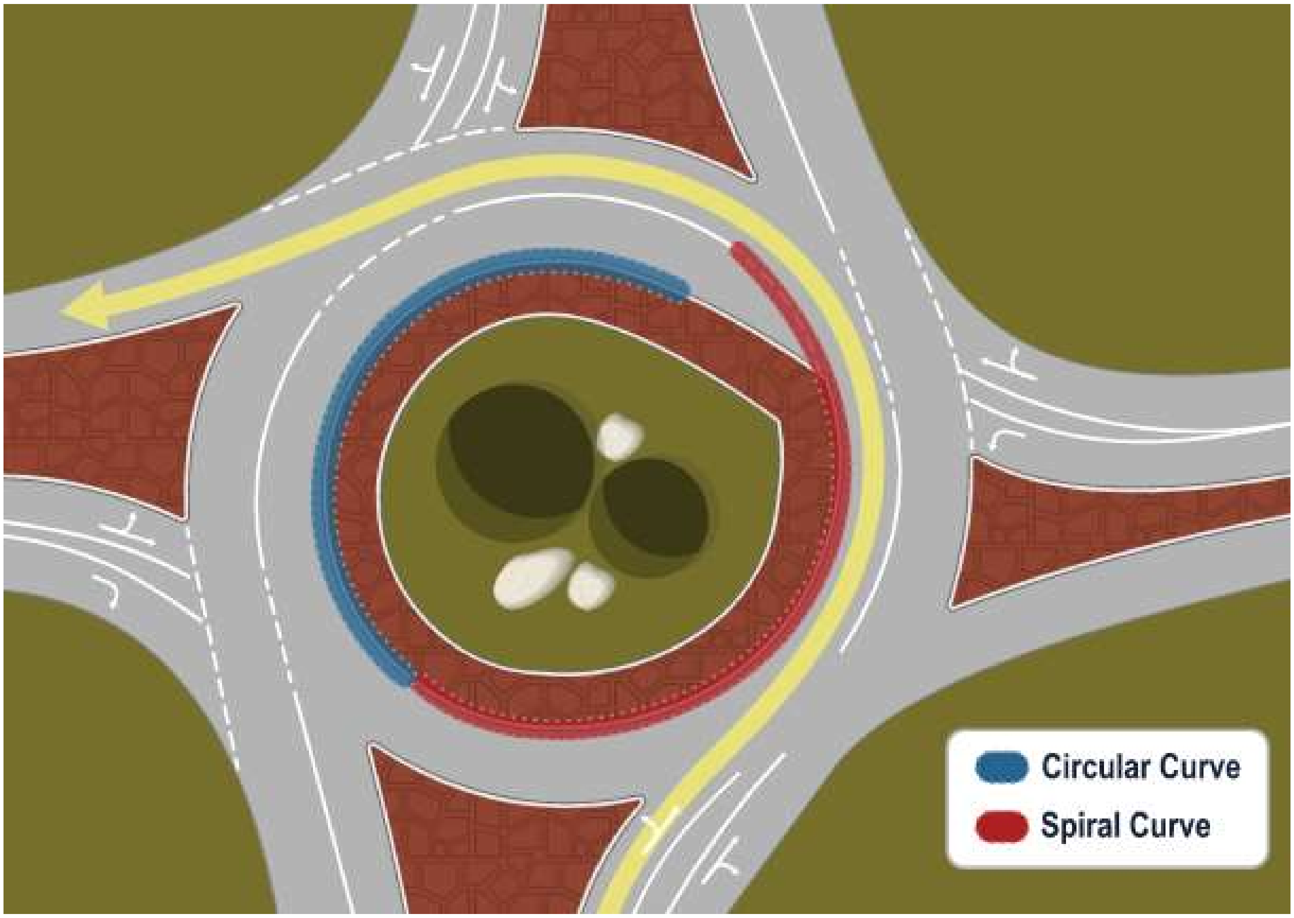

Figure 27. This image shows a well-designed spiral that positively reinforces lane use restrictions. Image reference and spiral technique from Florida DOT Roadway Design Manual, Figure 213.5.1.

10.8.4 Turbo Roundabout

Turbo roundabouts are a type of multi-lane roundabout with a spiral geometry that also includes physical lane channelization directing vehicles to stay in the appropriate travel lane reducing sideswipes and crashes at exits. The lane divider is raised in most of the European examples. Raised channelization is likely not implementable in Bend due to smaller ICD, design vehicles typically using multiple lanes, and the significant increase in winter maintenance. As an alternate, painted dividers with recessed pavement markers or rumble strips may be used (Figure 28).

Figure 28. A turbo roundabout with flush lane divider. Victoria International Airport, Sydney, British Columbia Canada.

10.9 Access Management and Parking

Access Management, the technique of limiting access points or movements to improve traffic flow and safety, is used at roundabouts and along corridors serving roundabouts. Limiting driveways in and near roundabouts reduces conflicts and congestion. New driveways are not permitted within the roundabout, within 50 feet of the crosswalk, or in a location that conflicts with the bike ramps. As feasible eliminate, combine, or relocate existing driveways away from the circulating lanes and entry/exits. Where driveways remain, physically restrict turns to right-in, right-out movements.

Along corridors where roundabouts are closely spaced, intermediate access points may be restricted to right in/right out where the roundabouts can be used to make the left turn movements. This may be beneficial where the intermediate access points have higher crash rates, increase delays from left turns in a through lane, or increase conflicts for people walking and biking.

Parking is not allowed on approaches to roundabouts along the length of the splitter island or inside of bike ramps.

10.10 Utilities

Coordinate with City of Bend Utilities to locate utilities, provide maintenance access, and develop designs that facilitate ongoing maintenance. Design parameters include:

- Locate fire hydrants outside the splitter island limits of the roundabout to minimize lane closures to access hydrants.
- Excluding storm facilities at low points, locate catch basins, sedimentation manholes, and drywell facilities outside the splitter island limits of the roundabout to minimize lane closures during maintenance.
- Where separated bike lanes are used, design drainage to flow either to inside of bike lane or use two catch basins; one in travel lane and one in the bike lane likely piped in series.
- Locate irrigation controllers outside the splitter island limits of the roundabout to minimize lane closures during maintenance. Avoid locating controllers in the center island where feasible.

