Part 500 Intersection Design

Section 501 Introduction

Part 500 covers the design criteria, guidelines, and processes for designing road approaches, signalized and unsignalized at-grade intersections and roundabouts for all road classifications and contexts on the State Highway system. For information on general design considerations not fully covered in this chapter, or other parts of this manual, refer to AASHTO's most recent version of "A Policy on Geometric Design of Highways and Streets" Chapters 9 and 10; the ODOT research report "Modern Roundabouts for Oregon, Report 98-SRS-522" and "NCHRP Report 1043, Guide for Roundabouts". In addition, supplemental information can be found in National Association of City Transportation Officials (NACTO) publications, including Urban Street Design Guide, Urban Bikeway Design Guide and Don't Give Up at The Intersection. Intersection control evaluation is important to determine the appropriate intersection control option to develop for a project. Intersection control evaluation is a function of the ODOT Traffic Section. The roadway designer should work with the Region Traffic Section and the ETSB, Traffic Engineering Services Unit staff concerning intersection control options.

The Technical Services Roadway Engineering Unit can provide design assistance in the areas of intersection design, channelizations, road approaches, roundabouts, large vehicle accommodation, and alternative mode accommodation. Consult the Technical Services Roadway Engineering Unit about complex intersection designs that cannot meet the criteria contained in this design manual. Information on traffic volumes and requirements can be found in Part 1200, Sections 1205 and 1206 of this manual or further information can be obtained from Region Traffic Units and the Analysis Procedures Manual published by the Transportation Planning Analysis Unit (TPAU) of the Policy, Data and Analysis Division of ODOT.

501.1 Documentation and Approval Font Key

Text within this part is presented in specific fonts that show the required documentation and/or approval if the design does not meet the requirements shown. Table 500-1 shows the four text fonts used along with their descriptions. The text in figures, tables, exhibits, equations, footnotes, endnotes, and captions typically does not utilize the font key.

Table 500-1: Documentation and Approval Font Key

Font	Documenting	Approver
Bold text	Design Exceptions	State Roadway Engineer (SRE) and for some projects, FHWA
Bold Italics text	Design Decisions Document	Region with Tech Expert input or other approver as described
Italics Text	Document decisions	Engineer of Record (EOR)
General Text (Not bold or italics)	N/A	N/A

Bold Text - Some standards appear in a bold font style. A design exception is required to justify and document not meeting a standard that appears in bold. The State Roadway Engineer (SRE) gives formal approval, and FHWA approves as required. See 501.2 for a description of design standards. In the case of 3R clear zone approvals and local agency projects off the state highway system, design exceptions can be approved by someone other than the State Roadway Engineer (see sections 402 and 1003.5).

Bold Italics Text - Both standards and guidelines may appear in a bold italics font style. While a formal design exception is not required when not meeting a standard or guideline that appears in bold italics, document and justify the decisions made by the Engineer of Record in decision documents or other engineering reports. When not meeting a standard or guideline that appears in bold italics, region approval with input from Technical Experts, or other approval as described in the HDM, is required. For urban projects, formally record decisions via the Urban Design Concurrence Document in the Design Decision portion. The Urban Design Concurrence document is located on the Highway Design Manual website. See 501.2 and 501.3 for descriptions of design standards and guidelines.

Italics Text - Design decisions that require documentation appear in italic font style in design parameters sections. While a formal design exception is not required, document the design decisions made by the Engineer of Record in decision documents or other engineering reports. See 501.3 and 501.4.

General Text - Any informational statement that does not convey any degree of mandate, recommendation, authorization, prohibition, or enforceable condition. The remaining text in the manual is general text and may include supporting information, background discussion, commentary, explanations, information about design process or procedures, description of methods, or potential considerations and all other general discussion. General text statements do not include any special text formatting. General text may be used to inform and support design exception requests, particularly where narrative explanations show best practices or methods of design that support the requested design exception.

501.2 Standards

A standard is a statement of required, mandatory, or specifically prohibitive practice regarding a roadway geometric feature or appurtenance. The verb “provide” is typically used. The adjective “required” is typically used in figures to illustrate Standard statements. The verbs “should” and “may” are not used in Standard statements. The adjectives “recommended” and “optional” are only used in Standard statements to describe recommended or optional design features as they relate to required design features. Standard statements are sometimes modified by Best Practices (see 501.4).

501.3 Guidelines

A guideline is a statement of recommended practice in typical situations. The verb “should” is typically used. The adjective “recommended” is typically used in figures to illustrate Guideline statements. The verbs “provide” and “may” are not used in Guideline statements. The adjectives “required” and “optional” are only used in Guideline statements to describe required or optional design features as they relate to recommended design features. Guideline statements are sometimes modified by Best Practices (see 501.4).

501.4 Best Practices

A Best Practice is a statement of practice that is a permissive condition and carries no requirement or recommendation. Best Practice statements sometimes contain allowable ranges within a Standard or Guideline statement. The verb “may” is typically used. The adjective “optional” is typically used in figures to illustrate Best Practice statements. The verbs “shall” and “should” are not used in Best Practice statements. The adjectives “required” and “recommended” are only used in Best Practice statements to describe required or recommended design features as they relate to optional design features.

501.5 Definitions

Access Control Line -	A line established along the state highway where the right of access between a property abutting the highway and the highway has been acquired by the department or eliminated by law.
Alternate Access -	The right to access a property by means other than the proposed approach. It may include an existing public right of way, another location on the subject highway, an easement across adjoining property, a different highway, a service road, a local road, or an alley, and may be in the form of a single or joint approach. The existence of alternate access is not a determination the alternate access is “reasonable” as defined in ORS 374.310.
Approach -	A legally constructed public or private connection that provide vehicular access to or from a state highway that has written permission under a permit to operate issued by the department, the department has recognized as grandfathered, or the department does not rebut as having a presumption of written permission.
Curb ramp -	A system of geometric components that are built up to or through a curb to access the walkway or street crossing in the public right of way or on building sites. It may also be referred to a sidewalk ramp or curb cut in portions of this manual.
Grandfathered approach -	An approach that the department has recognized in documentation dated prior to January 1, 2014, as having grandfathered status under the rules in effect on the date of the documentation.
Grant of Access -	The conveyance of a right of access from the department to an abutting property owner.

Section 502 Road Approaches and Intersections

502.1 General

The location and spacing of road approaches should be in conformance with the Access Management standards as described in the Oregon Highway Plan, Appendix C. The decision for placement and design of a road approach must be consistent with the function of the highway and optimize the safety and operational efficiency for vehicles as well as all users of the roadway no matter their modal choice. ***The road approach design must accommodate the turning movements of the appropriate design vehicle. All road approaches, public and private,***

require a construction permit from the appropriate District Maintenance Office. The District Manager and Region Access Management Engineer and/or Access Management sub-team should be involved early in any road approach discussion and decisions.

Road approaches can be classified as either private or public. Private approaches connect private property with a state highway across the highway right of way. Public approaches are at-grade intersections of public roadway right of way with a state highway.

Both its physical area and its functional area define an intersection or approach. The physical area is the fixed area of the intersection itself from curb-to-curb confined within the corners of the intersection. The functional area of an intersection extends both upstream and downstream from the physical area and includes any auxiliary lanes or channelization. The functional area includes the perception-reaction distance, the deceleration maneuver distance, the full deceleration distance and the storage length. Ideally, approaches to the highway are not constructed within the functional area of an adjacent intersection. Realistically, however, there are many factors that enter decisions regarding placement of approach connections. The roadway designer must consider all aspects and constraints when designing roadway approaches and provide the best overall connections possible. Figure 500-1 displays the functional area of an intersection.

Figure 500-1: Functional Intersection Area

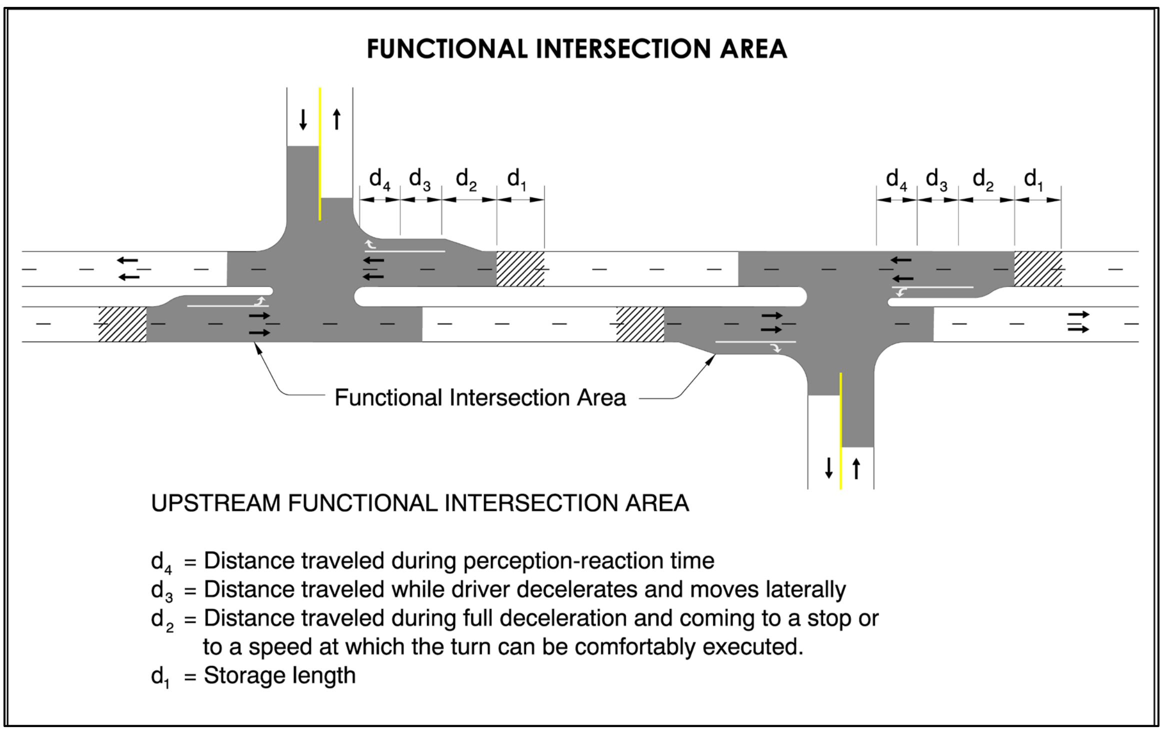
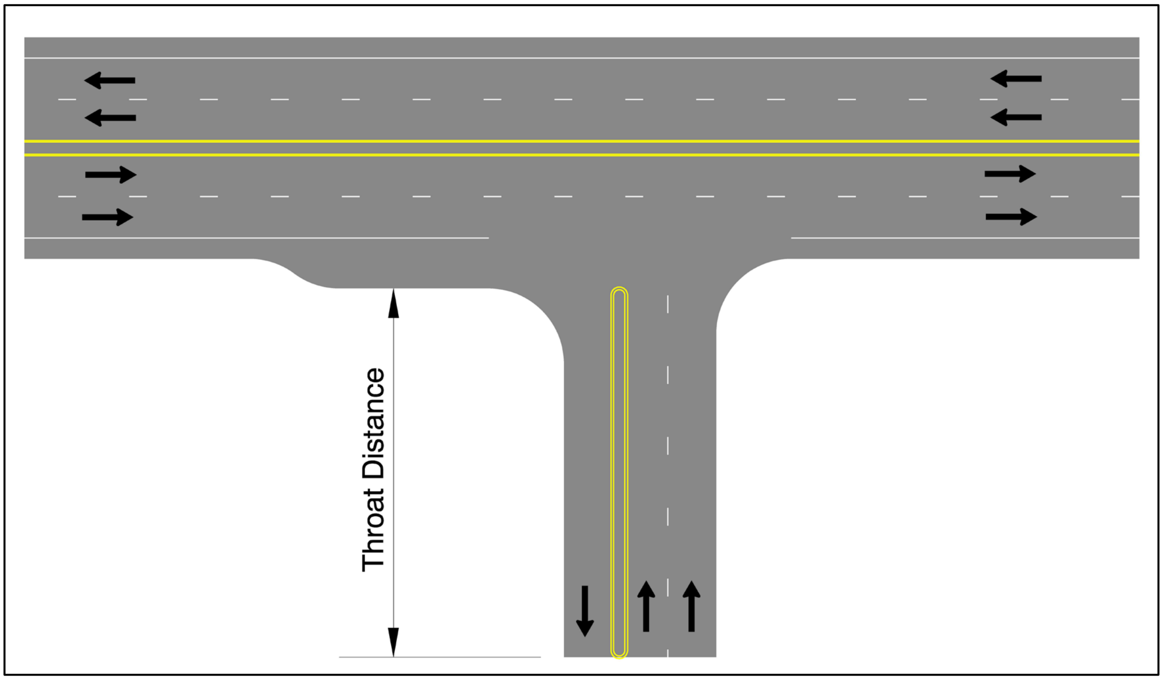


Figure 500-2: Throat Distance at Approaches



For approach connections from properties adjacent to the highway, the corresponding site circulation plan should specify the entry/exit throat distance. This throat distance is critical in order to provide an efficient and functional connection between the highway and the adjacent property. Throat lengths are critical for commercial and industrial type land use approaches. ***The Transportation Planning Analysis Unit or the Region Access Management Engineer can assist with determining the appropriate throat distance***. Figure 500-2 depicts the typical throat distance concept.

502.2 Design for or Accommodate Design Vehicle

Intersections should be designed for the appropriate design vehicle. An important concept concerning the design vehicle when designing an intersection or road approach is the concept of "accommodating" the design vehicle or "designing for" the design vehicle.

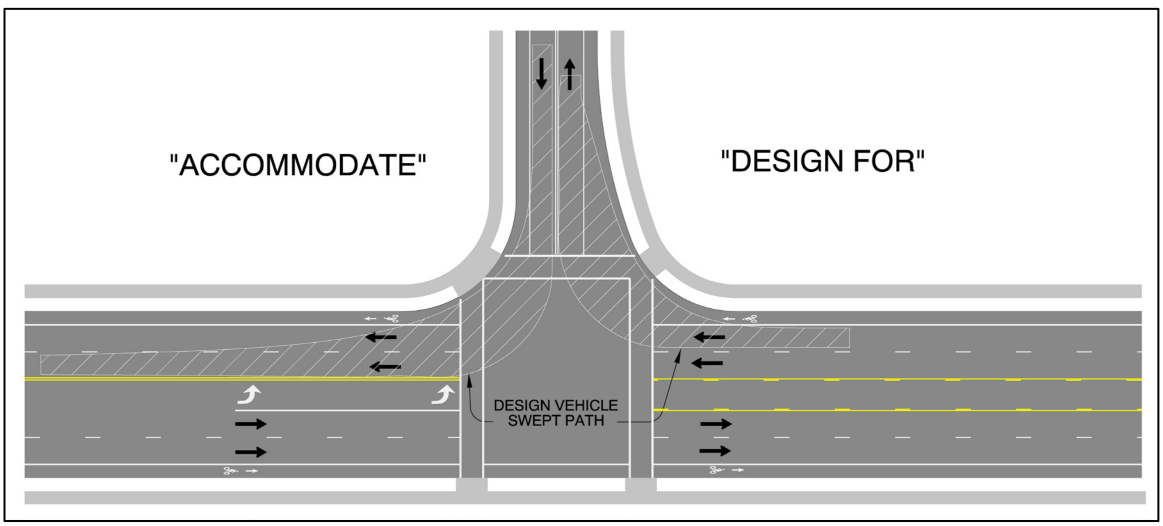
When an intersection is designed to accommodate the design vehicle, the intent is to provide enough physical space for the design vehicle to maneuver and turn through the intersection but may not be able to do so within the confines of a single lane. When an intersection is designed for the design vehicle, the design provides appropriate turning and maneuvering space to allow the design vehicle to remain within one lane.

While it is advantageous to design for the largest vehicle using the approach, often real-world constraints make it difficult or impossible to achieve. Large curb radii will accommodate larger design vehicles but can increase vehicle speeds and create a larger distance for pedestrian crossings.

Designing all approaches for a WB-67 type vehicle certainly provides a level of comfort for the variability of vehicles using the approach. However, not all approaches have a high need for WB-67 access. Freight distribution centers and industrial locations will most certainly need approaches and access designed for WB-67 type vehicles. However, most commercial and retail locations may only need access designed for single axle (SU) type delivery vehicles with accommodation for the occasional WB-67 type vehicle. See Section 222 for more information regarding design vehicle selection.

Approaches should be designed for the appropriate design vehicle. The designer must realistically consider the needs of the approach and design accordingly. Being judicious and fully analyzing the needs of an approach connection to create a design specific to the location can improve roadway conditions overall for all modal users of the state highway system. Providing an approach larger than necessary is not only inefficient in cost but can also have detrimental effects for other roadway users. Figure 500-3 illustrates the "Accommodate" and "Design For" concept.

Figure 500-3: Accommodating and Designing for a Design Vehicle



Section 502.1 is not intended to be a detailed discussion of approach road design. For more detail on approach road or median design refer to Section 506, and Parts 200 and 300.

502.3 Legal Considerations for Road Approaches

The legal issues involved with approaches are specialized and complicated. Refer to the "Access Management Manual" for access rights and road approach issues. This manual includes information from "Oregon Administrative Rules, Chapter 734, Division 51 – Access

Management," that defines legal criteria relating to road approach permitting and design. Additional information on access management can be found in Section 503.

502.4 Intersections and Interchanges - Expressways

Connections to both urban and rural expressways can be either at-grade intersections or grade separated interchanges. *At most rural expressway locations, the preferred connection type is grade separation.* ***Where appropriate, grade separated connections should also be considered at major rural highway intersections.*** However, there are many factors to consider in the design of these types of connections. For urban and Rural interchange spacing (crossroad to crossroad) and other design criteria see Part 600. Table 600-2 provides information for spacing criteria.

Section 503 Access Management and Access Control

503.1 Access Management

Access management is a tool available to designers, planners, and other transportation professionals to improve traffic safety, capacity, and efficiency while promoting economic development. The benefits of managing access to highways are well documented. Good access management techniques and strategies when designed properly along state highways will reduce the overall number of crashes and increase the highway's capacity. This section is not an exhaustive description of all the rules, laws, and techniques related to access management, but outlines some of the basic concepts, definitions, and appropriate tools for use on Oregon State Highways.