Where feasible, avoid placing utilities within the center island. Where they are located within the center island, provide a space for a utility service vehicle to stage (i.e., a flat area with drivable surface).

- Open infiltration facilities (i.e. swales, stormwater planters) are not preferred near or at the circulating roundabout lanes. See Section 14.1 for areas to avoid illumination pole placement for areas of off tracking concerns.
- Coordinate with franchise utilities regarding relocation and any planned upgrades to their facilities throughout the roundabout design to identify locations for facilities as well as trenching requirements.
- Drainage should be designed such that all drainage in the roadways flows away from the splitter and central islands. The roadways should not be used as conveyance from one curb line to another. In site constrained cases drainage facilities may be placed in the circulatory but is not a common practice. This should be evaluated on a case-by-case basis.
- Catch basins should generally be located to minimize stormwater flow across crosswalks (upstream). Plan placement to avoid the wheel path for vehicle off tracking to avoid tire damage from exposed angle iron, asphalt wear at catch basins, and damage to grate and inlets.

- Place and size inlets to avoid vehicle wheel path and minimize the impact on the bike lane.
- Place valves and manholes outside of the vehicle wheel path.

10.11 Bus Stop Placement

Coordinate bus stop locations with CET. Generally, bus stops are located a minimum of 50 feet downstream of the crosswalk. Place bus stops inside of the length of the splitter island to discourage motorists from passing the bus while it is stopped to pick up passengers.

10.12 Railroad Crossings

Engage rail stakeholders early and often. This includes the owner, i.e. BNSF, and ODOT rail. If the roundabout falls within the SSD of the railroad crossing or changes horizontal/vertical roadway geometry at the rail approach a crossing order may be required to be prepared. Design parameters for roundabouts at or near rail crossings will vary and are identified in the rail diagnostic and other rail design coordination meetings.

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11.0 VERTICAL DESIGNS AND CROSS SECTIONS

Vertical design is interrelated with many other design and operational elements. It may require an iterative process to balance drainage, user needs, maintenance needs, and other considerations as noted in Chapter 11 of NCHRP 1043.Design parameters include:

- Evaluate cross-slope and longitudinal drainage to prevent ponding and icing within the roundabout.

Where concrete is used instead of asphalt, evaluate grades for additional icing potential from the lighter colored surface and minimize by reducing limits of concrete or adjusting slopes.

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12.0 TRAFFIC CONTROL DEVICES, SIGNING, AND STRIPING

Refer to the current Manual on Uniform Traffic Control Devices (MUTCD), including the Oregon Supplement and the City of Bend Signing and Marking Manual for City roundabout signing, striping, and traffic control.

Additional traffic control at roundabouts may include metered signals or emergency vehicle pre-emption. Metering signals may be a tool considered to extend the capacity or mitigate extended queuing at existing roundabouts with approval of the City Engineer. A study to evaluate benefits/impacts and a pilot test are required. If installed, include emergency vehicle pre-emption on the approaches.

Locate signs out of the mountable areas and truck overhang areas of splitter islands.

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13.0 CURB AND PAVEMENT DETAILS

Bend has established a standard practice for several different curb types and surface materials used in building the various types of roundabouts. Refer to the City of Bend Standards and Specifications.

13.1 Pavement Design

Both Portland cement concrete (PCC) and asphalt concrete pavement (ACP) are used for roundabout construction. There are many pros and cons recognized for each material and method of construction. Asphalt is the standard material based on improvements in perpetual asphalt pavement, improved phasing/faster opening, existing asphalt maintenance program, flexibility to address drainage, rideability, and snow/ice management.

Concrete may be approved by the City Engineer with a study on life cycle costs, higher heavy vehicle volumes, or other site-specific factors that evaluate the benefits and impacts to installation, use, and on-going maintenance and operations versus asphalt. Concrete is required on streets that are concrete. Table 9 lists the minimum requirements for both asphalt and concrete. Additional pavement depth may be required based upon subgrade conditions and/or traffic volume and percent of trucks, at a minimum.

*Table 9: Roundabout **Minimum** Pavement Design Requirements*

	Portland Cement Concrete (PCC) Pavement	Asphalt Concrete Pavement (ACP)
Wearing Surface	9.0” plain, dowelled Class 5000-1.5” Concrete Slab	3”ACP Wearing Course PG 70-28ER Level 4, ½” Lime Treated/ 5”ACPBaseCourse Level 3, PG 64-28 (3 inch and 2-inch lift)
Base Material	6.0”, ¾”-0 or 1”-0 Aggregate Base	Minimum 7.0”, ¾”-0 or 1”-0 Aggregate Base – or – match approach section.
Subgrade	9,300 psi support minimum	9,300 psi support minimum

Alternatively, designers may provide a life cycle cost analysis and structural design assessment for the City Engineer’s review. The life cycle cost analysis and structural design will meet the City’s Public Improvement Construction Procedure Standard and Specifications using the 30-year design life’s cumulative equivalent single axle load repetitions (ESALs) according to the city’s specifications requirements and the American Association of State Highway and Transportation Officials (AASHTO) Guide for Rigid Pavement Design.

13.2 Jointing Plan

Provide a detailed concrete jointing plan designed for constructability, aligning/not conflicting with striping for lane clarity, and to support durability of the concrete. Avoid narrow pours and sharp angles within concrete panels. Develop a jointing plan that does not include small triangular sections or joints along the wheel path.

Develop the pavement jointing plan with the pavement striping plan to help improve visual cues to the driver. Avoid joint placement that might mis-lead drivers in spirals. An example jointing plan is shown in Figure 29.

Design joints between paving materials to be perpendicular to the path of travel for the asphalt joint locations and design to consider bike ramps (Figure 30). Use longitudinal joints within the shared-use path and transverse dowelled joints around a roundabout.

The ratio of maximum slab dimensions should not exceed 1.25 and spacing between transverse joints should not exceed 12 feet. FHWA TA5040.30 is an invaluable resource for designing jointing layouts.

Transition between concrete and asphalt with an asphalt paving to concrete paving transition as shown in Figure 31. This transition should be designed for site specific constraints such as changes in roadway classification and paving depths on individual legs.

ODOT standard detail 1600 is typically followed for doweling and tie bars in the concrete section of roundabouts. Separated lane roundabouts may require modification to jointing plans to place dowels in mountable curbs. The truck apron is doweled and contains tie bars. Special attention should be given to the circulatory to not exceed slab ratios as joints widen away radially from the truck apron.

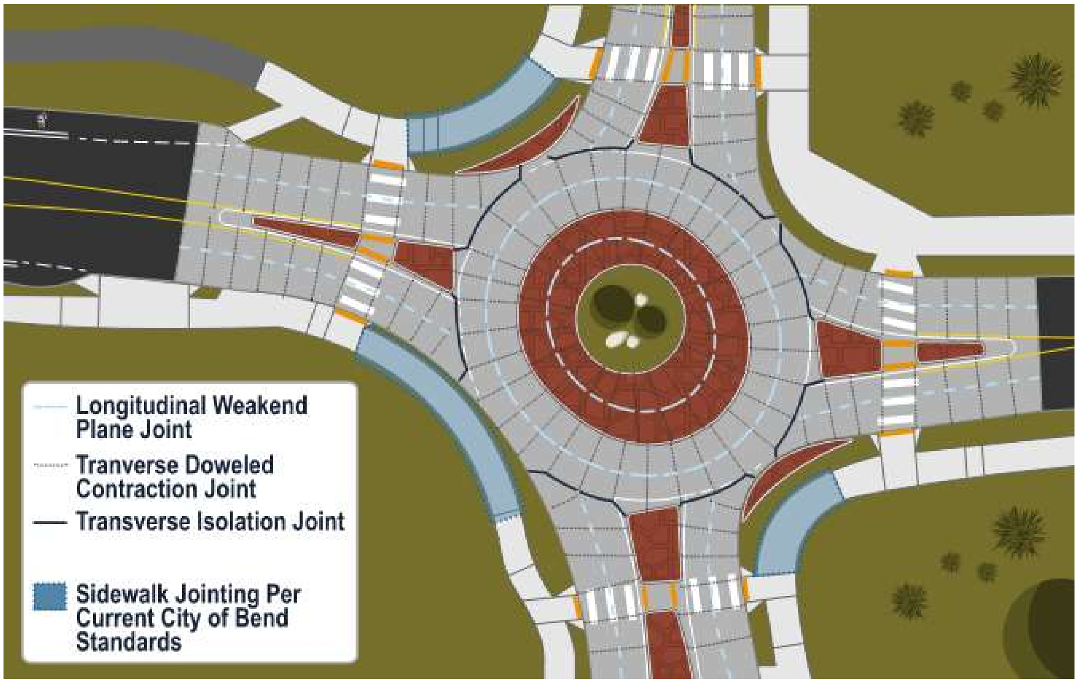

Figure 29. Example jointing layout.

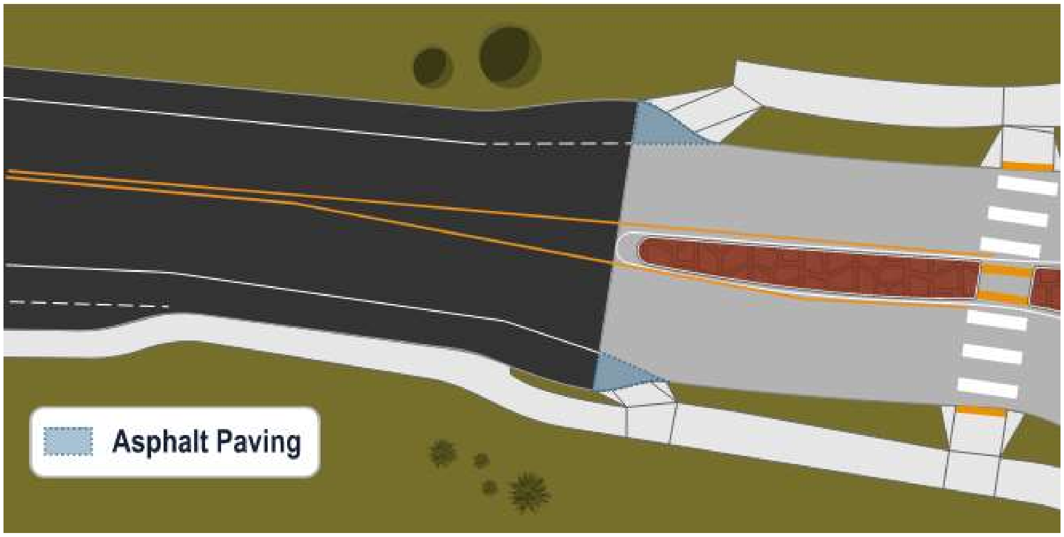

Figure 30. Design joints between paving materials to be perpendicular to the path of travel for the asphalt joint locations and design to consider bike ramps. In this example, the bike ramp should have been relocated out of the pavement material transition zone, or the joint should have been angled to be perpendicular to the bike ramp. Joints that are not perpendicular can cause loss of control.

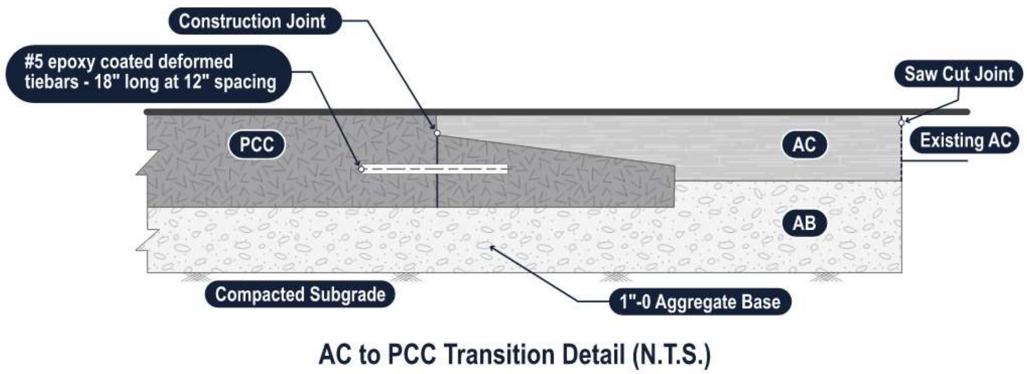

Figure 31. AC to PCC Transition Keyway and Construction Joint Detail. Dimensions to be designed to accommodate site specifics.