Access management is an important tool for maintaining the safety and functionality of a highway segment. ***In rural environments, access spacing conforms to the standards contained in OAR 734 Division 51.***

There are several documents that designers, planners, and field staff are encouraged to review to get a big picture understanding of access management. These include:

1. OAR 734 Division 51 – These are the administrative rules that the Department must comply with in carrying out the access management in permitting, planning, and project delivery.
2. ***Project Delivery Leadership Team Operational Notice PD-03 describes the accountabilities and deliverables for access management during project development.***

3. Access Management Manual - This manual consists of three volumes covering legal, technical, and procedural information and resources for the department's access management program. Volume 1, Chapter 3 entitled Guidelines and Resources for Access Management in Project Development provides guidance for implementation of project delivery operational notice PD-03. Volume 2 of the manual contains technical papers on various aspects of access management such as sight distance, access spacing, interchange management, functional intersection areas, and medians. Volume 3 is a user's guide for the Central Highway Approach/Maintenance Permit System (CHAMPS). CHAMPS is a computer-based system that is used by department staff to document the permitting process and issue approach permits.

503.2 Access Management - Expressways

Access management is critical to retaining the efficiency, safety, and function of an expressway. The expressway designation implies higher mobility along the corridor over access to individual properties. In general, private land access is limited where the property has alternative access. Expressways should discourage private access and focus connections at public roads. In some cases, this may require building alternate access to the property or the purchase of access rights. Existing private accesses should be eliminated when possible during project development. Additionally, public road connections that do not meet the spacing standards should be eliminated where possible during project development and in accordance with any adopted access management plans for the highway. If possible, full access rights should be purchased along the length of the expressway with access points only allowed at public roads that meet the spacing standards contained in Appendix C of the Oregon Highway Plan. ***The spacing standards can also be found in OAR 734-053-4020. Breaks in the access control line should only be given for those roadways that are connected during construction. All other future connections must obtain a grant of access to be connected.*** (See Section 503.7 for more information on the Grant of Access process.) The intent of this access control is to manage the number and locations of vehicular access to the expressway and to minimize potential conflict points along high speed, mobility centric highways. Where a multi-use pathway is provided along the expressway, additional connections for bicyclists and pedestrians to the local road system are strongly encouraged. These types of connections should be designed so that motorized vehicles are precluded from using them. ***For specific information regarding access management and Expressways, see the Oregon Highway Plan and OAR 734, Division 51.***

503.3 Access Management Plans

An access management plan is a useful management tool. An access management plan can be done as part of an ODOT STIP project or during a coordinated planning study. Access management plans developed in a coordinated planning process establish a plan for accessing properties in the future. An access management plan essentially is a detailed plan outlining how adjoining properties are to be accessed during project development.

503.4 ODOT Permit Process

The ODOT Permit Process is also outlined in OAR 734 Div. 51. See OAR734-051-1070(30) for information on "Grandfathered" accesses. *All approaches to a state highway must have department permission to be considered legal.* Through the permitting process ODOT can negotiate access designs, approach configurations, turn movement restrictions, and even shared approaches. Properties with multiple approaches can be modified to provide the minimum number needed. *Access management decisions are made by the Region Access Management Engineers (RAME). Work closely with the RAME for approach permit decisions.* ***The authority for issuing permits resides with the District Manager or designee.***

503.5 Access Control

Access Control is a term established in Oregon Right-of-Way and Access Rights statutes. A property that is access controlled has no right of access between the property abutting the highway and the highway. Interstate highways and freeways are access controlled with access only through grade- separated interchanges at public streets and highways. There is no access provided to adjoining private properties. Generally, expressways with grade-separated interchanges are access controlled. However, expressways with at-grade intersections may or may not have access control lines established. Preference is to establish access control on urban and rural expressways, but it may not always the case.

Acquiring the access rights from properties abutting a state highway provides a high level of protection to the highway. However, acquiring access control is not justifiable in all conditions. The Department has developed guidelines for access management decisions during project development. These guidelines are contained in Transportation Operations Bulletin PD-03a. They attempt to focus the Department's limited resources for projects that really need access control. Additional guidance can be found in OAR 735, division 51.

503.6 Access Control - Expressways

Maintaining access control on rural expressways is critical to retaining the safety and efficiency of the facility. No private approaches should be allowed on rural expressways. When an expressway is established along a highway, or if there are existing private approaches, a long term plan should be established to eliminate them or provide alternative access as opportunities occur. ***Space and control public road connections according to the access management spacing standards contained in the Oregon Highway Plan, Appendix C.*** Spacing standards can also be found in OAR 734-053-4020. Traffic signals are not recommended on rural expressways, and modernization of expressways that have traversable medians will typically result in non-traversable medians.

503.7 Grants of Access

A Grant of Access is a transfer of a property right to a property owner for a right of access at a particular location. The Department must follow the requirements of OAR 734 Div. 51 when issuing Grants of Access. Obtaining a Grant of Access can be a complex process. Before even considering a Grant of Access as part of a project, the designer should contact the Region Access Management Engineer.

Section 504 Access Management Design Tools

504.1 Right In – Right Out Only

Restricting an approach road to right turns in and out only is accomplished by the installation of a non-traversable median. In urban environments this median should be a raised curb style. In more rural environments the median could be raised curb, median barrier, or depressed median. Controlling the median with a non-traversable design is the only design that provides a positive reinforcement of the turn restrictions. Figure 500-4 and Figure 500-5 show some examples of median designs limiting approach roads to right turns only.

Figure 500-4: Median Detail: Right-In Right-Out (Median Barrier)

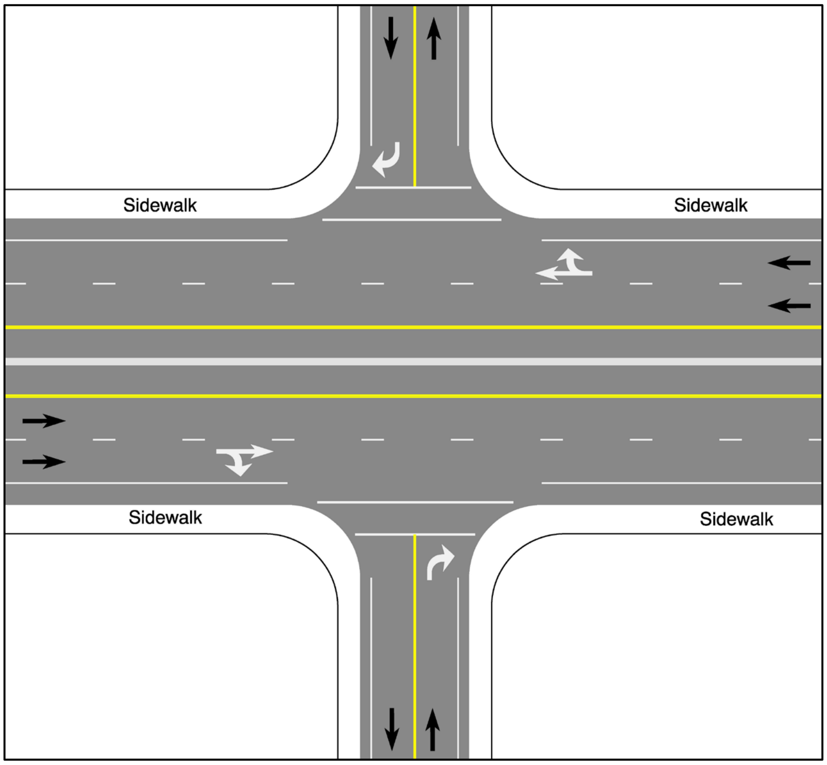


Figure 500-5: Raised Median Detail: Right-In Right-Out (Raised Curbed Median)

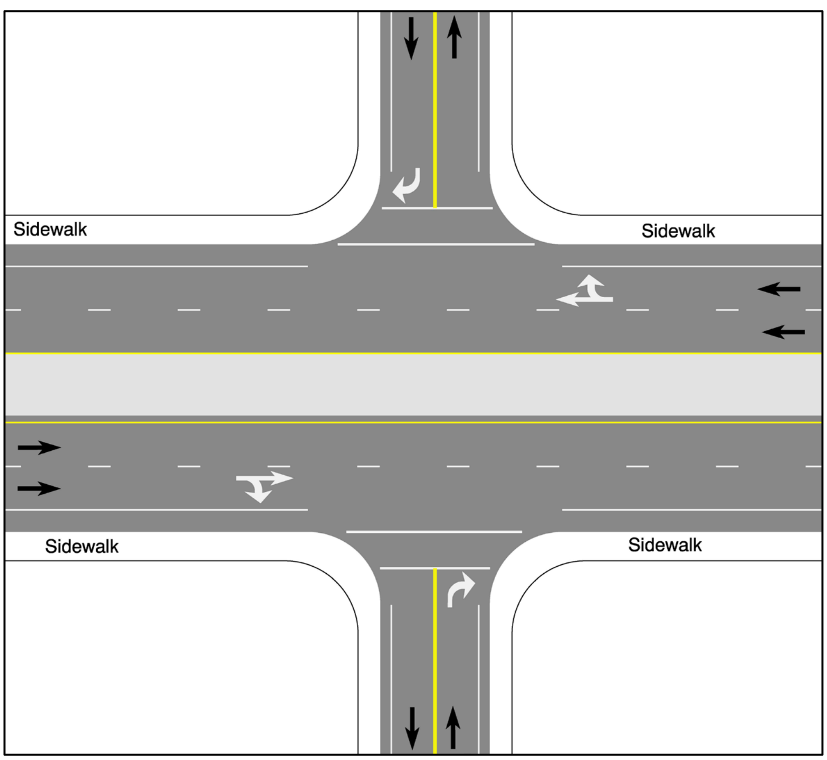


Figure 500-6: Benefits of Median Control for Pedestrians

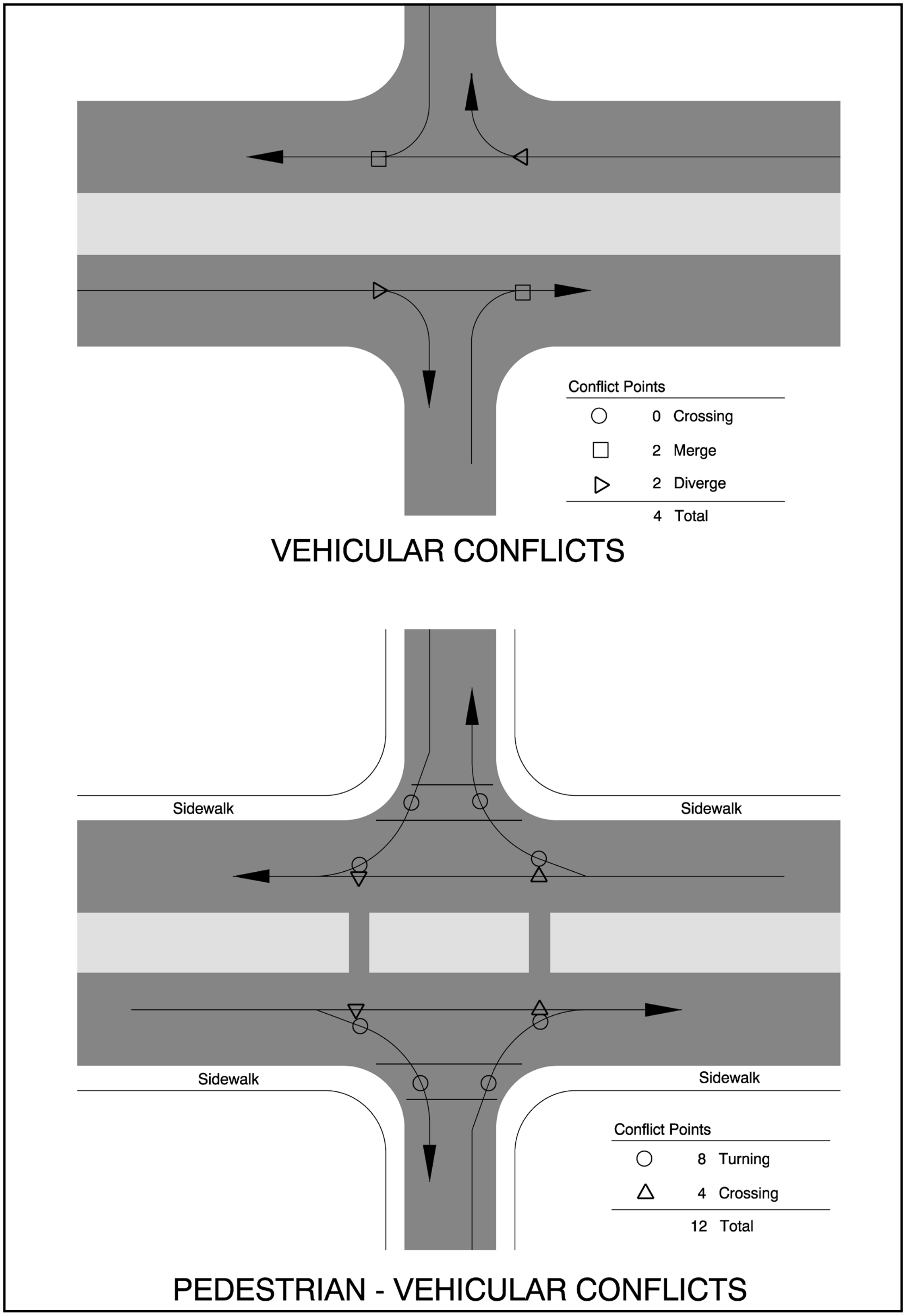
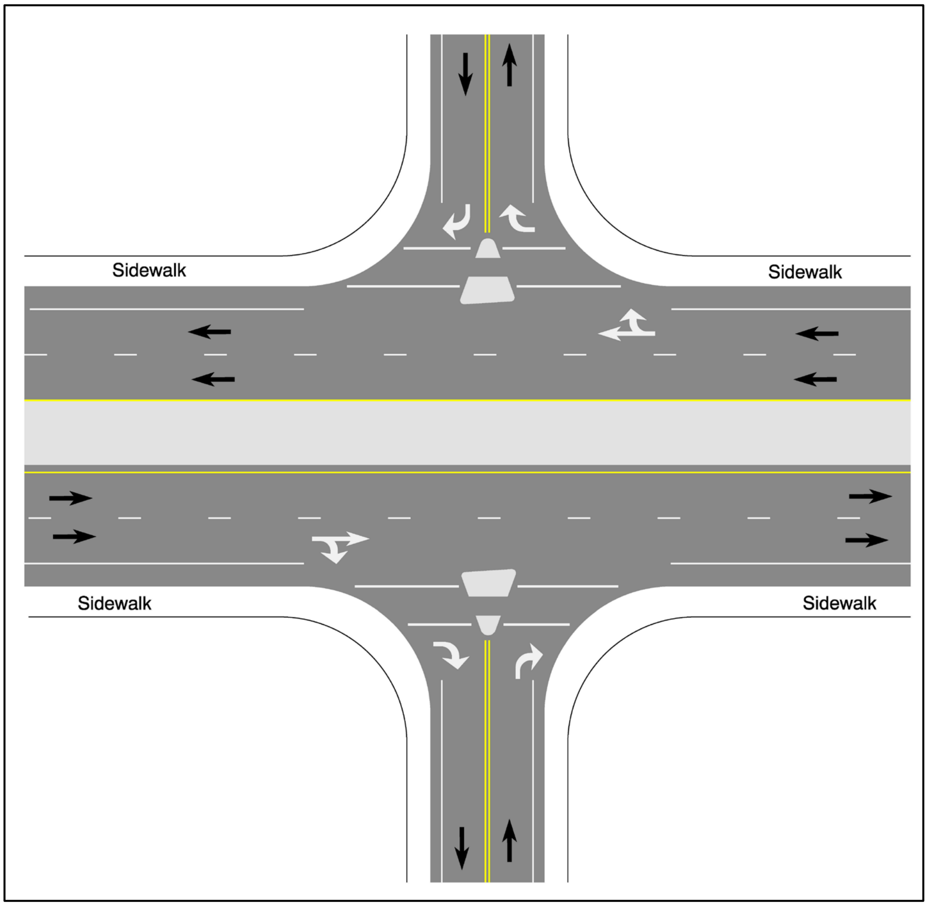


Figure 500-6 shows the benefits of median control involving pedestrians. For more information on median design, refer to Part 300, Sections 308 through 312. For more information on approach road design, refer to Section 101 and Section 506.

Note: ***The addition of any median treatment will need to be investigated for freight mobility issues and comply with ORS 366.215,*** Creation of state highways; reduction of vehicle-carrying capacity. For guidance in complying with ORS 366.215, see ODOT guidance document "Guidelines for Implementation of ORS 366.215, No Reduction of Vehicle-Carrying Capacity and the ODOT Highway Mobility Operations Manual".

Figure 500-7: "Porkchop" With Non-Traversable Median



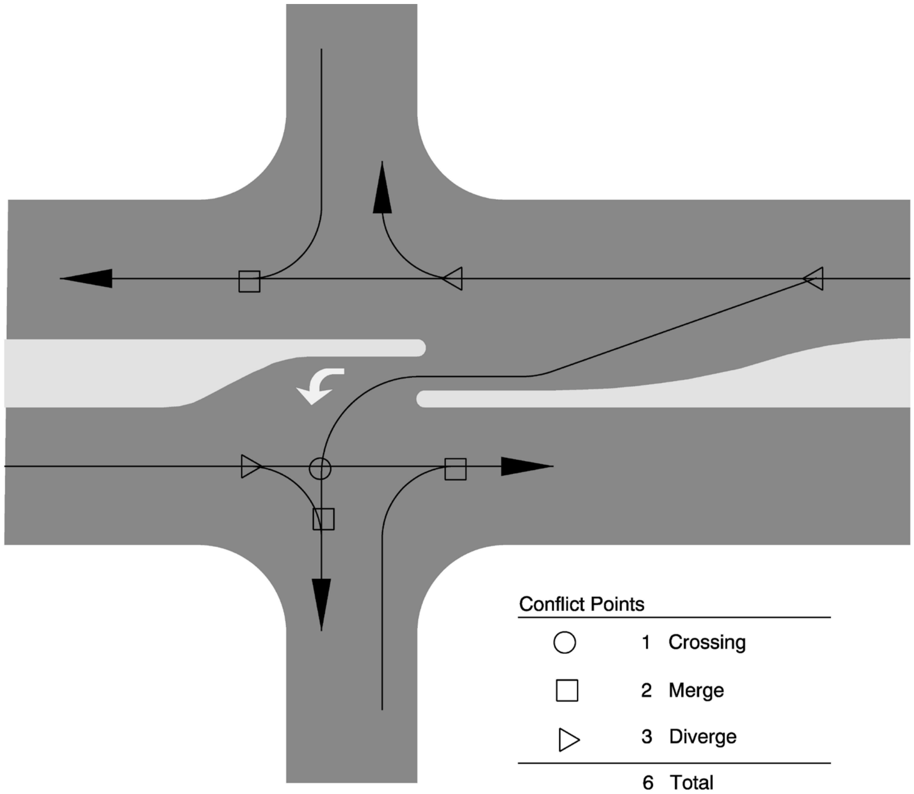
Another design option that may be considered in some situations is the use of a “pork chop” design. A pork chop design consists of a channelization island, usually with raised curb that directs traffic in the intended direction. The channelization island tries to discourage turn movements by angling the entry and exit so that left turn movements are uncomfortable. The problem with the pork chop design is that passenger vehicles are still physically able to make left turn movements. Most pork chop designs that do not include a non-traversable median design have a very high rate of non-compliance for the restricted movements. Therefore, a pork chop design should still include a non-traversable median design as well. Where a non-traversable median is not practical or is unacceptable, the designer should attempt to maximize the entry and exit angles to make left turn movements as difficult as possible. Figure 500-7 shows a "pork chop" design concept with median control.