13.3 Truck Apron and Splitter Islands

The concrete for truck aprons uses a two-color system so it is visible to drivers and is distinguished as a raised traversable area, different than the standard travel lane and shared-use path. Use the city standard: Davis Spanish Gold (#5084) for integral color and Davis Dark Grey (#860) for release color. Construct the truck aprons using the same dowelled and stamped concrete pavement as shown above.

The splitter islands use the same City standard color system: Davis Spanish Gold (#5084) for integral color and Davis Dark Grey (#860) for release color. Construct the splitter islands with concrete using the same high strength concrete specified for roundabout curbing and a stamping pattern as shown in Standard Detail R-24.

Generally, vertical curbing is provided at the crosswalk to provide a detectable edge. Beveled curbing is used on the leading edge to minimize plow damage (Figure 32). A 4-inch pedestrian exit curb may also be specified where appropriate; however, consider the location of drainage structures as curb inlets will require installation in 6-inch exposure curb.

13.4 Curbing

The two types of curbing used at roundabouts are:

1. traversable, allowing vehicles to drive over them if necessary, and
2. non-traversable with a vertical rise to discourage driving over.

Design the curves along the median curb and outside curb at bike ramps to accommodate the street sweeper, with a minimum radius of 15 feet. Curb types are shown in Standard Drawing R-3 typically used as follows:

- Outside Curb: Outside curbing is non-traversable City Standard Drawing R-3 City Standard Curb or City Standard Curb and Gutter based upon curb flowline grades with Curb Height (H), Curb Exposure (E), and Gutter Width (G) based on the highest approaching roadway classification. Check grade elevations to minimize flat sections and flat vertical curves where the outside curb grades transition from the circulatory to the entry and exit lanes.
- Splitter Island Curb: Splitter island curbing may be non-traversable, traversable, or a combination based on the configuration needed to meet the design criteria and the type of roundabout. Curbs are either non-traversable City Standard Curb or traversable City Standard Low Profile Mountable Curb with Curb Height (H), Curb Exposure (E), and Gutter Width (G) based upon highest approaching roadway classification. Use Curb detail R-3 for tapered curb on the downstream side of the crosswalk across the splitter island to minimize damage from snowplows that would occur if a city standard curb vertical face were used. As noted in previous section, target using vertical curbs at the crosswalk to provide a detectable edge, even if the nose of the splitter island is mountable (Figure 32).

Figure 32. A beveled curb edge to facilitate snow plowing and prevent damage to curbs.

Truck apron curb: Truck apron curbing is the Standard Low Profile Mountable Curb. Additional analysis and evaluation of the overall curb exposure height may be required for single-lane roundabouts to verify clearance for low boy tractor trailers based upon the circulatory profile.

- Central island inner curb: Inner landscape island curbing shall be City Standard Curb with Curb Height (H) = 16 inches, Curb Exposure (E) = 6 inches, and Curb Width modified to 12 inches.
- Consider, where appropriate, installing “pedestrian curb” on the splitter island at exit lanes. This is a 4-inch exposure curb to help deflect vehicles away from the refuge.

All curbing within the roundabout, generally using the bike ramps or splitter islands, whichever is further from the roundabout, as the limits, shall be high strength concrete, defined as Class 5,000 pounds per square inch (psi) commercial grade concrete with 1.5 pounds of fiber mesh reinforcement per cubic yard.

13.5 Sidewalk/Shared-Use Path

See standards and standard drawing R-4A for sidewalk/shared-use path pavement design.

14.0 ILLUMINATION, LANDSCAPING, AND ARTWORK

14.1 Illumination

Roundabout illumination is required to meet the outlined design and construction criteria in this manual in addition to the Illumination section of the current edition of the City of Bend Standards and Specifications. The roundabout illumination shall also conform to the latest version of the American National Standards Institute/Illuminating Engineering Society of North America (ANSI/IES) RP-8 American National Standard Practice for Roadway Lighting.

Illumination target levels for the City are based on the recommended pavement illuminance for roundabouts as described in the latest version of the ANSI/IES RP-8 American National Standard Practice for Roadway Lighting. Provide photometric analysis for existing and proposed street light locations in the plan sheet set with information on design including light fixtures, pole types, luminaire mounting height, fixture type, maintenance, and ownership. Photometric analysis should be summarized in a table including the design light levels/uniformity and achieved light levels/uniformity for the roundabout and marked crosswalks. The design must also take into consideration the following information:

- Design the illumination plan with the lowest lighting level appropriate to provide sufficient illumination for visibility and safety while minimizing the impact on the environment. While not a designated Dark Sky city, the illumination code and standards aim to meet many of the technical requirements.
- The achieved light levels should not exceed 1.3x the minimum average horizontal footcandle light level unless approved.
- Adjust illumination if concrete is used instead of asphalt, as appropriate for different reflectivity of pavement surface.
- Provide illumination for the circulating roadway and main conflict areas on each approach and exit including:
    - splitter island nose
    - bike ramps (entering and exiting)
    - crosswalks (front lit, light the approach)

  - circulatory roadway yield line.
- Provide achieved horizontal illuminance and uniformity calculations for roundabout with design target values.
- Provide achieved vertical illuminance calculations for all marked pedestrian crossings with design target values for entering and exiting approaches.

Lighting fixtures, poles, and bases for the roundabout lighting must be approved by the utility that owns and maintains the streetlight (either Pacific Power Corp or Central Electric Cooperative if within City right-of-way). As noted in the City of Bend Standards and Specifications, decorative lighting and solar lighting within the City ROW will not be permitted without special approval and maintenance agreements signed by the City Engineer and approved by the TMD Director. Typical features of the streetlight are a cobra-head fixture with mast arm light pole. Designers and/or contractors to reach out to the utility's local representative for the current approved list of equipment.