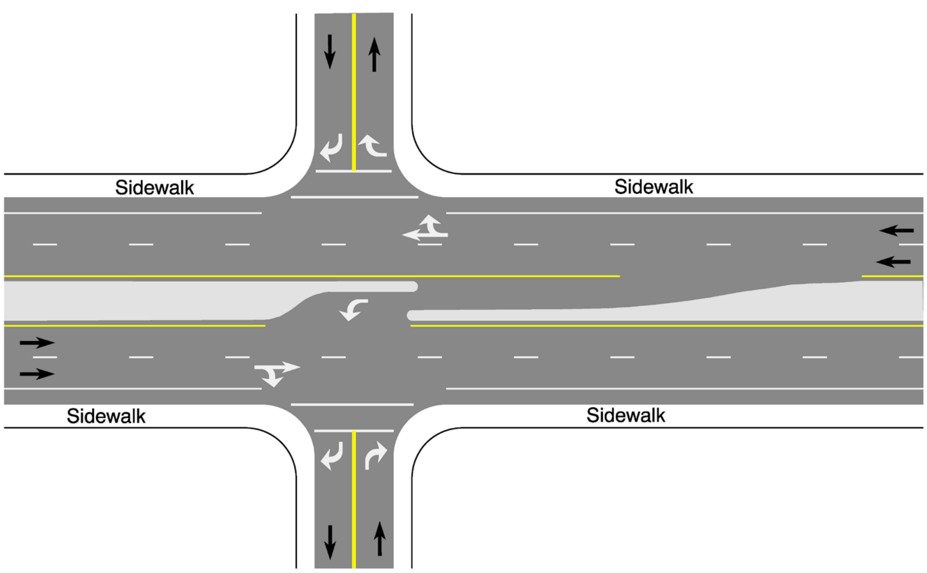
504.2 Right In – Right Out with Left In

From a traffic analysis perspective, the left turn out movement from approach roads usually operates worse than all other movements. This is because in the hierarchy of turn movements, the left turn out from an approach road is the last priority. In addition, the left turns from an approach road usually experience a higher number of accidents than the other movements. Because of these factors, there are several situations where eliminating a left turn out movement from an approach road is the preferred design solution. The only effective design option for this technique is a non-traversable median as shown in Figure 500-4 and Figure 500-5.

Based on the outcome of a region evaluation of overall roadway section operations and safety concerns, there may be locations where allowing a left turn in from the main line to the approach road is acceptable. When a left in option is deemed viable, the preferred median style is a raised curb, median barrier is not applicable. When designing this type of median, it is critical to physically exclude the left turn out movement. The basic concept of this design is to break the raised median and extend a traffic separator along the right edge of the left turn entering traffic creating a channelization for the left turn vehicle. This separator should extend back away from the approach road far enough so that passenger vehicles cannot physically turn left from the approach road. The design still must accommodate the appropriate design vehicle. Figure 500-8 illustrates this design concept.

Figure 500-8: Right-Out, Right-In, Left-In (One Direction Only)

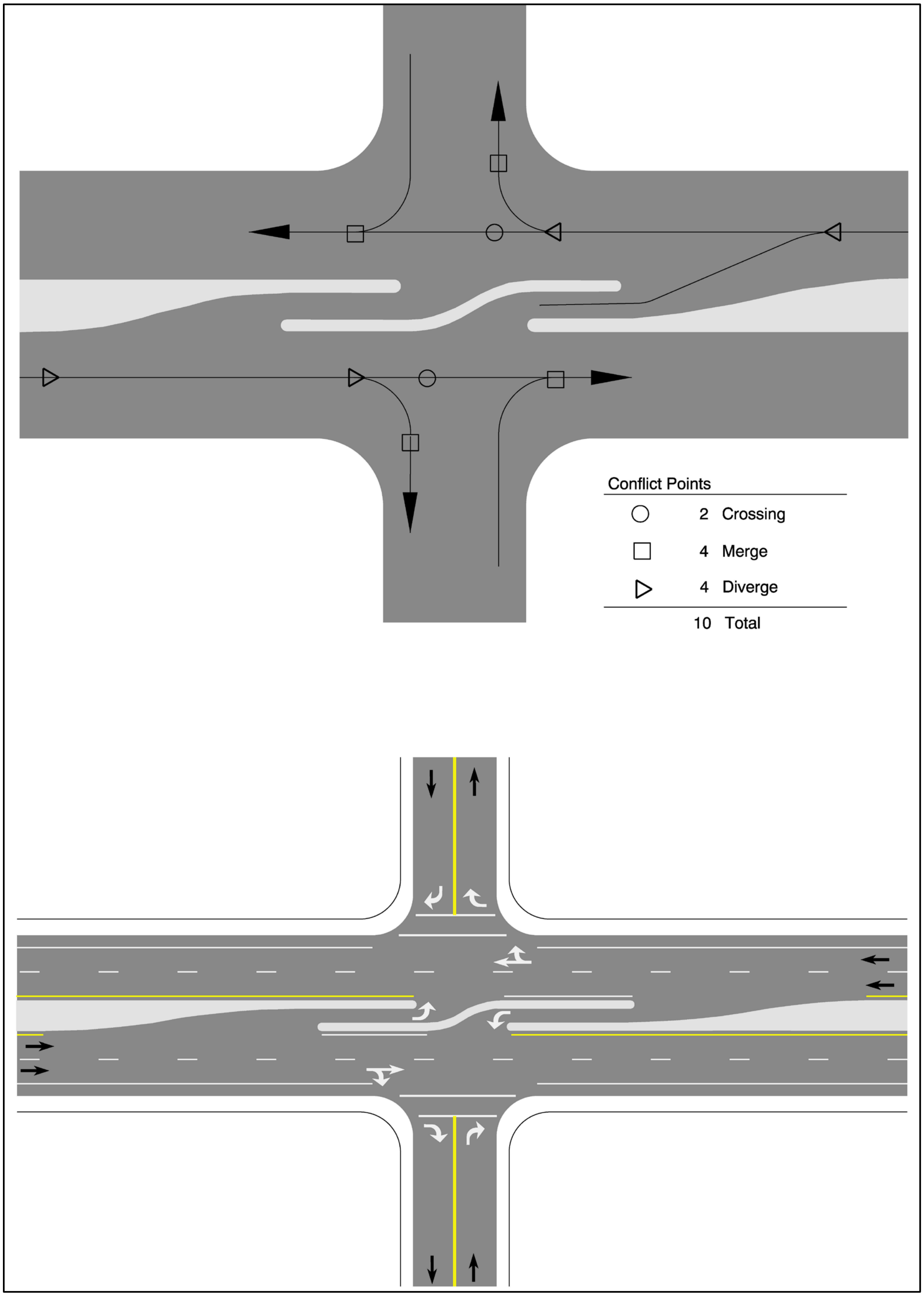




504.3 Opposing approaches with Left In

In many urban environments, approach roads will be directly opposite from each other. In some situations, eliminating left turns out of the approaches, but maintaining left turns into the approach road is desired. In these cases, the appropriate design is very similar to the design described in “Right In, Right Out with Left In” for a single approach restricting left turns out. The difference is the median design now accommodates opposing left turn traffic. The concept remains the same however, physically eliminate the ability for vehicles to make a left turn out movement. The difference is the traffic separator must now “snake” through the intersection transitioning from one side of the median to the other using reversing curves. The curvature is determined by the design vehicle. It is preferred with this technique to obtain additional width of the traffic separator in the middle of the median. This will provide additional visual guidance through the intersection. Figure 500-9 illustrates the use of this design concept.

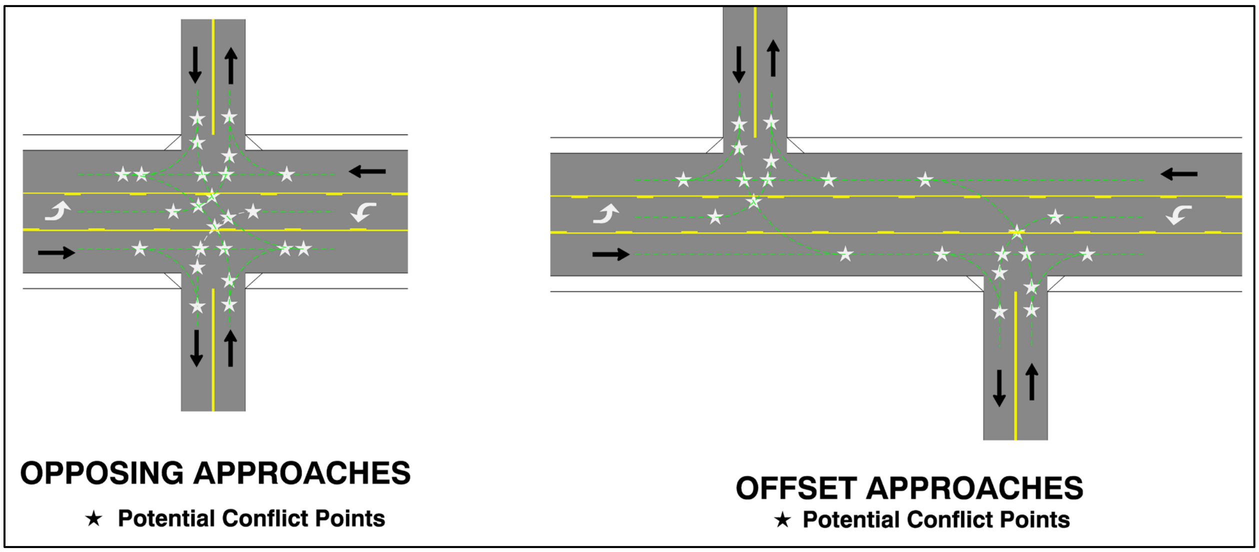
Figure 500-9: Opposing Approaches, Right-In, Right-Out, Left-In (Both Directions)



504.4 Offset Approaches

Primarily, this design option is used in rural or fringe areas where spacing between approach points is large. This design tool is implemented where a four-leg intersection is experiencing significant operational and safety problems. By separating the intersection into two individual intersections, the number of conflicts is reduced which should improve the safety of the intersections. ***If this design option is chosen, the intersection needs to be split in the correct direction. The approaches should be offset to the right in order to eliminate the back to back left turn queue conflict.*** The amount of the offset will vary depending upon the highway volume, approach road volume, surrounding land uses, speed of the highway, and direction of the offset. The designer considers the functional area of each intersection and the amount of weaving traffic. In addition, contact the Region Access Management Engineer and the Roadway Engineering Section when considering offset approaches. For more information on offset approaches/intersections refer to Figure 500-10.

Figure 500-10: Conflict Points - Opposing Approaches and Offset Approaches

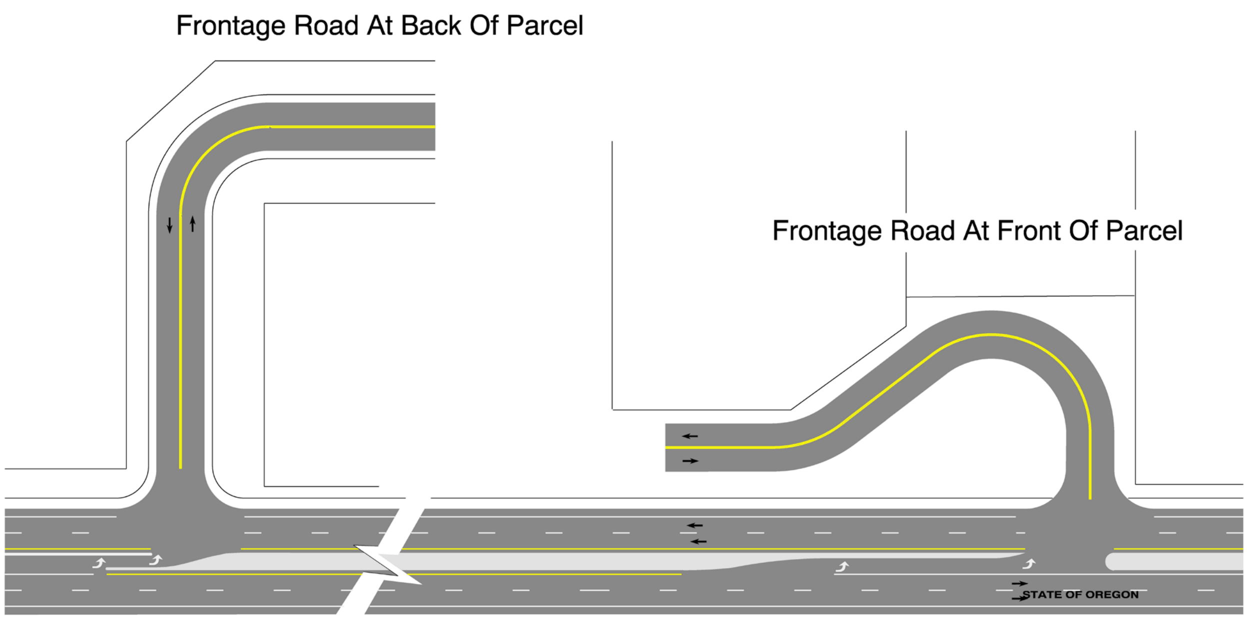


504.5 Frontage Roads

Frontage roads are a very useful design to eliminate or restrict direct highway access from a section of highway. Design frontage roads to accommodate the volume and type of traffic anticipated. Two of the most important elements of the frontage road design are the connection to the highway and turning roadway. Design the connection to accommodate the allowable turning movements for the appropriate design vehicle. If trucks are to use the frontage road, they must be considered in the design. Secondly, the design of the connection to the frontage road is critical. Usually, this connection is a turning roadway, but may be an intersection. The connection needs to provide off-tracking room for trucks using the frontage road. The design needs to consider the roadway alignment and width to make sure trucks can physically make the turns required. Finally, frontage roads should be offset from the highway so as not to interfere with highway operations. ***The frontage road must be physically separated from the highway by use of barriers, fencing, or ditches. The separation between the highway and frontage road edges of pavement must be at least 40 feet, but preferably 50 feet or more.*** The design also needs to consider clear zone requirements and the effect of headlight glare on both roadways.

Another option involving the location of the frontage road is to locate the frontage road on the back side of the adjacent properties. This is often called a "backage" road. This option may be more appealing from a visual standpoint allowing the properties to front the mainline roadway while the parking lot and frontage road are located further away from the mainline roadway. This option may also provide for better mainline/frontage road traffic operations. See Figure 500-11 or frontage road examples.

Figure 500-11: Examples of Frontage Road Locations



504.6 U-Turns

Where a section of highway contains a non-traversable median for an extended length, there may be a need to accommodate U-Turning traffic. There are several design techniques available to accommodate U-Turns. The first option is at a standard intersection. This design option generally requires widening the highway in one quadrant of the intersection to accommodate the required turning space of vehicles. Designs need to consider the type of vehicle using the U-

Turn. In most situations, trucks will be prohibited from using this style of U-Turn. The widening can make use of a far side bus stop or can be tapered. **All U-Turns using this type of design technique at a signalized intersection must have the approval of the State Traffic Engineer in consultation with the State Roadway Engineer.**

A second design option for accommodating U-Turning traffic is the use of a jug-handle. There are two options for jug-handle U-Turn designs. One option is the left side jug-handle. The left side jug-handle is a turning roadway alignment located on the left side of a highway. U-Turning traffic makes a left turn from the highway into the jug-handle. The jug-handle circulates the traffic back to the highway where vehicles re-enter the traffic stream as right turns through normal gaps in traffic flow. This style of jug-handle can be used at an existing "T" intersection or mid-block. *The jug-handle is only compatible with a right side "T" intersection, which may or may not be signalized. Jug-handle intersections would typically accommodate U-Turn truck movements.*

The other jug-handle design option is the right side jug-handle. The right side jug-handle is located on the right side of the highway. U-Turning traffic makes a right turn off the highway into the jug-handle, and then loops around to the left. The vehicles then make a left turn across the highway. This movement may or may not be signalized. *As with the left side jug-handle, the right side jug-handle is only compatible with a "T" intersection. In this case, however, the intersecting roadway is on the left side of the highway.* The major disadvantage of this style is traffic must make a left turn across both directions of highway traffic and is therefore less efficient and may also have additional safety risks.

See Figure 500-12 and Figure 500-13 for U-Turn treatments.

Jug-handle style U-turns can be used at mid-block locations. These may be used downstream of an intersection to improve operations and safety at an intersection as described below in the Indirect Left Turns section.

Also, see the ODOT Traffic Manual and the ODOT Traffic Signal Policy and Guidelines for traffic related design and approvals. Consult with the region Traffic Section.

Figure 500-12: U-Turns at Intersections

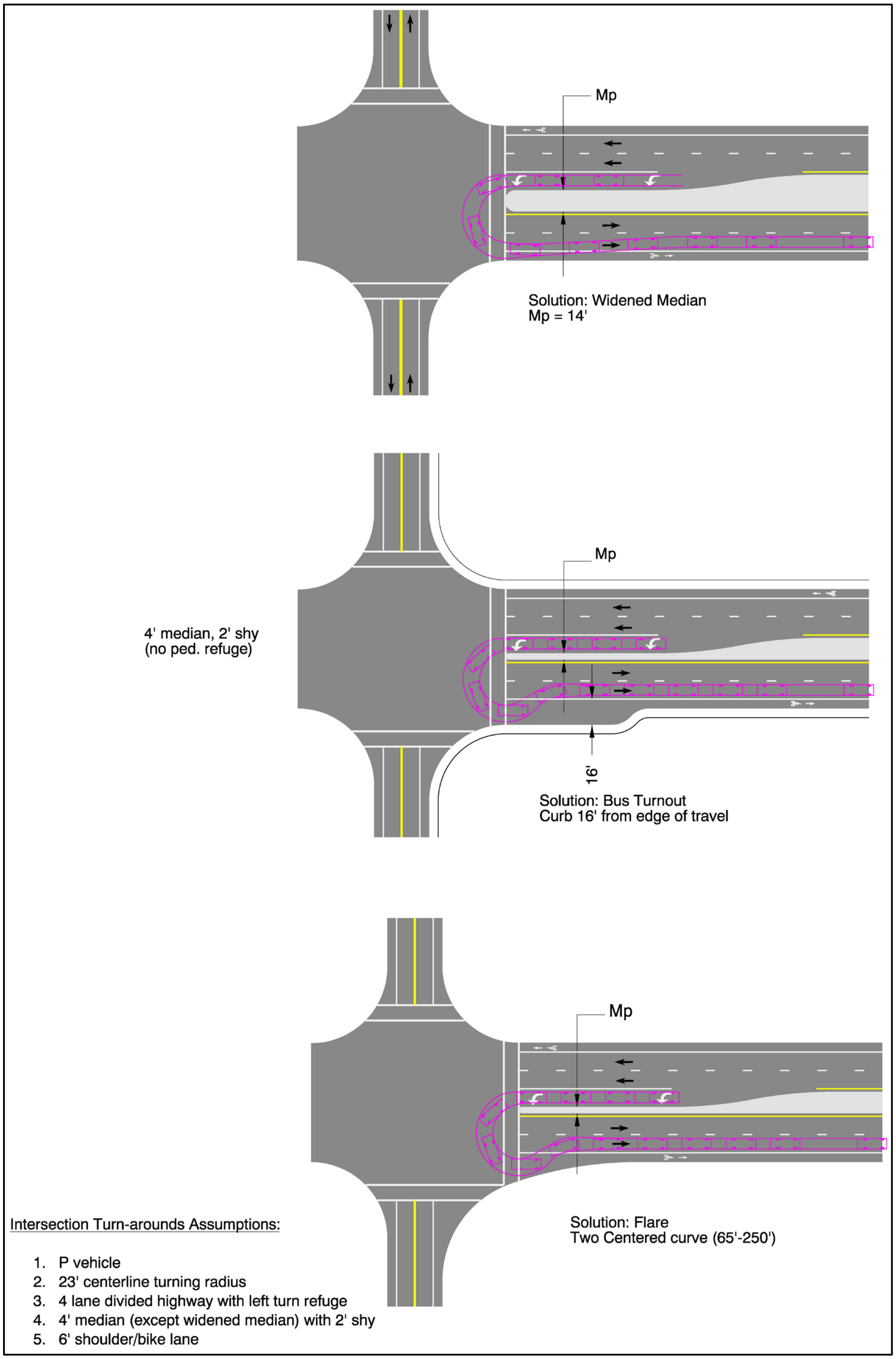
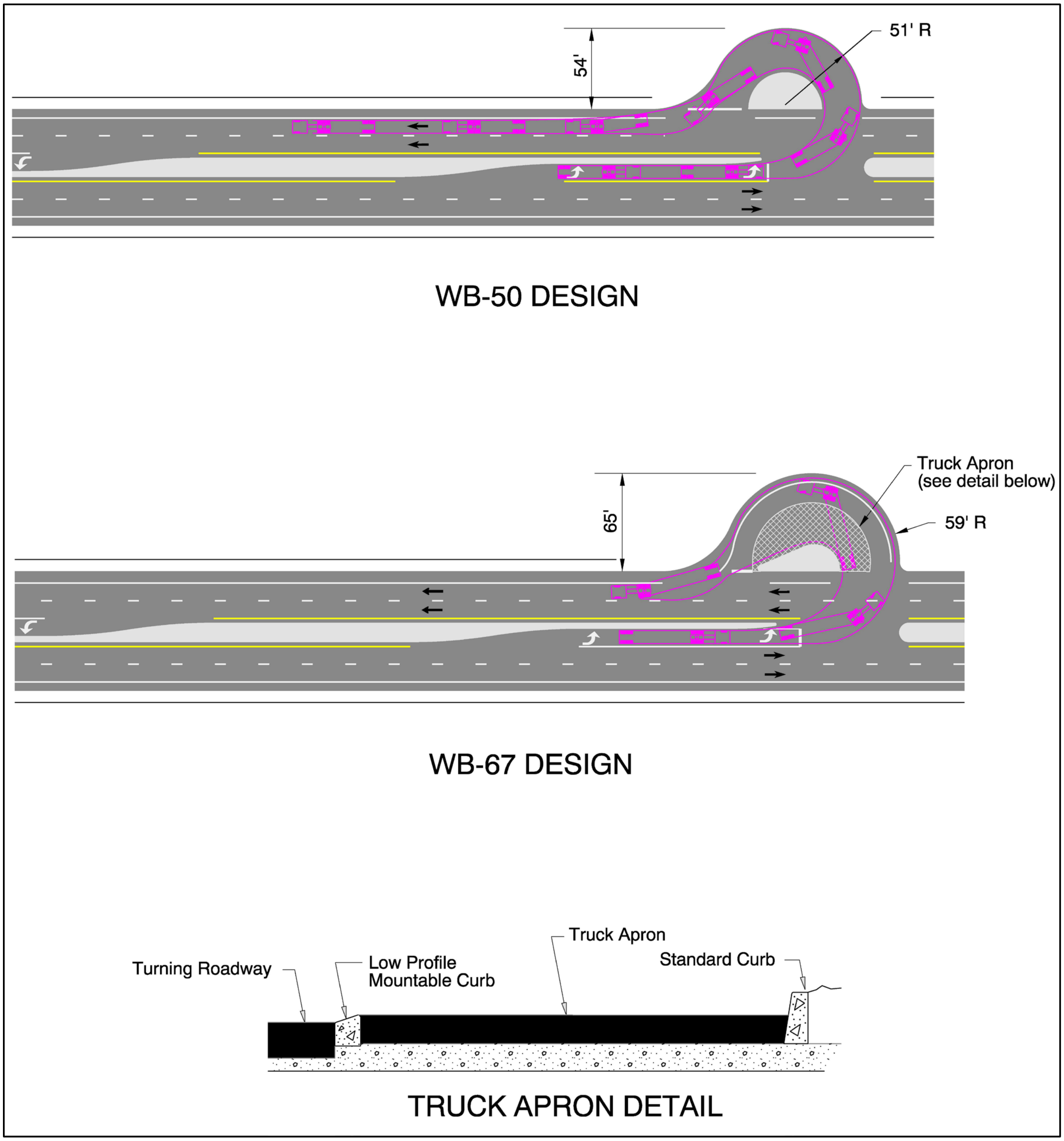


Figure 500-13: U-Turns at Mid-Block



504.7 Indirect Left Turns

One tool available is indirect left turns at intersections. In some situations, for operational capacity or safety reasons, it may be desirable to remove left turning traffic. The left turns are accomplished by other connections. The first option available is the use of a right side jug-handle just like the one described for U-Turns above. Vehicles wishing to turn left actually leave the highway on the right side then cross the highway. Generally, these designs are signalized to facilitate the crossing movement. Again, this particular type of jug-handle is only compatible with a left side "T" intersection.

A different type of indirect left turn design uses connecting roadways. This design concept is similar to the jug-handles described in the U-Turn section. Within this type of design are several options. These include the single quadrant and double quadrant. The single quadrant design provides one connecting roadway that provides for two way traffic operation. Location of the connecting roadway is dependent upon traffic flow characteristics, adjacent roadside development, need for intersection spacing, and signalization needs. The concept of the single quadrant design is to remove all left turning traffic from a specific intersection. The traffic uses the connecting roadway to gain access to the particular street. Location of the connecting roadway is critical to the operation on the highway, particularly if both intersections are to be signalized. Prior to design acceptance, the Traffic Engineering Services Unit and Transportation Planning and Analysis Unit (TPAU) should have reviewed the design concept through an engineering study, such as an Intersection Control Evaluation (ICE) and determined if the design concept is supported. The State Roadway Engineer approves the type of the traffic control for the intersection.

As mentioned previously, another option is the double quadrant design. This design is very similar to a jug-handle style interchange, except that the intersecting roadways are not grade separated. Again, turning traffic, generally left turns, use the connecting roadways. The roadways may provide for all movements or may be right in/right out only depending upon traffic capacity and safety needs. The Traffic Engineering Services Unit and TPAU should review and support this type of design prior to design acceptance. In addition, there may be access management issues on these connecting roadways. The Region Access Management Engineer should be consulted to identify and address these issues. In many situations, these last two design alternatives may be a phased approach towards grade separation in the future.

Section 505 Driveway Design

505.1 Design Requirements for Private Road Approaches

Private approaches are connections to adjacent businesses, residences, or other private roadways. Generally, private approaches provide access to/from the highway and an adjacent property across the highway right of way. These approaches service all land use types including residential, commercial, and industrial. Typically, private approaches in urban areas will use a 'dust pan' style approach. This style drops the curb and possibly the sidewalk to highway grade to allow vehicular access. ***Use Standard Drawings RD725 through RD750 when designing "dust pan" style private approach roads. For high volume driveways or driveways that are part of a signalized intersection, use a radius design style similar to that used by a public approach. Refer to Table 500-2 to determine the style of approach to be used. The Signal Design Manual, Section 5.1.6 has additional information for driveways at signals.***

There are three general types of private road approaches. These are:

- Type A Non-curbed, ditch section highway with radius style approach.
- Type B Curbed highway section with "dust pan" style approach.
- Type C Curbed highway section with radius style approach.

Design Type C private approaches in accordance with Section 506 General Intersection Design. The design of Types A and B are described below.

The design of private road approaches is affected by many factors. The type of access, volume of vehicles, type of vehicles, grades, alignment, and adjacent land use all influence the design. ***The spacing of approach roads should be consistent with the spacing guidelines specified in the Oregon Highway Plan, Appendix C. Use the Access Management Policy contained in the OHP and Oregon Administrative Rule (OAR) 734, Division 51 for spacing guidelines and other guidance pertaining to access management.***

1. ***All road approaches should be placed so that intersection sight distance is provided.*** The vehicle entering the traffic stream should have a view along the highway equal to the intersection sight distance for the design speed of the highway. **At a minimum, stopping sight distance for the design speed of the highway must be provided at all approaches.** For more information on intersection and stopping sight distances refer to the AASHTO Green Book and HDM Part 200, Section 217.4 for Intersection Sight Distance. ***Any proposed approach that cannot provide sight distance as required by Oregon Revised Statute (OAR) 734, Division 51 must obtain an approval from the Region Access Management Engineer (RAME)***. For more information related to access management deviations, see Section 503. Cut slopes may need to be widened and roadside vegetation removed to provide required sight distance.
2. ***Both public and private road approach grades should be designed so that drainage from the approach does not run on or across the traffic lane, shoulder areas, or sidewalk. The normal slope of the shoulder should not be altered.*** In urban areas where the drainage is along a curb and gutter, only the paved approach area to the right of way line may drain into the gutter. In the case of an approach below the street grade, a short vertical curve should be used to confine the drainage in the gutter line. In some instances, inlets may be required on each side of the approach to collect runoff without ponding or to ensure that roadway drainage does not leave the right of way. *For approach road design, provide a flat landing area for vehicles entering the highway for at least 20 feet from the edge of the*

shoulder. A grade of two percent is desirable for these landings and four percent is the maximum. Approach grades steeper than four percent should be carefully evaluated by the Designer.

3. **The maximum grade break between highway shoulder and approach is eight percent for Type A and B approaches.** *In addition, a 20 foot landing area should be provided.* In some situations, the maximum break cannot be met. When this is the design condition, the designer should attempt to achieve a roadway-to-approach transition as smooth as possible. This may require using a short vertical curve.

4. **The approach must at least accommodate the appropriate design vehicle.** Generally, commercial accesses are designed for at least a Single Unit (SU) truck design vehicle. Vehicles larger than an SU are not to be treated as the design vehicle unless 3 or more WB-40 or larger trucks are anticipated between 7:00AM and 7:00PM. ***Anytime the design vehicle is larger than a SU, the approach is designed as a radius style.*** When vehicles larger than an SU are anticipated, but are not the design vehicle as described above, the approach must accommodate the larger vehicle. (‘Accommodation’ only refers to the physical ability to make the maneuver including encroaching on other lanes, whereas ‘designed for’ means that design elements do not require encroachment. A site visit and discussion with maintenance personnel along with information gathered from property and business owners will help determine the appropriate design for an approach. (See Figure 500-3 for more detail concerning “design for” and “accommodate for”.)

5. **All approaches must be designed to aid in the longitudinal crossing of pedestrians.** It is preferable to maintain sidewalks at a continuous grade. However, without a buffer strip or set back to provide a ramp down area to street grade, this is nearly impossible. Route continuity is also important to pedestrians. If a curbside sidewalk cannot be set back for a significant longitudinal distance, it is best to leave it curbside rather than break up the pedestrian continuity. **Sidewalk cross-slope must be maintained at 2 percent or less for accessibility.** To meet this requirement approaches may need to be designed with more than one slope to transition from roadway grade to final approach grade. Roadway standard drawings in the RD700 series and RD900 series provide information and various design options for curb, sidewalk, and driveway design at approaches and curb ramps.

6. *All curbs and delineators used at approaches on highways without continuous curbs should be placed at the normal shoulder width from the edge of the traveled way to provide adequate shoulder adjacent to the approach.*

7. *Approaches on opposite sides of the highway should be located across from each other whenever possible. However, under high speed and or high traffic volume conditions, approaches may need to be offset to reduce the complexity and number of conflicts (see Figure 500-10).* In addition to reduction in conflict points, separating approaches breaks the crossing maneuvers into distinct steps and isolates them, reducing driver tasks and anxiety. When designing, the approaches need to be separated far enough that they operate independently outside

their functional areas (see Figure 500-1). Although this situation is possible at some high volume private approaches, this treatment is generally only appropriate for public road approaches. Not all intersection locations are good candidates for separated approaches. The Technical Services Roadway Engineering Unit and the Region Access Management Engineer should be contacted when considering separation of private approach roads. Major public roads with large volumes of through traffic should generally not be separated.

8. *Approach roads should not be constructed within the functional area of an adjacent intersection.* Refer to the Access Management Policies from the Oregon Highway Plan and OAR 734, Division 51 for more information on functional area (see Figure 500-1).

9. ***Where a private approach serves a high volume of traffic, additional design and/or traffic controls may need to be incorporated into the design.*** High volume approaches often will require channelization along the highway. Refer to Section 506 for details on left and right turn lanes. In some instances, the approach may require a traffic signal to operate safely and efficiently. A private approach located opposite of a signalized intersection forms an additional approach to the intersection and all approaches to a signalized intersection must be signalized. It is best to avoid this type of driveway configuration. However, when it is necessary, see the Signal Design Manual, Section 5.1.6 for guidance. The designer should work with the Region Access Management Engineer to determine solutions for high volume private approaches and potential private approaches opposite signalized intersections. Private approaches are not allowed directly opposite interchange ramp terminals.

   NOTE: All traffic signals must be approved by the State Traffic Engineer prior to installation. Generally, only public road approaches should be considered for signalization. Avoid signalizing private approaches.

10. *Type A approaches need to be designed to minimize the pedestrian longitudinal distance.* This may require the design to incorporate a two-centered curve rather than a single radius when accommodating design vehicles larger than a Single Unit (SU) truck.

11. *The approach design and corresponding site circulation plan should specify the entry/exit throat distance.* This throat distance is critical to provide an efficient and functional connection between the highway and adjacent property. Throat lengths are critical for commercial and industrial type land use approaches. The Transportation Planning Analysis Unit or the Region Access Management Engineer can assist with determining the appropriate throat distance. See Figure 500-2.

Table 500-2: Typical Private Approach Style and Width

Land Use Type	Approach Peak Hour Volume	Approach Style	Typical Throat Width[1]
Single Family Residential[2]	0 – 10	Dust Pan	16′
	11+	Dust Pan	24′
Multiple Family Residential	0 – 10	Dust Pan	16′
	11 – 150	Dust Pan	24′ – 28′
	151 – 300	Dust Pan[3]	36′ – 40'
	301 – 399	Radius[4]	Variable[5]
	400+	Radius	Variable[5]
Commercial	0 – 20	Dust Pan	24′
	21 – 150	Dust Pan	28′ – 32′
	151 – 300	Dust Pan[3]	36′ – 46′
	301 – 399	Radius[4]	Variable[5]
	400+	Radius	Variable[5]
Industrial		Dust Pan/Radius[6]	Variable[5]
Special Uses[7]		Radius	Variable[5]

1 The typical throat widths are only to be used as guides to the designer or permit specialist. The throat width needs to be checked to ensure traffic movements are accommodated acceptably.

2 Generally, multiple single-family residences don’t share a single approach unless they are on a public road.

3 The dust pan style designs are primarily to be used. However, a radius style may be used if the traffic composition at the driveway contains a substantial number of recreational vehicles, buses, and single unit trucks, and the highway posted speed is greater than 35 mph, or access spacing each side is 660 feet or more.

4 The radius style design should generally be used. However, a dust pan style may be considered where the highway posted speed is 30 mph or less and access spacing is 165 feet or less.

5 The typical width is variable dependent upon approach style, design vehicle, and number of lanes.

6 Special care should be used when determining the appropriate style. Some industrial uses operate similar to commercial uses and should use commercial style approaches and dimensions. Heavy industrial/warehouse uses that serve significant truck volumes should use a radius style.

7 Special Uses include developments such as truck stops, amusement parks, stadiums, distribution centers, etc.

Section 506 General Intersection Design

506.1 General Design Considerations

This section describes the standards and guidelines for the geometric design of traditional at-grade intersections including lane widths, shoulders, superelevation, skew angles, turning radii, left turn lanes, right turn lanes, channelization islands, curb extensions, and bicycle and pedestrian needs. Context of the roadway and roadside is important to the final intersection design. Contextual factors in the design of intersections include the adjacent land use, urban or rural condition, vehicle speeds, traffic volumes and highway operation. The ODOT Practical Design Policy of Safety, Corridor Context, Optimize the System, Public Support and Efficient Cost (SCOPE) can aid in applying context design to a project. (See ODOT Practical Design Strategy.)

Specific design issues and concerns related to signalized and unsignalized intersections are discussed in Section 507 and Section 508 respectively. The design standards and considerations for modern roundabouts are contained in Section 509.