Designers must work with the City representative to fill out a service request with the utility company. These service requests will generate a work order or reference number for the project and assign a project manager from the utility company to aid in the design and construction of the project. Designer to work with the utility company to delineate construction responsibilities including equipment procurement and equipment installation. Service request forms can be found on the utility company's website. All equipment installed must abide by the utility design requirements as defined in the utility company's Electrical Service Requirements and additional guidelines provided by the utility.

All new lighting conduits to have a non-conducting poly pull line with a minimum of 500-pound tensile strength installed. If there is future planned art or irrigation, install a spare conduit line from electrical source to a new junction box in the roundabout's center island for future electrical needs.

Place street light poles for the roundabout outside areas susceptible to vehicular impact as seen in Figure 33. This typically places the pole bases behind the sidewalk or shared-use path along the circulatory roadway and exits.

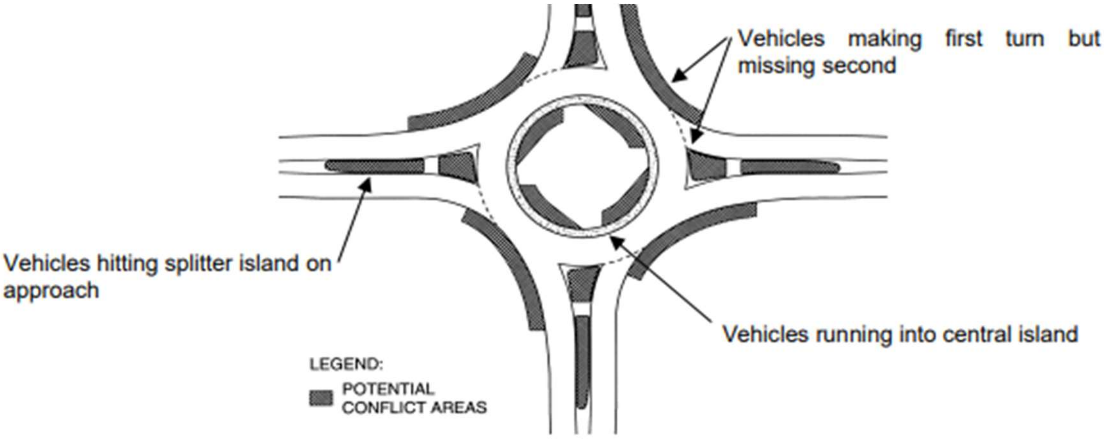

Figure 33. Areas to avoid for pole placement.

14.2 Landscaping

Landscaping shall comply with the City of Bend Standards and Specifications including xeriscaping that reduces water consumption and on-going maintenance requirements.

Typical application:

- Elevate the central island to improve intersection conspicuity, create a terminal vista (where drivers cannot see more than their stopping sight distance) and reduce headlight glare (Figure 34).
- The central island landscaping may include swales or stormwater planters to reduce overall stormwater run-off.
- Include an access and parking pad to facilitate central landscaping maintenance, stormwater maintenance, and servicing of any utilities.
- Landscape rock mulch is not used in the planter strip or for areas adjacent to the roundabout due to maintenance issues created by rock migrating to the travel lanes, bikeway, and sidewalk/shared-use path. When space is constrained, the use of oversize landscape rock mulch (6 inches) may be considered.

Figure 34. An elevated and landscaped central island slows vehicles and queues drivers to turn by creating a terminal vista.

All final designs must include a landscape plan identifying plant types and locations.

14.2.1 Artwork

Artwork in roundabouts is commissioned, funded, and installed by the non-profit group Art in Public Places through an agreement with the City. Contact Art in Public Places to initiate roundabout art. Any artwork illumination must be solar powered. Water fountains and other features that produce noise are not permitted.

15.0 PLAN SETS/SUBMITTAL REQUIREMENTS

See City of Bend Engineering Standards 2.3 Information Required on Plans subsection 2.3.3.1 Streets – Roundabouts for specifics related to plan submittal requirements. More details on plan items specific to roundabouts are provided below.

15.1 Details

15.1.1 Roundabout Details

Provide details sheets for all City of Bend details as well as special roundabout/project details.

15.2 Construction Staging

Provide plan details by stage of construction based upon traffic management requirements. Evaluate opportunities and needs for road closures. Work closely with City staff to determine if road closures are required and/or allowed.

When maintaining traffic through the work zone, prepare construction sequencing/staging plans clearly showing active lanes of traffic, active work zone, and temporary pedestrian and bicycle facilities.

15.3 Work Zone Traffic Control

For complete and partial road closures, prepare detour plans with detour route and required temporary signage.

When maintaining active traffic through the work zone, prepare plans with cross sections for the active travel way showing travel widths, bicycle and pedestrian facilities, temporary traffic control devices and slopes, drop-offs, and trenching, per the latest version of the Oregon Temporary Traffic Control Handbook, and latest version of the MUTCD.

15.4 TPAR

Provide a detailed plan and design for temporary pedestrian routing and temporary traffic control devices to maintain an accessible route around or through the construction zone at all times.

15.5 Site Plan

Provide a plan sheet that, at a minimum, has some basic site-specific elements labeled such as:

- Curb types and locations
- ROW labeled
- Stormwater facilities and types labeled
- General dimensions such as:
  - Lane, sidewalk, splitter island, and shared-use path widths.
  - Sidewalk and shared-use path widths.
  - Diameters and/or radii of the truck apron, inscribed circle, curb return radii, curb radii, and splitter island curve radii.
  - Typical section widths labeled on approaches (including striping).
- Nearby landownership labeled per Deschutes County Property Information (DIAL).
- Jointing plan if concrete surfacing is used.

15.6 Typical Sections

Dimensioned typical sections including at a minimum:

- The circulating lane section with pavement types, aggregate base, curbs, sidewalk, buffer strip backfill identified, depths provided, and slopes identified. The alignment and profile reference point should also be labeled.
- Approach lane sections with pavement types, aggregate base, curbs, sidewalk, and buffer strip backfill identified, depths provided, and slopes identified.

15.7 Alignment and Profile

15.7.1 Roadway

Provide centerline plan and profile sheets through the circulatory. Clearly identify the location of areas controlled by the circulating lane plan and profile.

15.7.2 Circulatory

Provide circulatory plan and profile sheet that clearly shows the location of the alignment and vertical profile. The profile should return to the "same point" and, unless necessary, avoid grade breaks in the circulating lane.

15.8 Curb Returns

Provide curb return plan and profile sheets that clearly detail the alignment geometry of the curbs and provide a curb return profile that has clearly labeled points where the lane breaks away from the typical section "normal crown" profile and begins to be controlled by the curb return profile. Between these geometry points the lane cross slope begins to be controlled by the curb return profile rather than the centerline profile.

15.9 Sidewalk/Shared Use Path

Prepare sidewalk and/or shared use path plan and profile sheets when location and elevation vary from a typical section to show ADA compliance and drainage impacts.

15.10 Grading and Drainage

Provide drainage basin and calculations as required by the City's current design standards. Provide contours at an interval showing flow patterns, high points, and low points, clearly. Identify any areas under one percent slope in any direction. Provide grading and details for splitter islands and bike lanes.

15.11 ADA grading

Provide detailed plans with dimensioning, stationing with offsets, slopes, and elevations to a level for design review and approval, construction, and inspection.

15.12 Illumination

Provide construction plans showing the luminaire location, junction boxes, conduit runs, pole type, wattage, fixture type, and horizontal and vertical luminance and uniformity.

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16.0 EDUCATION AND COMMUNICATION

While Bend was an early adopter of using roundabouts, significant growth and tourism bring travelers who may not be familiar with using roundabouts. Education and communication are important tools for safe roundabout operations. For mini, compact, multi-lane, separated, turbo, or other innovative designs (such as ramp metering), include education materials as part of the design to be shared before and after the roundabout opens. The ICE Step 2 will identify if any educational materials are required and what type. Examples include:

- Video or one page info graphic showing how to navigate the roundabout walking, biking, and driving.
- Video or one page infographic showing how pedestrians and bicyclists cross multiple lanes.
- Post video or info graphic to social media posts, news stories, neighborhood association newsletters, etc.
- Mailer included with utility bills.
- Creating a braille or three-dimensional roundabout layout and coordinating outreach through City of Bend Accessibility & Equity Manager.

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APPENDIX A: EXAMPLES OF DO/DON'T DO

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Figure A-1. The bike lane ends appropriately at the ramp. In this photo, the curvature helps reinforce the bike rider's choices of merging into the traffic lane or exiting onto the shared-use path and is a good example. The shared-use path, however, should have been extended further, to get past the bike ramp, so someone walking with low vision doesn't easily walk down the bike ramp.

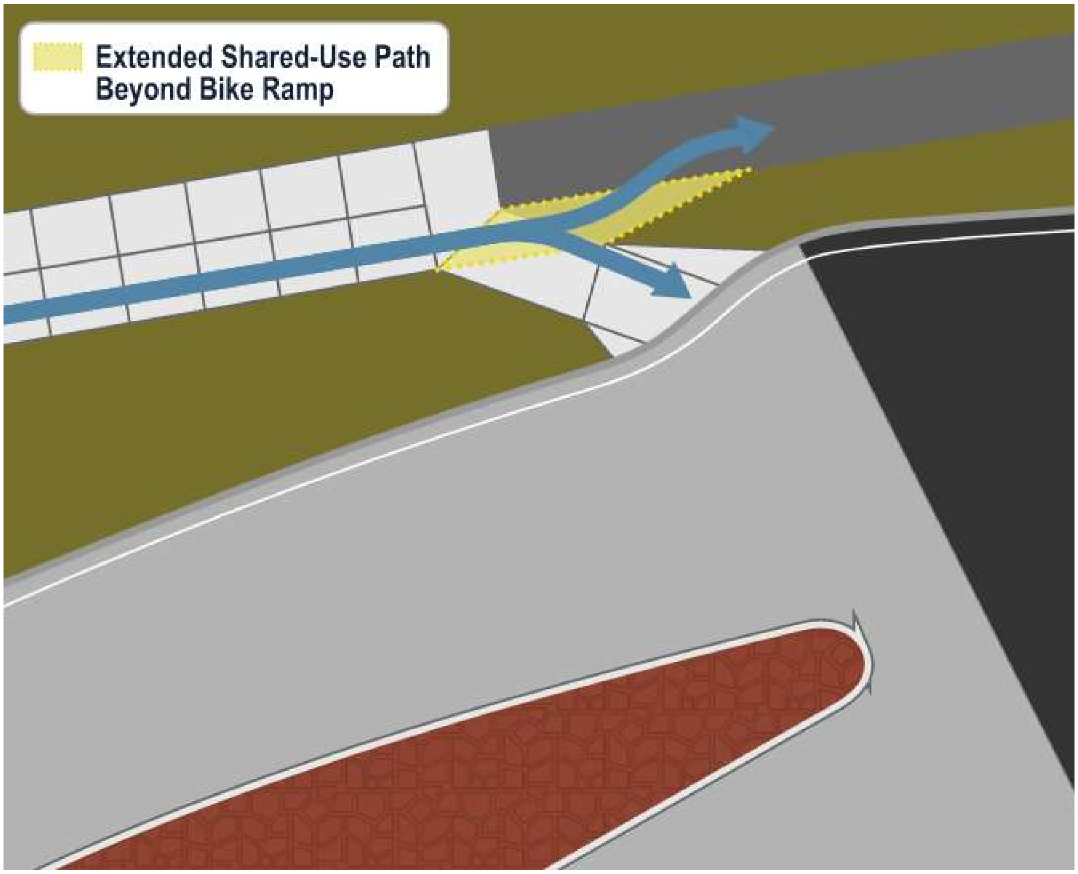

Figure A-2. Extend the shared-use path past the top of the bike ramp and to project limits. Design so to ensure a sidewalk/path user isn't directed down the bike lane ramp. This makes the roundabout design more accessible for those travelers with low vision or blindness. Do not use truncated domes at the bottom or top of the bike ramp to eliminate any confusion on them being an accessible route. The bike ramp should feel like a driveway to someone caning.