506.2 Approach Grades

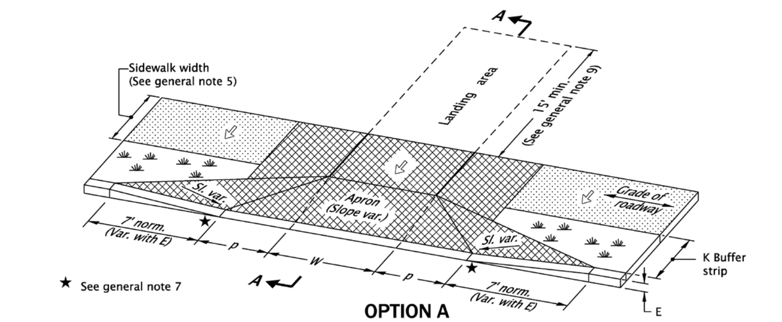
There are two types of approaches to state highways. Public road connections are one type of approach and private approaches such as driveway connections are the second category. *For public roads, the approach grades of intersecting roadways with a state highway should be kept to a minimum. It is undesirable to have road connections along superelevated curved sections of state highway and these connections are discouraged. When this type of connection cannot be avoided, special care must be taken by the designer to provide an adequate connection.* It is preferable to have a relatively flat or slightly elevated roadway connecting with a state highway. This helps improve the visibility of the intersecting roadway and can also help control highway drainage.

In order to effectively match intersecting roadway grades with state highway grades, vertical curve alignments should be used on all approach connections. *Generally, the intersecting roadway's vertical alignment should match with the cross slope of the highway if the cross slope is less than 3 percent. Where the cross slope is equal to or greater than 3 percent a small break in the grade or vertical curve at the outer edge of shoulder not exceeding 2 percent may be acceptable. In addition, a 20 foot paved landing should be provided to aid an entering vehicle transition to the highway.* The goal is to provide a connection that does not require vehicles to stop and enter the highway from a steep grade. The flatter the approach, the better, particularly for large vehicles. *Due to acceleration and deceleration characteristics of various vehicle types using public roadways, grades of public road approaches at state highway connections greater than 3 percent should be avoided*. However, in many locations due to existing terrain or right-of-way constraints, constructing approach grades less than or equal to 3 percent may be costly or infeasible to accomplish. In these locations, a more practical threshold would be to provide a maximum grade on the connecting road of 6 percent. *In locations where the connecting approach grade exceeds 6 percent, special care needs to be taken by the designer to provide adequate vertical transition from the steep road approach to the highway grade.*

Due to typically expected operating conditions, driveway approaches to state highways can be constructed with greater differential changes in grade than public roadway connections. Figure 500-14 and Figure 500-15 provide design and layout information for an approach with sidewalk and without sidewalk. Additional information and options about the design and layout of sidewalks and driveway approaches is available from Oregon Standard Drawings. Pertinent standard drawings include RD715, RD720, RD721, RD725, RD730, RD735, RD740, RD745 and RD750.

Regardless of roadway connection type, where a marked or unmarked crosswalk exists, the allowable cross slope is dependent on intersection control type. The best practice for new construction is 2 percent or less to meet accessibility requirements. Crosswalks, whether marked or unmarked, exist across each approach to an intersection. See HDM Section 802 for crosswalk location determinations. Figure 500-16, HDM Part 800, and the Oregon Standard Drawing RD900 series provide information about curb ramps. In addition, adequate sight distance must be provided at all road connections.

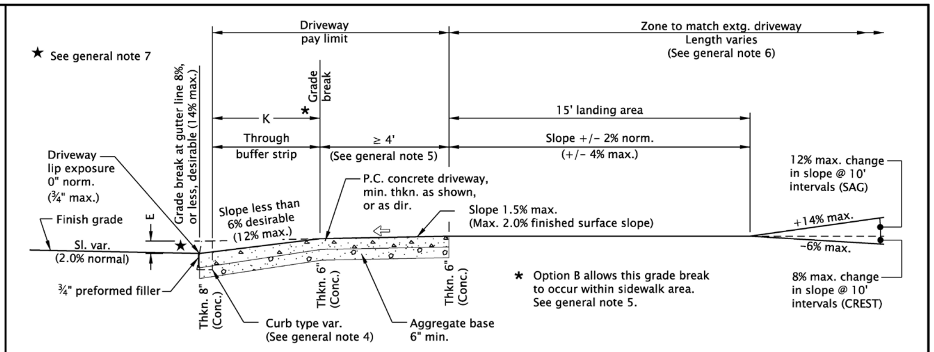
Figure 500-14: Driveway Approaches with Sidewalks



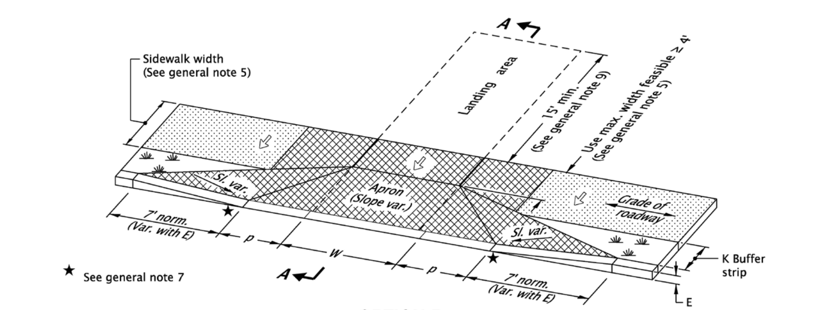
OPTION A

TYPICAL SEPARATED SIDEWALK DRIVEWAY

(Use one of the options below if slope requirements shown in Section A–A cannot be met)

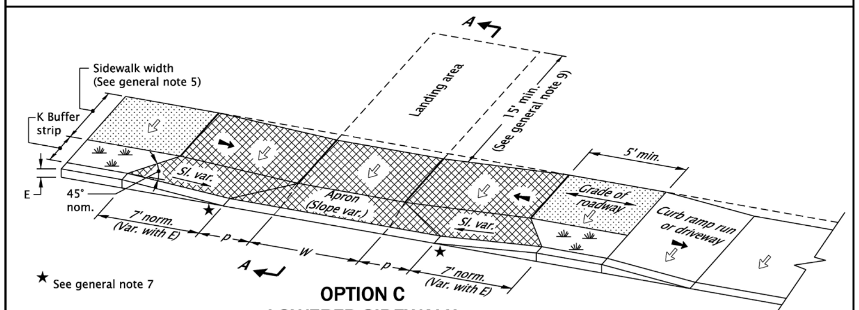


SECTION A-A



OPTION B

DRIVEWAY ENCROACHES INTO SIDEWALK



OPTION C

LOWERED SIDEWALK

GENERAL NOTES FOR ALL DETAILS ON THIS SHEET:

1. Details are based on applicable ODOT Standards.
2. Only use details allowed by jurisdiction.
3. The following dimensions are as shown on plans, or as directed: driveway width, driveway slope, sidewalk width, buffer strip width, curb exposure, driveway lip exposure, landing area length and width. See project plans for details not shown.
4. Curb, gutter, and sidewalk types varies, see plans.
   See Std. Dwgs. RD700 & RD701 for curb details.
   See Std. Dwg. RD721 for sidewalk details.
   See Std. Dwg. RD722 for joint details.
5. A greater than or equal to 4' unobstructed clear passage with cross slope 1.5% max. (Max. 2.0% finished surface slope) is required behind driveway apron. Sidewalk profile grade of the pedestrian accessible route shall not exceed the adjacent roadway profile grade.
6. Where existing driveway is in good condition, and meets slope requirements, construct only as much landing area as required for satisfactory connection with new work.
7. Check the gutter flow depth at driveway locations to assure that the design flood does not overtop the back of sidewalk at driveway. If overtopping occurs place an inlet at upstream side of driveway or perform other approved design mitigation.
8. Construct a full deph expansion joints with ½" (In) preformed joint filler at ends of each driveway. Tooled joints are required at all driveway slope break lines.
9. 15' min. of the driveway behind the sidewalk should be surfaced to prevent tracking of gravel onto the sidewalk.

LEGEND:

- Sidewalk
- Driveway pay limit (See project plans for details not shown)
- ⇦ Cross slope 1.5% max. (Max. 2.0% finished surface slope) (Normal sidewalk cross slope)
- ← Running slope 7.5% max. (Max. 8.3% finished surface slope)
- W Width of driveway
- K Buffer strip width (5' normal, 3' min.)
- E Curb exposure
- p 7.0' in commercial land use types; 3.5' in residential land use types

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING SECTION

SEPARATED SIDEWALK DRIVEWAYS OR ALLEYS (OPTIONS A, B & C) ODOT HIGHWAYS

HIGHWAY DESIGN MANUAL

Figure 500-15: Driveway Approaches Without Sidewalks

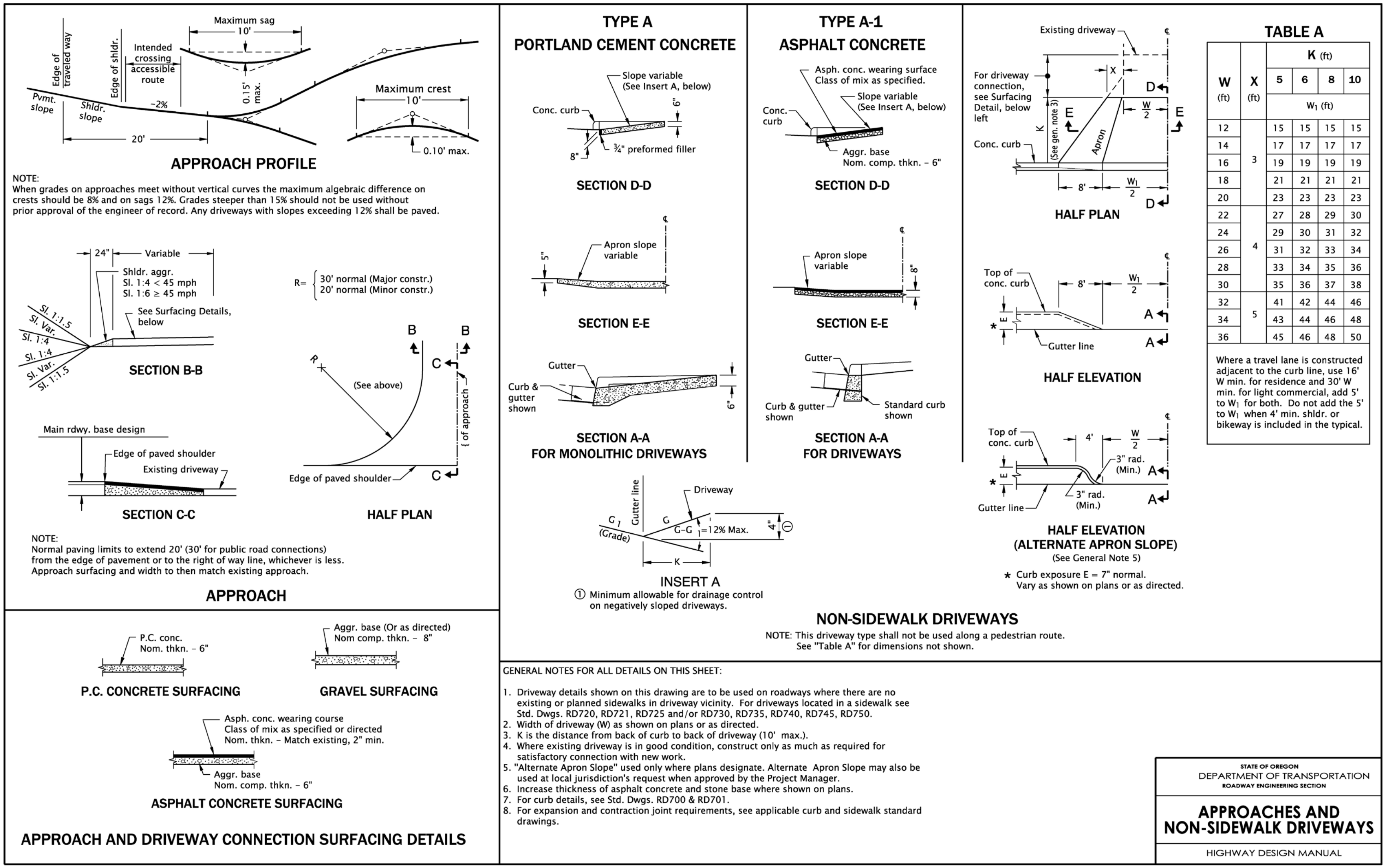


TABLE A

W (ft)	X (ft)	K (ft) 5	6	8	10
		W_1 (ft)			
12	3	15	15	15	15
14		17	17	17	17
16		19	19	19	19
18		21	21	21	21
20		23	23	23	23
22	4	27	28	29	30
24		29	30	31	32
26		31	32	33	34
28		33	34	35	36
30		35	36	37	38
32	5	41	42	44	46
34		43	44	46	48
36		45	46	48	50

Where a travel lane is constructed adjacent to the curb line, use 16' W min. for residence and 30' W min. for light commercial, add 5' to W_1 for both. Do not add the 5' to W_1 when 4' min. shldr. or bikeway is included in the typical.

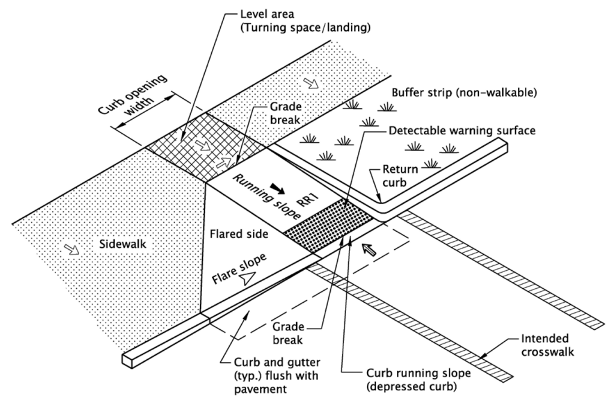
GENERAL NOTES FOR ALL DETAILS ON THIS SHEET:

1. Driveway details shown on this drawing are to be used on roadways where there are no existing or planned sidewalks in driveway vicinity. For driveways located in a sidewalk see Std. Dwgs. RD720, RD721, RD725 and/or RD730, RD735, RD740, RD745, RD750.
2. Width of driveway (W) as shown on plans or as directed.
3. K is the distance from back of curb to back of driveway (10' max.).
4. Where existing driveway is in good condition, construct only as much as required for satisfactory connection with new work.
5. "Alternate Apron Slope" used only where plans designate. Alternate Apron Slope may also be used at local jurisdiction's request when approved by the Project Manager.
6. Increase thickness of asphalt concrete and stone base where shown on plans.
7. For curb details, see Std. Dwgs. RD700 & RD701.
8. For expansion and contraction joint requirements, see applicable curb and sidewalk standard drawings.

Figure 500-16: Typical Curb Ramp Components and Legend

CURB RAMP INDEX

STD. DWG. NO.	STD. DWG. TITLE
RD900	Curb Ramp Components And Legend
RD901	Curb Ramp Legend And Corner Identification
RD902	Detectable Warning Surface Details
RD904	Detectable Warning Surface Placement For Curb Ramps
RD905	Detectable Warning Surface Placement For Directional Curbs
RD906	Detectable Warning Surface Placement For Accessible Route Island
RD908	Detectable Warning Surface Placement
RD909	Detectable Guide Strip Placement At Bike Ramps
RD910, RD912	Perpendicular Curb Ramp
RD913	Perpendicular Curb Ramp With Closure
RD916	Perpendicular Curb Ramp Single Ramp
RD920	Parallel Curb Ramp
RD922	Parallel Curb Ramp Single Ramp
RD930, RD932 & RD936	Combination Curb Ramp
RD938	Combination Curb Ramp Single Ramp
RD940	Blended Transition Curb Ramp Single Ramp
RD950 & RD952	End Of Walk Curb Ramp
RD960	Unique Curb Ramp



TYPICAL CURB RAMP SYSTEM COMPONENTS
(PERPENDICULAR TYPE SHOWN)

LEGEND:

- Marked or intended crossing location
- Sidewalk or other traversable surface
- Detectable warning surface (DWS)
- Level area (Turning space/landing)
- Cross slope 1.5% max.
  (Max. 2.0% finished surface slope)
  (Normal sidewalk cross slope)
- Running slope 4.0% max.
  (Max. 4.9% finished surface slope)
- Running slope 7.5% max.
  (Max. 8.3% finished surface slope)
- Counter slope 4.0% max. ascending or descending
  (Max. 5.0% finished surface slope)
  Slope as required for drainage
- Flare slope
  (Max. 10.0% finished surface slope)
- 4'x4' clear space
- RR1 Ramp Run Position 1

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING SECTION

CURB RAMP COMPONENTS AND LEGEND

HIGHWAY DESIGN MANUAL

506.3 Travel Lane Widths

Travel lane width through an intersection needs to remain constant. In general, the through travel lane width at rural high speed, channelized intersections is 12 feet as shown in Figure 500-19. For specific locations, the appropriate travel lane width is determined by the location (rural or urban), design speed, volume of trucks, highway designation and alignment. *Use the rural or urban highway design sections of this manual to determine the appropriate through lane width.* In most urban locations and Special Transportation Area (STA) designated roadway sections, 11-foot travel lane width is preferred, depending on functional classification, volume and nature of traffic, pedestrian mobility, freight mobility and accessibility goals. In other urban locations with significant constraints, 11-foot travel lane width may be allowable. See Part 200 and Part 300 for guidance on the use of lane widths less than 12 feet. **However, travel lane widths shall not be reduced through an intersection. Lane width approaching an intersection is to be maintained through the intersection.**

When an intersection is a part of or connecting to a turning roadway, the lane widths may need to be increased to allow for large vehicle off tracking. Refer to chapters 3 and 9 of the AASHTO Green Book for more details of turning roadways.

Any reductions in existing lane widths will need to be investigated for freight mobility issues and comply with ORS 366.215, Creation of state highways; reduction of vehicle-carrying capacity. For guidance in complying with ORS 366.215, see ODOT guidance document "Guidelines for Implementation of ORS 366.215, No Reduction of Vehicle-Carrying Capacity" and the "ODOT Highway Mobility Operations Manual".