Figure A-3. PROWAG requires separation between the shared-use path around a roundabout and the road. The stamped concrete buffer did not provide adequate detectability, so the yellow detectable buttons were added to enhance its conspicuity. However this is not a preferred solution. The image on the right shows the use of decorative rock mulch, which is readily detectable.

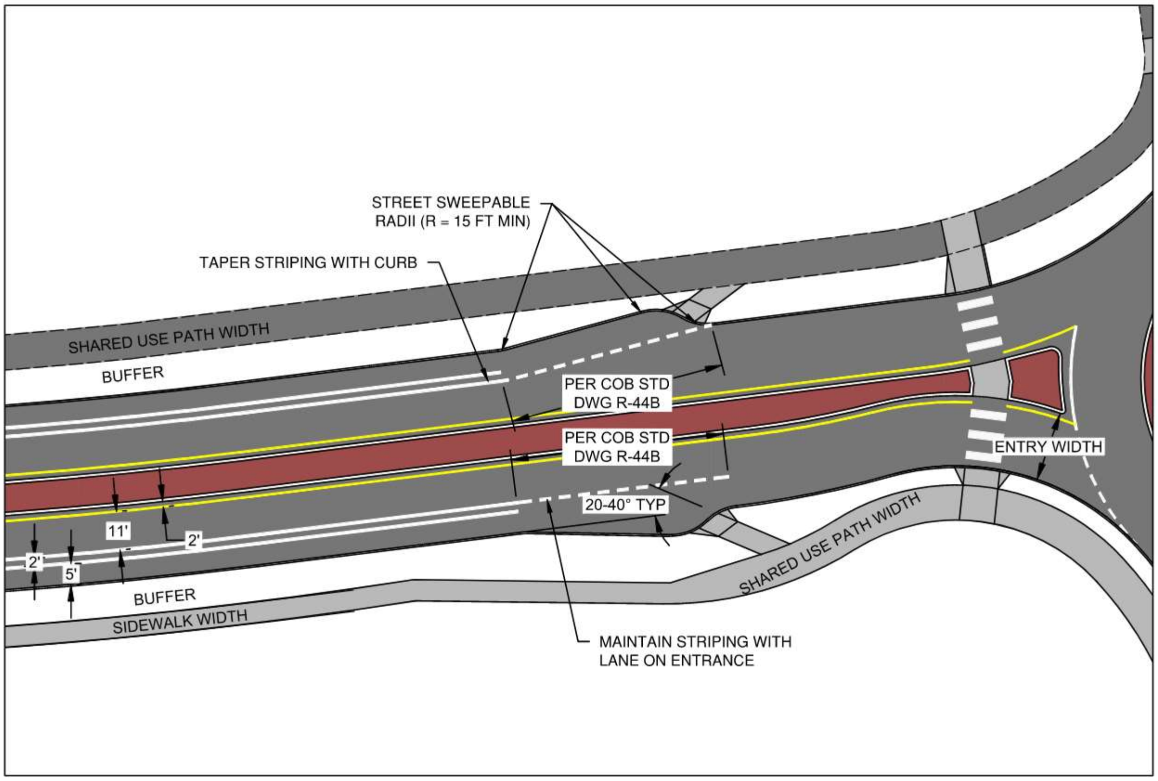

Figure A-4. Entrance and exit bike ramp details.

Figure A-5. This photo shows the use of mountable curb at the nose of a splitter island to facilitate use by larger vehicles that may need to use the splitter for turning movements and to facilitate snow plowing up to the edge of the circulatory.

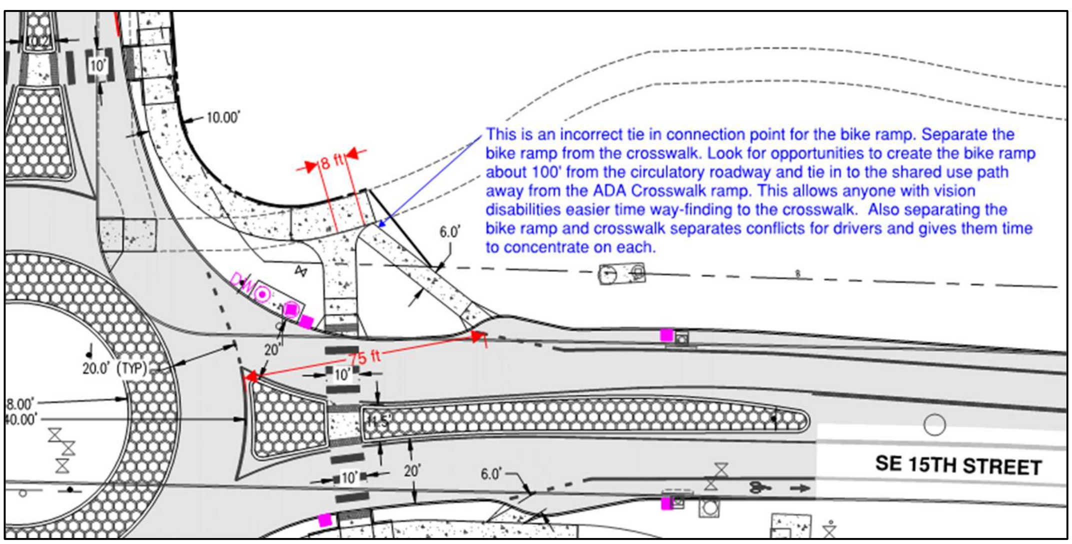

Figure A-6. Separate bike ramp and crosswalk. Bike ramp should be 100' from the yield line. This example does not provide enough separation between the bike ramp and crosswalk ramp.

Figure A-7. This roundabout has a poorly designed spiral, which results in drivers incorrectly exiting the roundabout from the inside lane, which can cause sideswipe crash potential with drivers exiting from the correct outside lane. There is a small painted wedge that is insufficient to push the driver into the outside lane.