506.4 Travel Lane Alignment

Similar to through travel lane width, travel lane alignment should remain constant through an intersection. *If a proposed design creates misalignment of lanes across an intersection, rather than introducing angle points that create abrupt deflections to vehicle pathways across the intersection, a better design option would be to incorporate slight alignment and striping changes upstream and downstream of the intersection to better transition lanes smoothly, thereby effectively reducing or eliminating the lane shift.* The alignment changes upstream and downstream should provide curvature to smooth the transition. This is particularly true with intersections on curves. Shifting of lanes through signalized or stop controlled intersections is strongly discouraged and should only be done when site constraints make it infeasible to keep lane alignment consistent. **Travel lanes on the mainline highway shall not be shifted at uncontrolled intersections.**

At signalized intersections, lane lines should line up through the entire intersection and not be offset. This helps to not only discourage unintentional lane changes through the intersection area, but also minimizes the possibility of a driver inadvertently encroaching on the adjacent lane. ***However, in cases where it is deemed necessary to shift a lane through a signalized intersection, refer to the following guidance provided in the remainder of Section 506.4 and Figure 500-17 (Travel Lane Offset Layout) for discussion of potential lane offset.***

Guidance for Lane Shift when deemed necessary:

Posted Speed Limit Less than 30 mph:

Maximum Offset – 4 feet

Posted Speed 30 mph to 35 mph:

Maximum Rate of Change Across Intersection – 1ft. lateral in 20 ft. longitudinal

Maximum Offset - 4 feet

Posted Speed 40 mph to 45 mph:

Maximum Rate of Change Across Intersection – 1ft. lateral in 30 ft. longitudinal

Maximum Offset – 3 feet

Posted Speed Greater Than 45 mph:

No Offset Permitted Across Intersection

Shifted travel lane rate of change is measured in the direction of travel between marked crosswalks by projecting a line along the center of the entering travel lane from the closest crosswalk stripe entering the intersection to the farthest crosswalk stripe exiting the intersection. If no crosswalk is present, then project a line perpendicular from the end of the lane striping to the center of the travel lane entering the intersection to determine a beginning measuring point for the lane shift and rate of change distance. Since most controlled intersections without a marked crosswalk should have a stop bar present, the stop bar with respect to the travel lane center could also be used as an alternate method to determine a starting point. In either method, the ending point is the intersection of the projected entering lane center and the intersection of the furthest crosswalk stripe exiting the intersection. If no crosswalk is present on the exiting side of the intersection, then project a perpendicular line from the beginning of the lane striping leaving the intersection to the center of the shifted lane to determine the end point. In all cases the rate of change shall be applied evenly across the entire distance along the projected center of the entering travel lane.

Travel lane offset is measured from the center of the travel lane entering the intersection to the center of the shifted travel lane exiting the intersection. For multi-lane roadways, all travel lanes in the same direction shall be offset equally and remain parallel to one another unless site specific constraints make this infeasible. For locations where lanes cannot be shifted equally or cannot remain parallel to one another, contact Region Roadway and Traffic staff or Technical Services Traffic and Roadway Engineering Section staff for guidance.

For stop-controlled intersections, the maximum offset that may be applied is 4 feet across the intersection.

When lanes are shifted through an intersection, care must be taken to ensure that adequate space is maintained between travel lanes and roadway features like curbs; raised median islands, signs, illumination or signal poles, etc. All proposed lane shift designs must be reviewed by appropriate staff in the Region Traffic and Region Roadway sections as well as appropriate Traffic and Roadway staff in the Technical Services Traffic and Roadway Engineering Sections regardless of proposed lane shift amount. Agreement for the lane shift is required from the Region Roadway Manager/Engineer, the Region Traffic Manager/Engineer and the Technical Services Traffic and Roadway Sections.

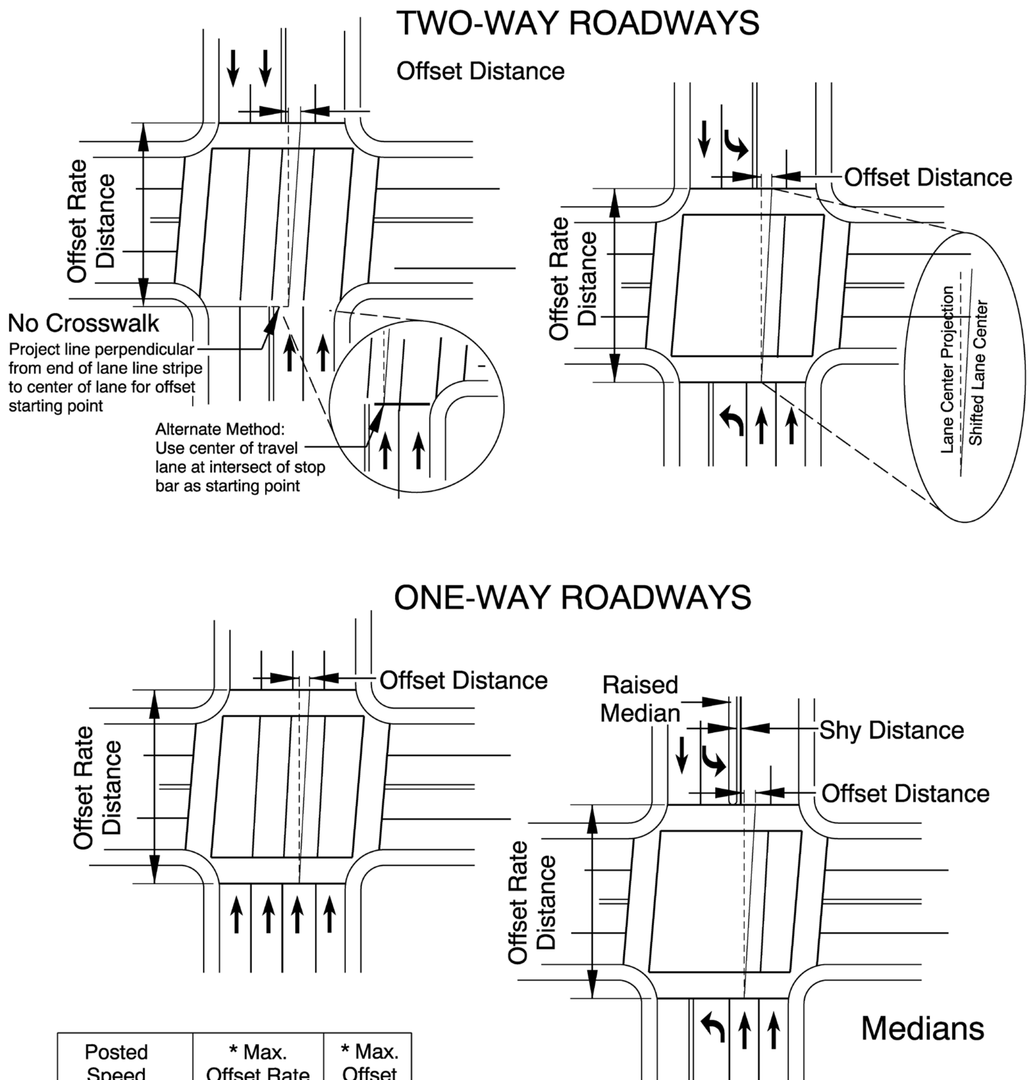
At signalized intersections, excessive shifting of lanes may cause signal head misalignment with their respective lanes. ***Signal heads should be shifted to match the lane shift. If this cannot be accomplished, then lane shift shall be limited to a maximum of two feet with approval from the Region Traffic Engineer.***

If shifting lanes through a signalized intersection is necessary, an option for mitigation is to carry some form of lane marking, generally dotted striping, through the intersection to inform drivers of the shift and help keep them aligned with the lanes. Contact the Region Traffic Section for appropriate use of lane markings through the intersection.

Providing guidance for layout of lane offset at intersections in this manual does not imply agreement to any specific design proposal. It is the designer's first responsibility to provide a design that transitions a vehicle from one side of an intersection to the other smoothly. Only after it has been demonstrated and determined through the review process that a smooth transition is not feasible will a design incorporating a lane shift be considered as a viable option. Figure 500-17 illustrates travel lane offset layout when a shift of the travel lane is necessary.

Figure 500-17: Travel Lane Offset Layout

TRAVEL LANE OFFSET LAYOUT



Posted Speed (mph)	* Max. Offset Rate (ft./ft.)	* Max. Offset (ft.)
less than 30	——	4
30-35	1 in 20	4
40-45	1 in 30	3
Over 45	Not Permitted	

* All Lane Offset Proposals Shall be Reviewed for Agreement by Appropriate ODOT Staff. See Text, section 506.4

Note:

1) Drawings on this page reflect general layout of lane offset measurement for illustrative purposes. For intersections that include other conditions such as curved alignments, varying lane widths, or other site specific design elements, it is the designer's responsibility to follow as closely as possible the travel lane offset parameters outlined in section 506.4. Contact Region Roadway staff or Technical Services Roadway staff for guidance.

2) Lane shift parameters apply to both left or right offsets of the travel lane.

506.5 Travel Lane Continuity

Lane continuity is also important for effective traffic flow at an intersection. *When a through lane drops downstream of an intersection, adequate length of the lane being eliminated needs to be established to allow the two traffic streams to merge safely and effectively as well as to allow for standard signing and striping of the lane drop.* This distance may vary by location due to specific intersection operation, number of downstream access points, on-street parking or other constraints. Each location needs to be thoroughly investigated and an appropriate length determined. Failure to provide adequate length for necessary maneuvers may impact intersection operation and expected capacity due to uneven lane balance. Anticipated lane utilization through the intersection may not occur if it is too difficult to merge downstream. Drivers familiar with the intersection may be reluctant to use the lane that is dropping if they have had difficulties merging downstream in the past and they may choose to merge into the other through lane prior to the intersection. This is particularly true for locations where a through lane is added just prior to the intersection to increase intersection capacity and then immediately dropped downstream of the intersection. Consult the Region Traffic Engineering Unit and the ODOT Transportation and Analysis Unit (TPAU) to provide information about appropriate merge length.

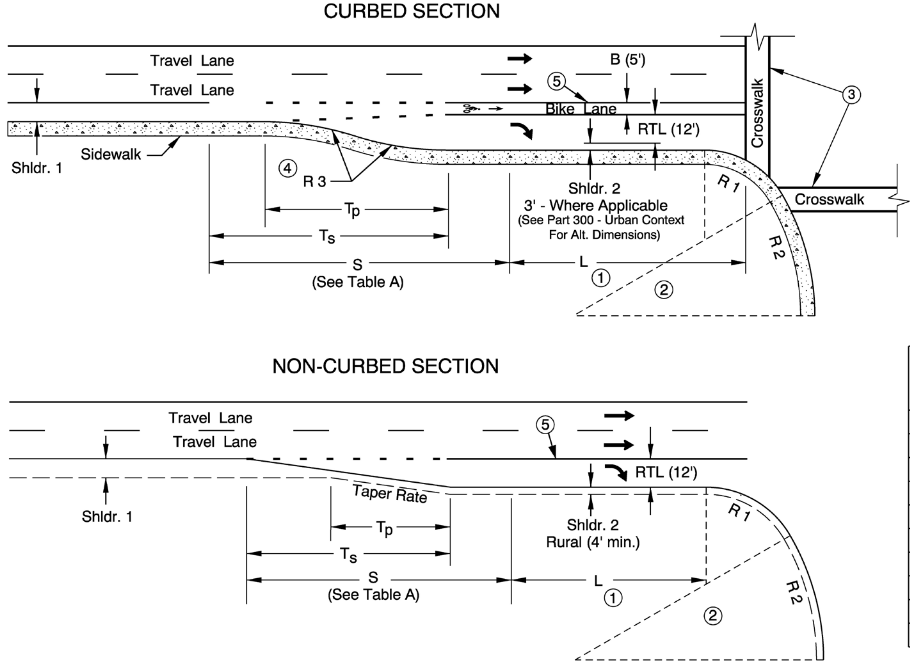
506.6 Shoulder Widths

As with travel lanes, the width of shoulders should generally remain constant through an intersection. However, two-lane highways that are flared to provide left turn channelization may require shoulder width modifications. Urban and rural design criteria will determine appropriate shoulder width at specific locations. Standard shoulder width should be utilized through rural and higher speed intersections. **In constrained locations where left turn channelization is being considered, the shoulder width may be reduced, but shall be no less than 4 feet in rural locations.** Reduction of shoulder width below the design criteria width may require a design exception. For urban shoulder width, See Part 200 and Part 300 for design criteria.

When only a minimum 6-foot bicycle lane is provided adjacent to the highway, reducing shoulder width requires discussion about bicycle accommodation needs. Part 900 and the Oregon Bicycle and Pedestrian Design Guide provide information about shoulder widths and consultation with the ODOT Bicycle and Pedestrian Design Engineer or the project resource for active transportation may provide additional appropriate design options. Shoulder widths will also require modifications where the intersection includes a right turn lane. If the design is providing only a minimum 6-foot bicycle facility adjacent to the highway, then shoulders should be designed to match the dimensions of Figure 500-18. This would provide only a minimum level of design. ***Highway projects should provide the highest appropriate level of bicycle and pedestrian facilities possible within project scope and funding.*** Consider separated and protected bicycle facility design options. On projects where funding categories limit project scope to specific items, there may be other sources of funding that can be allocated to include bicycle and pedestrian improvements. Contact the region Active Transportation Liaison to determine bicycle and pedestrian facilities appropriate for the project and to determine if alternate funding sources are available for even greater improvements to the bicycle and pedestrian networks along the highway.

Figure 500-18: Right Turn Channelization

To be used in locations where a traffic investigation has determined a right turn lane to be warranted.



1. Minimum Storage Length 'L'
   Unsignalized:
   Provide 50' minimum beyond end of 'T_S' distance.
   Signalized:
   Determined by traffic study.
2. Compound radii accomodate large design vehicles, yet minimize pedestrian crossing distance. See discussion on accommodating vs designing for the design vehicle under Turning Radii in this chapter.
3. See Traffic Section for placement of crosswalk.
4. R 3 for reversing curves used only in curbed sections.
5. Through bike lane is generally constructed and striped in sections with a posted speed of 45 mph or less, even where there is no approaching shoulder or bike lane. See Oregon Bicycle and Pedestrian Design guide.

TABLE A

Design Speed (mph)	Taper Rate(*)	S (ft.)
25	8:1	155
30	8:1	155
35	9:1	175
40	10:1	190
45	11:1	215
50	12:1	265
55	13:1	320
60	14:1	385
65	15:1	450
70	15:1	520

* For Freeway Ramps See Section 605.9

DESIGN EQUATIONS AND VARIABLES

S = Deceleration distance for initial speed

T_P = Pavement or Curb Taper Length = Taper Rate x [(B + RTL) + (Shldr. 2 - Shldr. 1)]

T_S = Striping Taper Length = Taper Rate x (B + RTL)

R 3 = Reversing Curve Radius

$$= T_P \times \frac{\text{Taper Rate} + \frac{1}{\text{Taper Rate}}}{4}$$

B = Bicycle Lane Width (5' typ.)

RTL = Right Turn Lane Width (12' typ.)

DESIGN PROCEDURE

1. Decide on values for 'B', 'RTL', 'Shldr.1' and 'Shldr.2'
   For Urban Contexts, See Parts 307 through 312 for dimensions
2. Determine 'S' from Table A
3. Calculate 'T_S'
4. Determine 'L' (see note 1). For unsignalized intersections, check to see that $S - T_S \geq 50'$. If so, L = 0. If not, $L = 50 - (S - T_S)$.
5. Calculate 'T_P' for layout of curb or edge of pavement

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING SECTION

RIGHT TURN CHANNELIZATION

HIGHWAY DESIGN MANUAL

506.7 Intersections on Curves and Superelevation

An intersection should not be located within a horizontal curve. Intersections on curves present design challenges that affect superelevation, sight distance, driver comfort and vehicle stability. However, in many existing situations, intersections are present within highway curves and in many of these locations, these connections cannot be effectively relocated. Signalized intersections in curves compound operational problems, as well. Stopping traffic on steep cross slopes determined by main line design superelevation needs is undesirable due to the potential for slippage under ice conditions or potential load shifting on trucks. *Intersection Sight Distance (ISD) should be achieved at all intersections.* **Stopping Sight Distance (SSD) shall meet the minimum requirement.**

When an intersection occurs within a highway curve, the highway superelevation should be kept to a minimum. However, the highway still needs to provide for safe movement of traffic through the intersection at highway speeds. As a result, the designer must balance the superelevation need of traffic on the main line in free flow conditions with operational issues of the intersection. In these types of locations, some designers prefer to merely limit maximum superelevation to 4 percent. However, in some cases, trying to hold the superelevation to 4 percent or less may result in design speeds less than desirable for a specific highway. A better solution is to determine an appropriate superelevation for a specific location based on needs at that location.

At a minimum, the superelevation at an intersection should provide speeds determined from the Comfort Speed matrix shown in Part 300 equal to the desirable design speed. This means that if the design speed for the highway segment is 45 mph, then the comfort speed for the curve at the desired superelevation must be at least 45 mph.

> <u>Example</u>:
>
> Using the Suburban Superelevation & Spiral Lengths in Part 300 and a design speed of 45 mph with an 8 degree curve, the design superelevation would be 6 percent. This may be an undesirable condition with a signalized intersection on a curve. An alternative is to use the Comfort Speed values. Entering the table for an 8 degree curve and following across the row until the column for 45 mph is reached returns a 4 percent superelevation. This would reduce the design superelevation by 2 percent and may be an acceptable option.

Reducing superelevation should not compromise the overall geometry of the alignment and subsequently create a new problem while using an alternate superelevation design. **A design exception is required to utilize an alternate superelevation design based on Comfort Speed in relation to Design Speed.** It is critical to ensure that connections on the high side of a superelevated highway curve provide an approach with adequate sight distance. Ideally, intersection sight distance should be provided. Where this is not feasible or practical, as a minimum, stopping sight distance must be provided.

Another important consideration in designing a road connection on the high side of a horizontal main line curve is the comfort factor for side road traffic. Operation of the main line is the first concern, but it is important to create a comfortable transition across the superelevation for the traffic entering onto the main line. Where possible, keeping superelevation to a minimum on the main line while establishing grades on the connecting road to minimize vertical and lateral movement inside the vehicle entering onto the main line is desirable.

In addition to consideration of vehicles entering from the side road to the main line, main line traffic turning dynamics at intersections on curves must be evaluated as well. Main line turning vehicle dynamics and driver comfort also benefit from minimum superelevation when making turns onto side roads. Main line vertical grade can have great effect on turning dynamics. Negative (downhill) grades in conjunction with horizontal curvature and its respective superelevation can exacerbate turning forces acting on a vehicle. Not only can these forces be uncomfortable for drivers and passengers, in the case of trucks or other vehicles with higher centers of gravity like RVs and buses, these forces can cause loads to shift or, in extreme cases, cause roll over crashes.

When it is necessary to design or improve an intersection located on a horizontal curve, it is important to carefully analyze the interaction of the horizontal curvature and superelevation with all intersecting grades, grade breaks and vertical alignments on both the side road and the main line in relation to anticipated vehicle turning movements and dynamics. It is important to keep these forces and reactions to a minimum and within acceptable levels to ensure safe and effective operation of the intersection.

Intersections on horizontal curves can produce problems for pedestrians as well. Care must be taken to ensure sight lines to crosswalks provide ample vision for drivers to see pedestrians and for pedestrians to see approaching vehicles and adequately evaluate the approach speed and the time needed to cross the roadway.

506.8 Skew Angles

Roadway connections with a state highway should intersect at a 90-degree angle. 90-degree intersections maximize sight distance, improve safety, increase efficiency, and improve operations and safety of bicycle and pedestrian movements. In some situations, however, obtaining a 90-degree intersection is impractical or has excessive cost. Where this is the case, skewed intersections may be unavoidable. Skew angles of up to 30 degrees from perpendicular may be justified. However, the amount of skew should be held to a minimum. Figure 500-27 shows an intersection with excessive skew and the intersection reconfigured to improve skew. Figure 500-28 shows skew configuration with right turn lanes and islands to accommodate pedestrian movements. The presence of large trucks needing to negotiate this type of intersection can have direct effect on the final design layout.

Several factors can help determine the amount of skew that is acceptable for any particular intersection. ***Intersections with all or most of the following characteristics might justify allowing a skew angle of up to 30 degrees.***

- Highway speeds are low, generally 35 mph or less;
- Volumes on both the highway and intersecting roadway are low (at or below left or right turn channelization warrant limits);
- Large vehicle turning movements are minimal;
- Intersecting roadway has a functional classification of minor collector or below, and
- Intersection sight distance is available.

For all other intersections not meeting criteria on this list, the maximum skew should be held to 15 degrees from perpendicular. Refer to the AASHTO 2018 Green Book, Chapter 9 for possible alignment solutions to skewed intersections. Chapter 9, Figure 9-18, page 9-59 provides information on sight triangles as skewed intersections.

506.9 Turning Radii

Turning radii are one of the most important design elements of intersections. The operations, safety, and efficiency of an intersection are controlled by the turning movements. If the turning vehicles are geometrically limited from completing the maneuver properly, the intersection may break down, capacity is limited, and crash potential may increase.

The appropriate design vehicle must be identified prior to designing the intersection turning movements. *Selection of the appropriate design vehicle can sometimes be difficult. Issues to take into consideration in choosing a design vehicle include number and type of trucks, functional classification of the intersecting roadways, surrounding land use, consideration of future changes in land use and traffic, freight route designation, etc.* See Part 200 and Part 300 for additional information on design vehicle selection. After determining the appropriate design vehicle, a decision needs to be made as to the level of design accommodation. In other words, is the intersection radii to be designed for the design vehicle or merely to accommodate the design vehicle? The concept of designing for the design vehicle is to provide a path for the vehicle that is free of encroachments upon other lanes. Providing a design that only accommodates the design vehicle means that some level of encroachment upon other lanes is necessary for the vehicle to make a particular movement (see Figure 500-3). An example of an intersection that would need to be designed for trucks with no encroachment into adjacent lanes would be a stop-controlled intersection with a state highway, the highway being two lane or multi-lane with higher speeds and/or high traffic volumes. If a traffic study concludes that finding a gap in multiple traffic flows is not possible, the intersection would need to be designed for the design vehicle so that the truck driver can turn from his lane into a single lane. *Other factors to consider in turning radii are the effects on pedestrians and bicycles. Large radii create long crossing distances with increased exposure times and* *may add time to signal timing cycles. Large radii can also result in higher speed turns.* ***When it is necessary to design the intersection with large radii for larger vehicles, a balance needs to be obtained between the necessary radii and impacts to all intersection users.*** See Section 502.2 for accommodation for design vehicle.

Another item that must be decided is the turning radius of the design vehicle. The turning radius of the design vehicle determines the ease and comfort of making the turning maneuver. The smaller the turning radius, the larger the off-tracking of the vehicle and the slower the speed. Forcing large vehicles to use very small turning radii forces the driver to perform a very slow maneuver that may not be in the best interests of the operation of the intersection. Generally, the radius chosen is in line with the surrounding culture. Tighter radii are chosen for low and/or urban speeds, while larger radii are selected for higher speeds and rural intersections. When designing with tighter radii, it is important to evaluate the impacts of large vehicle off-tracking. ***Large vehicle off-tracking should not occur over pedestrian ramps and sidewalks or interfere with signal or utility pole locations.***

Once the design vehicle is selected and the level of design accommodation determined, then the intersection radii can be designed. Intersection radii should be kept as small as possible to minimize the size of the intersection and the pedestrian crossing distance. ***Any time the design vehicle is larger than a Single Unit (SU) truck or a bus, consider using a two-centered curve.*** Off-tracking templates or automated off-tracking programs should be used to determine the vehicle path. Once this path is identified, a two-centered curve can be developed which closely emulates this path. The designer may need to look at a range of vehicle turning radii and the subsequent intersection designs. This allows the designer to select the best design for the design vehicle while minimizing the size of the intersection.

Keep the size of intersections to a minimum. When accommodating large trucks, intersection radii can become very large. This can substantially increase the size of the intersection. Larger intersections generally have greater crash potential, are difficult to delineate, can be confusing, require more right-of-way, and significantly increase pedestrian and bicycle crossing times and distances.

506.10 Left Turn Lanes

On some higher volume and higher speed highways, left turning traffic can become a major safety concern, especially on two-lane highways. *On rural highways, left turn lanes should generally only be considered at public road intersections.* The Analysis Procedures Manual (Transportation Planning and Analysis Unit) discusses citing criteria for installing left turn lanes. ***A left turn lane should be considered in the design when these criteria are met.*** Generally, left turn lanes are not to be constructed for private accesses in rural areas unless the siting criteria are met and installation of a left turn lane will not create additional safety concerns on the highway. A major concern regarding left turn lanes for private access is that successive accesses may require installation of a section of a continuous two way left turn lane (CTWLTL).

Using CTWLTLs in rural environments should be discouraged. *Rural CTWLTLs may be considered where needed specifically for safety in short sections or within the boundaries of a rural community.*

As stated above, providing left turn lanes at multiple locations that are spaced closely may create a need for a CTWLTL. It is undesirable to provide a typical section that creates an hour glass shape. This is where a highway is widened to provide a left turn lane, then narrowed back to the original typical section, only to be immediately widened again. This situation should be avoided. ***Left turn lanes in rural areas should be selected where adequate spacing exists to avoid this hourglass problem. Figure 500-31 provides an equation to avoid an hourglass.***

Providing a left turn lane at an intersection will significantly improve the safety of the intersection. Eliminating conflicts between left turning vehicles decelerating or stopping and through traffic is an important safety consideration. ***A left turn lane must be provided at all non-traversable median openings, and they are strongly recommended to be installed at other intersections meeting the installation criteria.*** The left turn lane installation criteria are different for signalized and unsignalized intersections. Refer to Section 507 for Signalized Intersections and Section 508 for Unsignalized Intersections for the appropriate siting criteria. For additional information about siting criteria for left turn lanes, see the ODOT Analysis and Procedures Manual (APM).

Left turn lanes for rural and higher speed locations shall be 12 feet wide plus the appropriate traffic separator width and shy distance when required. For urban locations, see Part 200 and Part 300 for left turn design criteria.

The installation of a traffic separator at urban left turn lane locations is critical when there are access points to adjacent properties along the length of the left turn lane. The separator will protect the left turn lane operation and safety by eliminating the opportunity for vehicles to cross it when entering and exiting adjacent accesses. The width of the traffic separator is determined by several factors. **If the median includes a raised curb design, the traffic separator width shall be a minimum of 4 feet in higher speed locations**. **However, when pedestrians are to be accommodated on the raised portion of the median with separate phases for the crossing maneuver, the raised traffic separator shall be 6 feet minimum in width**. *Medians that use raised curb also need to provide the appropriate shy distance from the curb and adjacent through travel lanes.* The width of paint-striped medians is determined by the design speed of the highway and the type of land use area. **For design speeds of 55 mph or less, the paint-striped median shall be 2 feet and 4 feet for design speeds of 60 mph or greater.** For more information on median design, refer to Part 300, Cross-Section Elements.

Development of left turn lanes should be in conformance with Figure 500-19. However, where the median width is developed non-symmetrically, a reversing curve should be used in lieu of the straight speed tapers. The reversing curve option can reduce the overall widening thereby saving construction costs and possibly saving right of way or significant features. Figure

500-19 depicts the standard left turn channelization design. Figure 500-20 depicts the reversing curve channelization option.

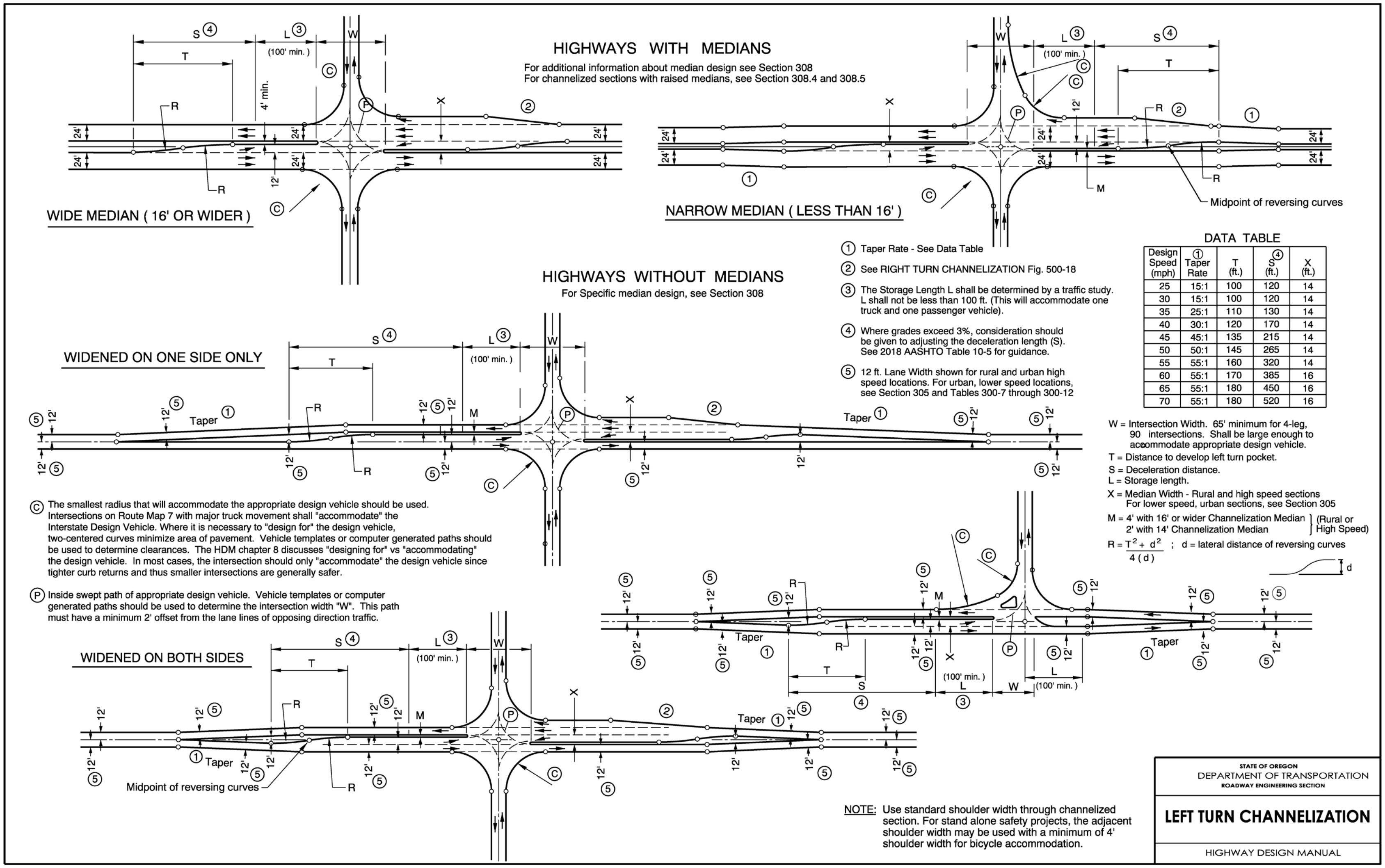
Left turn lanes are striped in accordance with the ODOT Traffic Line Manual. Essentially this means that the reversing curve entry taper shall be used for:

1. All dual left turn lanes;
2. All left turn lanes developed from sections without medians or with narrow medians, and
3. All left turn lanes located within wide median sections or CTWLTLs that have design speeds greater than 45 mph.

It is critical to the operation of intersections to provide adequate storage length for left turning vehicles out of the through traffic lanes. **At a minimum, provide 100 feet of storage.** ***The Region Traffic Engineering Unit and the Analysis Procedures Manual (APM) should be consulted to determine the appropriate storage length for specific intersections***. For specific analysis procedure questions or interpretation of the APM or for complex projects requiring additional study, contact the ODOT Transportation Planning and Analysis Unit (TPAU) for guidance or technical help on the particular project or methodology.

In some instances, dual left turn lanes may need to be considered. **When designing dual left turn lanes, there must be dual receiving lanes on the connecting roadway with adequate length downstream prior to any merge points.** The designer must determine the appropriate design vehicles to use for side-by-side operation through the turning movement. *In rare locations, like at freeway ramp terminals leading to truck stops or warehousing districts, the design may need to be two WB-67 vehicles making the turn simultaneously. However, in most locations, a WB-67 and an SU vehicle side-by-side is adequate for design. In other locations where truck volumes are low, an SU vehicle and a passenger vehicle may be sufficient*.

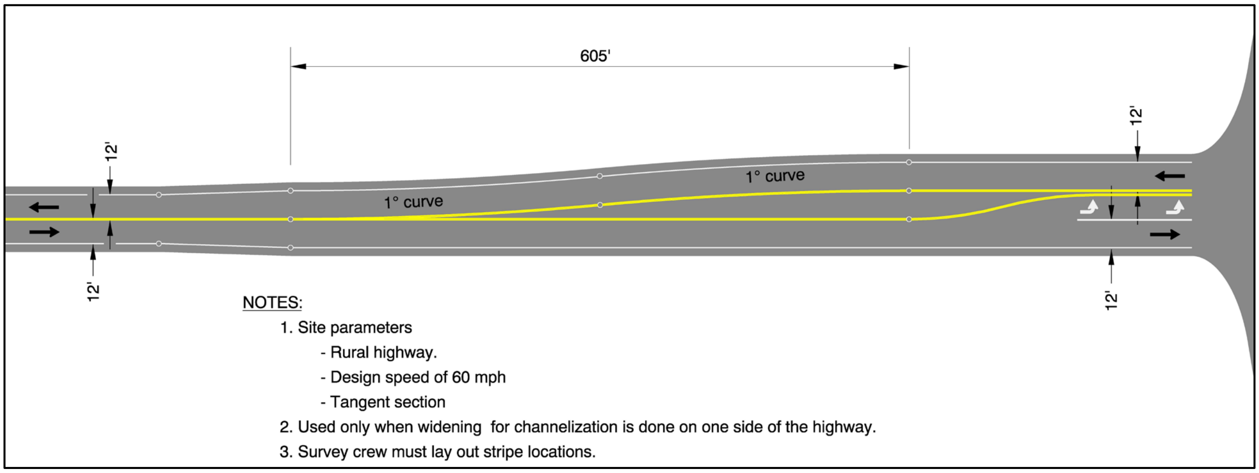
Figure 500-19: Left-Turn Channelization



DATA TABLE

Design Speed (mph)	① Taper Rate	T (ft.)	④ S (ft.)	X (ft.)
25	15:1	100	120	14
30	15:1	100	120	14
35	25:1	110	130	14
40	30:1	120	170	14
45	45:1	135	215	14
50	50:1	145	265	14
55	55:1	160	320	14
60	55:1	170	385	16
65	55:1	180	450	16
70	55:1	180	520	16

Figure 500-20: Reversing Curve Option for Left-Turn Channelization – Rural Highway



506.11 Right Turn Lanes

Similar to left turns, right turning traffic may sometimes create a safety issue at some intersections. However, right turn traffic does not normally need to come to a complete stop and wait for an opposing gap to complete the maneuver, except in the case of a pedestrian crossing. Therefore, the safety implications are not as significant as with left turning vehicles. At some intersections, the volumes on the highway and the right turning traffic may be significant enough to create a safety problem. The Analysis Procedures Manual (Transportation Planning and Analysis Unit) discusses siting criteria for installing a right turn lane. ***A right turn lane should be considered only at public road intersections that meet these criteria. Right turn lanes should not be used for private drives unless the access has significant turning volume, a specific crash problem could be corrected by utilizing a right turn lane, or the access is within a rural community area and meets the criteria from the Analysis Procedures Manual.***

Speed differential between right turning traffic and through traffic can create significant safety problems at intersections. To reduce this conflict, installation of right turn lanes may be appropriate at some intersections. Right turn lanes also help improve traffic operations and mobility standards at some intersections. *Installation of right turn lanes should be considered at intersections that meet the siting criteria. For information about siting criteria for right turn lanes, see the ODOT Analysis and Procedures Manual (APM).*

(https://www.oregon.gov/odot/Planning/Pages/APM.aspx)

Not all intersections that meet the siting criteria should have right turn lanes installed. In urban situations, only significant public roads and large private approaches should be considered for installation of a right turn lane. A proliferation of right turn lanes along an urban arterial is undesirable for bicycles and pedestrians, creates an aesthetically unpleasing typical section, and may not improve safety throughout the section. Multiple right turn lanes could, in effect, create a continuous right turn lane, which is not desirable on state highways.

Right turn lanes should be designed in conformance with Figure 500-18. Preferably, a right turn lane should be 12 feet wide with a shoulder of 3 feet or 4 feet for curbed or non-curbed sections respectively. This allows for additional space for larger turning vehicles. In some instances, right turn lanes could be considered a turning roadway. Turning roadways are usually thought of in relation to interchange ramps. However, according to AASHTO, turning roadways include interchange ramps and intersection curves for right-turning vehicles. The AASHTO publication, "*A Policy on Geometric Design of Highways and Streets - 2011*" has extensive information on turning roadway design including sections on minimum radii, control radii, corner islands, minimum edge of traveled way, lane configuration and swept paths. However, in urban locations where space is constrained by the built environment, flexibility is necessary when laying out right turn lanes. *For urban locations, the dimensions in Figure 500-18 may be modified to meet context needs for flexibility.* See Part 200 for context information and Part 300, Sections 307 - 312 for urban right-turn lane design criteria.