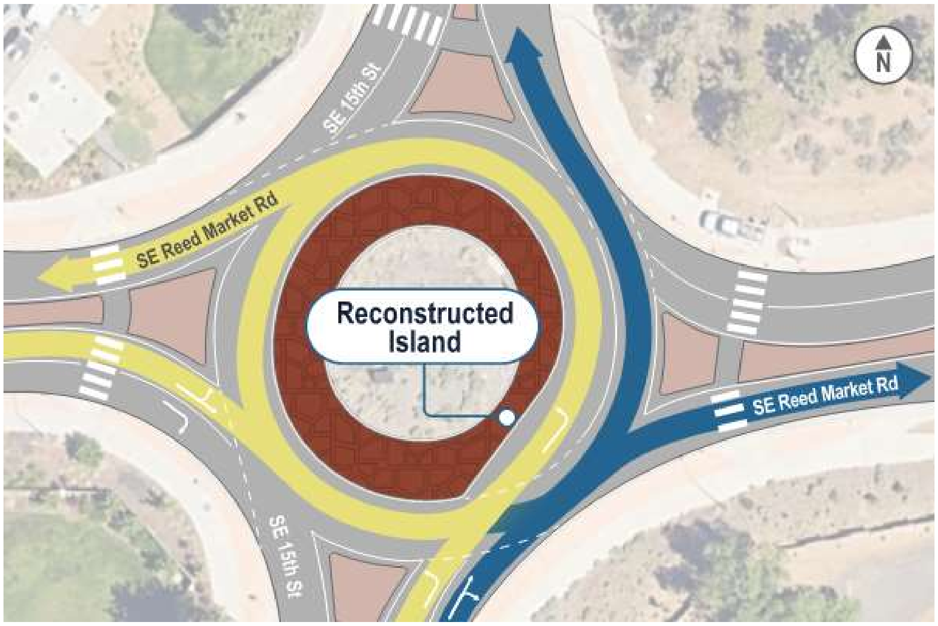

Figure A-8. To fix this issue, the central island truck apron needs to be partially reconstructed as shown in this exhibit to create the needed spiral. The central island curbing would do most of the work to enforce the spiral movement, and this would be reinforced with spiral striping on the pavement.

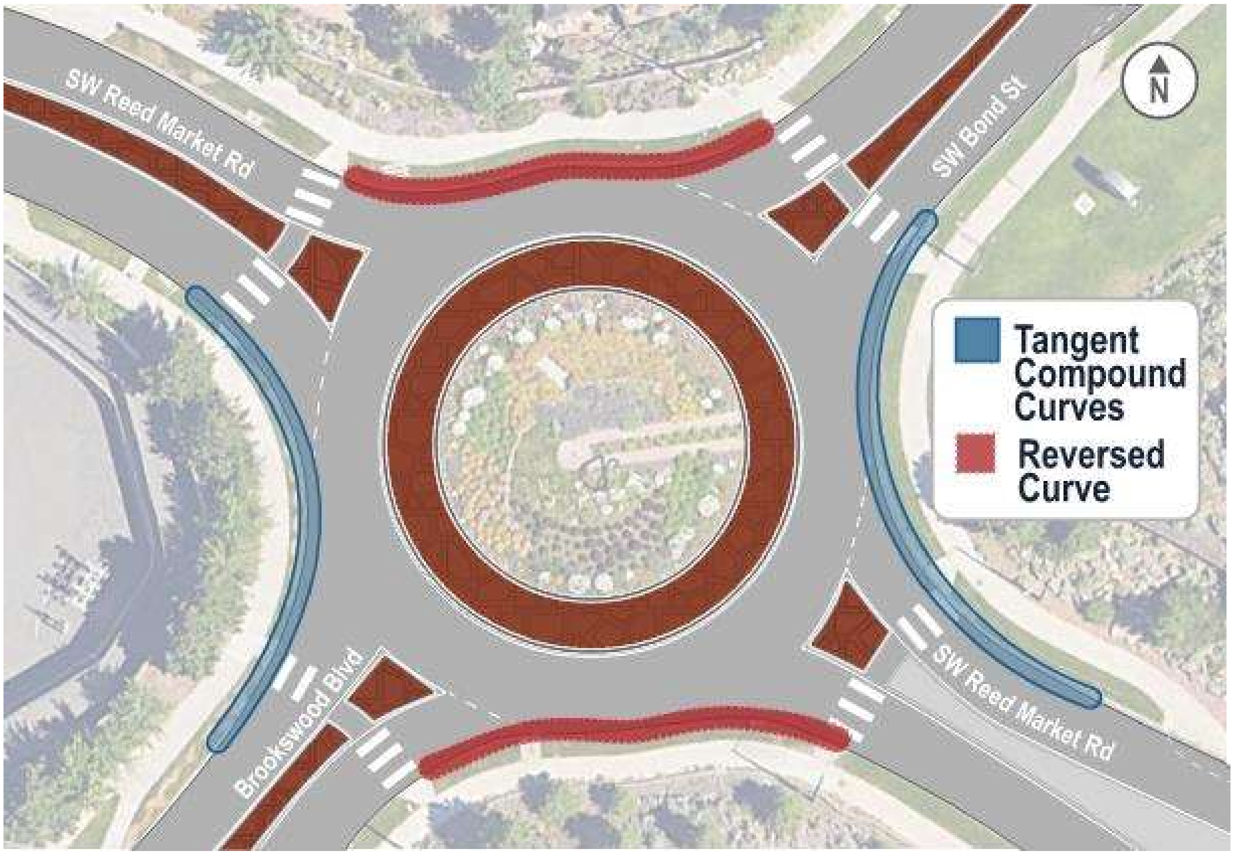

Figure A-9. Reed Market and Bond Street has reversed curves between SB entry and WB exit legs. The oversized ICD causes higher circulating speeds. Combined with the reversed curve it makes it difficult for EB entry leg drivers to identify gaps or get up to speed from a stop to fit into available gaps in circulating traffic.

CITY OF BEND

APPENDIX B: INTERSECTION CONTROL EVALUATION SCOPING FORM

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