When designing an urban right turn lane, bicyclist movements need to be accommodated. The goal for highway projects is to provide the highest appropriate level bicycle and pedestrian facilities possible within project scope and funding at a given location. It is desirable to connect new and existing networks while projects are being constructed. ***Contact the region Active Transportation Liaison to determine bicycle and pedestrian facilities appropriate for the project and to determine if alternate funding may be available.***

Where minimum bicycle lanes adjacent to the travel lane are existing or proposed, add a bike lane to the left of the right turn lane. This helps reduce conflicts between right turning vehicles and through cyclists. In addition, providing the bike lane between the through travel lane and the right turn lane better aligns the cyclist with the downstream shoulder or continuation of the established bike lane. Creating a bike lane between the through lane and the right turn lane establishes the conflict point further back from the intersection where the paths of right turning vehicles and cyclists must cross. ***Care must be taken to balance bicycle speeds, right turning vehicle speeds and operational queue lengths in the right turn lane to establish the appropriate bike and motor vehicle crossing location.*** Part 900 provides guidance for designing bicycle facilities. In this conflict area, the bike lane is generally marked with short skip striping. The MUTCD and FHWA now allow this area to be colored green inside of the skip stripe to draw more attention to the conflict area. Region Traffic and Roadway sections, ODOT bicycle and pedestrian coordinators and the ODOT, Technical Services, Roadway Engineering Section should be consulted for current guidance if it is determined that using this treatment in this location would be beneficial.

The standard width for a bike lane between a through travel lane and a right turn lane is 5 feet. This width is narrower than a standard bike lane against a curb. However, it is a minimum width and if the bike lane is too wide, it may appear to vehicle drivers as an added lane. Also, width added to a bike lane increases the overall width of the roadway section that must be crossed by pedestrians. Width of the right turn lane is critical as well. *The preferred width is 15 feet (12' lane, 3' shoulder) from the adjacent travel lane or bike lane to curb for most right turn lanes.* The additional 3 feet provides space for truck off-tracking and minimizes the need for a right turning truck to encroach on the adjacent lane when making the turn. In some instances, a 3-foot shoulder may not be adequate and additional width might be needed. However, that additional width has consequences. Right turn lane width in conjunction with bicycle lane width is a balance between providing enough space for the respective vehicle's lane use but minimizing the crossing distance for pedestrians at an intersection within the space available. *In urban locations, narrower than preferred right turn lanes may be appropriate. Part 200 and Part 300 provide design criteria for urban cross-sections and urban right-turn lanes.*

In some instances, dual right turn lanes may need to be considered. If used, dual right turn lanes need to be carefully evaluated for overall performance and impacts. When designing dual right turn lanes, there must be two lanes on the connecting roadway to turn into and there must be adequate length provided downstream before any lanes merge. The designer also must determine the appropriate design vehicles to use for side-by-side operation through the turning movement. *In rare locations, like at freeway ramp terminals leading to truck stops or warehousing districts, that may need to be two WB-67 vehicles making the turn simultaneously. However, in most locations, a WB-67 and an SU vehicle side-by-side is adequate for design. In other locations where truck volumes are low, an SU vehicle and a passenger vehicle may be sufficient. When considering dual right turn lanes as an option, consult the Region Traffic Section for input.* Dual right turn lanes are also difficult for pedestrians and bicyclists to navigate. Part 900 and the Oregon Bicycle and Pedestrian Design Guide provide information in regard to bicycle and pedestrian accommodation at dual right turn lanes. Consult the ODOT Bicycle and Pedestrian Design Engineer or the project resource for active transportation for guidance on design alternatives.

506.12 Deceleration & Acceleration Lanes

Deceleration lanes are encouraged at intersections and required at interchanges. Deceleration at an interchange can look similar to a standard right turn lane or a freeway exit ramp. *Each situation must be evaluated and analyzed to determine the appropriate treatment.* Figure 500-18 should be used for all right turn deceleration lanes at interchanges. The information contained in Part 600 can be used to determine acceptable exit ramp designs.

Acceleration lanes should generally only be used at interchanges on rural expressways. Acceleration lanes at at-grade accesses or intersections may not be appropriate. ***Acceleration lanes should only be used where they will not be influenced by downstream intersections or accesses. At-grade intersections and access locations may include acceleration lanes only where access management spacing standards are met, the type of turning movements are considered, and where an engineering analysis shows they will operate safely.*** Design guidance and criteria for at-grade intersections are found in Section 506.13 and Section 506.14.

For freeway style interchanges, freeway type acceleration lanes are necessary. For jug handle and at-grade acceleration lanes, the parallel type shown in Section 506.13 may be most appropriate. Part 600 and the AASHTO Green Book provides guidance for determining the appropriate acceleration lane length. The length may need to be increased when a significant volume of truck traffic is using the merge lane or where high volumes are merging into a single lane.

506.13 At-Grade Right Turn Acceleration Lanes

At-grade intersections generally should not have short tapers or acceleration lanes constructed for vehicles entering the state highway from a crossroad or another state highway. *Acceleration lanes are generally only provided at grade separated facilities. However, in some situations, acceleration lanes may be justified.* ***The following criteria outlines where at-grade right turn acceleration lanes can be considered. All of the criteria must be satisfied and requires joint approval from the State Traffic Engineer and State Roadway Engineer through the design exception process.***

- The posted speed on the main highway shall be 45 MPH or greater.
- The V/C ratio of the right-turn movement without the acceleration lane shall exceed the maximum value listed in Tables 6 and 7 of the OHP for the corresponding highway category and location.
    a. Exception 2a: If trucks represent at least 10 percent of all right-turning vehicles entering the highway, then the V/C criteria may be waived.
    b. Exception 2b: If substandard sight distance exists at an intersection or right-turning vehicles must enter the highway on an ascending grade of greater than 3 percent, then the V/C criteria may be waived.
    c. Exception 2c: If crash data in the vicinity of the intersection shows a history of crashes at or beyond the intersection attributed to right-turning vehicles entering the highway, then the V/C criteria may be waived.
- The peak hour volume of right-turning vehicles from the side street onto the state highway shall be at least 10 vehicles/hour for Rural Expressways and 50 vehicles/hour for all other highways.
- **No other access points or reservations of access shall exist on both sides of the highway within the design length, taper, and downstream from the end of the taper within the decision sight distance, based on the design speed of the highway.**
    a. Exception 4a: **If positive separation between opposing directions of traffic exist such as raised medians or concrete barriers, then access control is only needed in the direction of the proposed acceleration lane.**

The State Traffic Engineer shall determine if a right-turn acceleration lane proposal meets the above criteria. Proposals are submitted to the State Traffic Engineer from the region and include an engineering investigation with data supporting the above criteria and a drawing encompassing the intersection and design length of the acceleration lane showing all access points and reservations of access to the highway. Only proposals for right-turn acceleration lanes from public streets should be considered. If the State Traffic Engineer determines that a right-turn acceleration lane proposal meets the above criteria, the proposal will be forwarded to the State Roadway Engineer for consideration of design standards. All right-turn acceleration lane proposals shall require the joint approval of the State Traffic Engineer and State Roadway Engineer.

Special consideration is given to cyclists and pedestrians. Acceleration lanes create an unexpected condition for both pedestrians and cyclists. Every reasonable effort must be made to create conditions that make the crossing safer and easier for pedestrians and cyclists. **The acceleration lane shall be designed in accordance with Figure 500-21 "Right Turn Acceleration Lane from At-Grade Intersection".**

Free-flow acceleration lanes may be considered in rural or suburban areas provided the turning radius is tightened and the angle of approach is kept as close to a right angle as possible. These combined elements will force right-turning drivers to slow down and look ahead, where pedestrians and bicyclists may be present, before turning and accelerating onto the roadway.

Figure 500-21: Right Turn Acceleration Lane from at Grade Intersection

RIGHT TURN ACCELERATION LANE FROM AT GRADE INTERSECTION

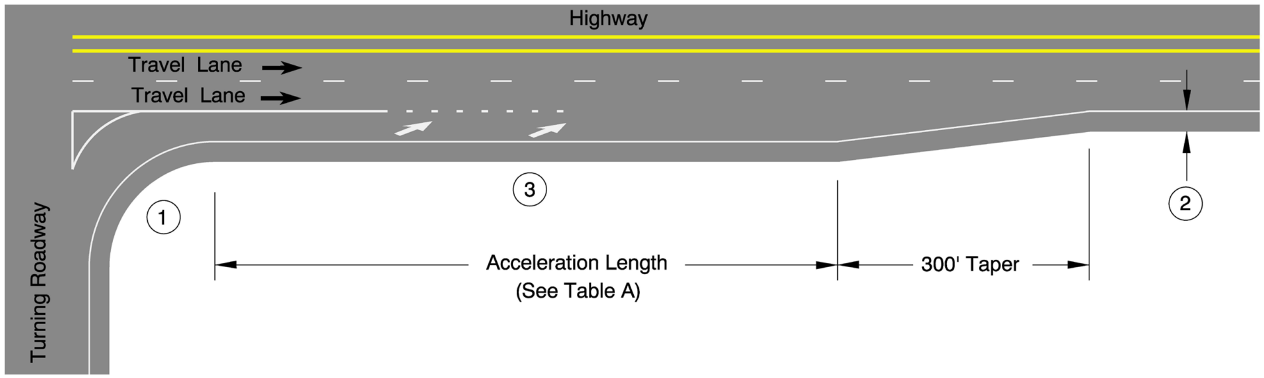


TABLE A
MINIMUM ACCELERATION LENGTH

Design Speed of Highway (mph)	Design Speed of Turning Roadway	
	Stop Condition	15 mph
50	720	660
55	960	900
60	1200	1140
65	1410	1350
70	1620	1560

TABLE B
MAINLINE GRADE AJUSTMENT FACTORS

Design Speed of Highway (mph)	% Grade	Upgrade	Downgrade
50	3% to less than 5%	1.3	0.65
55		1.35	0.625
60		1.4	0.6
65		1.45	0.6
70		1.5	0.6
50	5% and over	1.5	0.55
55		1.6	0.525
60		1.7	0.5
65		1.85	0.5
70		2.0	0.5

NOTES:

1. Radius shall accomodate design vehicles, yet minimize pedestrian crossing distance. Compound radii are recommended for larger design vehicles. Radii are measured to the edge of travel lane or face of curb.
2. Design shoulder width as required per Highway Design Manual
3. Use Table B to determine acceleration lenght adjustment due to grade.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING SECTION

RIGHT TURN ACCELERATION LANE FROM AT GRADE INTERSECTION

HIGHWAY DESIGN MANUAL

506.14 Median Acceleration Lanes

For ODOT purposes, a median acceleration lane is a lane added to the median of a roadway at an un-signalized intersection to allow left turning vehicles from a side road to gain speed and merge with main line traffic. Median acceleration lanes may seem like a reasonable solution to left turn problems onto busy, high-speed roadways and, in some locations, they may be an acceptable feature. However, their use should be reserved for locations with specific needs. Improper installation of a median acceleration lane may create unanticipated problems greater than the problems the installation is attempting to solve. ***Any location where a median acceleration lane is proposed must be analyzed carefully before a median acceleration lane is considered to be appropriate.*** Overall, there is little definitive research or information available on the use or effectiveness of median acceleration lanes. The location is of critical importance to the effective function of a median acceleration lane. *Site specific analysis is paramount in determining the appropriateness of installing a median acceleration lane.*

Median acceleration lanes function best on rural, multi-lane, free flowing roadways with ample median width and decision sight distance to accommodate not only the turning movements of all vehicle types, but to also provide the acceleration lane itself. ***Median width must be provided over a long enough distance to allow the accelerating driver to choose a gap in the traffic stream and merge smoothly prior to the end of the median acceleration lane.*** Median acceleration lane length will likely need to be longer than typical right side acceleration lane length to ensure adequate, comfortable and safe merge maneuvers into the traffic stream. *Additional run-out length should be provided downstream of the median acceleration lane taper. This will provide a "bail out" area or escape route if no adequate gap is available for the accelerating vehicle in the main line traffic stream.* **Median acceleration lanes are not always appropriate for two lane roadways on the state highway system and shall not be installed on state highways without State Traffic and State Roadway Engineer approvals.** Figure 500-22 and Figure 500-23 provide information about Median Acceleration Lane layout.

Although not recommended, it may be possible to install a median acceleration lane on some limited access, divided, urban arterials or expressways with posted speeds of 45 mph or greater. However, this type of installation must be considered carefully. ***Median width and intersection spacing must be appropriate to allow the acceleration lane to function.*** **In addition, there shall be no right-side access points to the main line highway along the length of the median acceleration lane or within decision sight distance of the left side merge taper.** Right side accesses along a section of roadway with a median acceleration lane on the left side create the scenario of the main line traffic being impacted from both sides of the roadway at the same time. **Median acceleration lanes shall not be installed in locations with posted speeds below 45 mph.** When speeds are below 45 mph, the differential of an accelerating vehicle and the traffic stream are not as great, and a median acceleration lane does not provide added benefit.

As discussed in the preceding paragraphs, in limited situations, a median acceleration lane may provide an incremental improvement to a multi-lane expressway by providing left turning vehicles an opportunity to accelerate and reduce speed differential before entering the traffic stream. This is particularly true where there are large numbers of left turning trucks. Where sufficient gaps exist in the main line traffic stream, a median acceleration lane is not needed and the cost of installation as well as potential environmental impacts of adding new impervious surface may not be justified. However, where there are few gaps in the main traffic stream and there is a high demand for left turning trucks or other large vehicles like RVs, motor homes or buses from the side road, a median acceleration lane may serve as an acceptable interim solution. ***A median acceleration lane is not a typical design. Contact Technical Services Roadway Engineering Unit staff for information regarding the installation of median acceleration lanes.*** **Before any median acceleration lane can be installed on the state highway system, approval from the State Traffic and State Roadway Engineers must be obtained.**

Consideration may be given to install a median acceleration lane when all of the following criteria are met:

1. A multi-lane, divided expressway or arterial highway with a posted speed of 45 mph or greater
2. Adequate Median width to allow for desirable dimensions as shown in Figure 500-22 and Figure 500-23
3. Large left turning volume from side road – particularly truck volumes and recreational vehicle
4. Insufficient gaps or inadequate intersection sight distance (Particularly AASHTO B1, Right Side)
5. No right side accesses onto main line along the length of the acceleration lane or within decision sight distance of the end of the taper
6. Significant crash history – particularly truck crashes

Table 500-3: Desirable Length of Full Width Median Acceleration Lane

Posted Speed (mph)	2/3 of Posted Speed (mph)	Desirable Length of Full Width Median Acceleration Lane, Rounded (ft.)
45	30	810
50	34	995
55	37	1203
60	40	1435
65	44	1680

Note: Desirable Length Based on 200lb/hp Truck Accelerating to 2/3 posted speed
Minimum Median Acceleration Lane Length – 810'

The 200 pound per horsepower truck equates to the 85 percent truck in the national fleet based on studies reported in NCHRP Report 505, Review of Truck Characteristics as Factors in Roadway Design published in 2003. Table 29 in NCHRP Report 505 lists average acceleration capabilities for several different weight to power ratio classes of trucks. For the 200 pound per horsepower vehicles, the average acceleration listed is 1.22 ft./s^2. The following formula for uniform acceleration was used to determine the desirable lengths for Median Acceleration Lanes listed in Table 500-3.

$$V_f^2 = V_i^2 + 2AS$$

Where:

V_f = Final speed achieved at the end of distance S, ft./sec.

V_i = Initial speed, ft./sec. for Table 500-3, $V_i = 0$

A = Acceleration, ft./sec^2. A=1.22 ft./sec^2

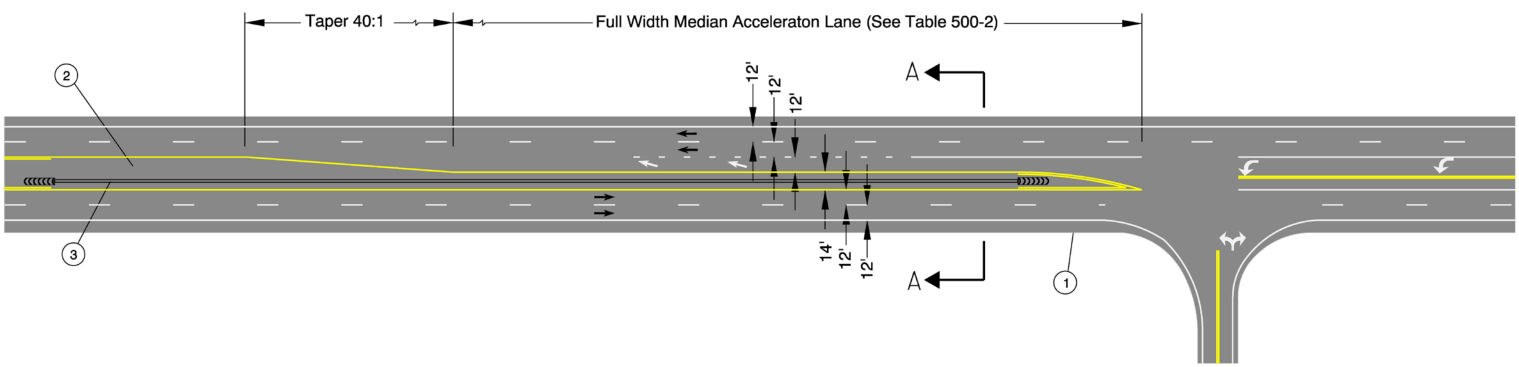
S = Distance to accelerate to 2/3 of posted speed, ft.

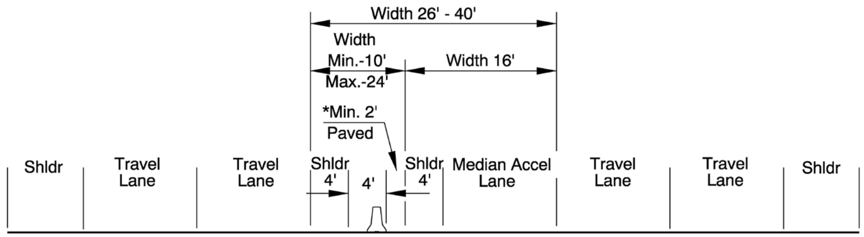
Figure 500-22: Median Acceleration Lane - Narrow Median

MEDIAN ACCELERATION LANE - NARROW MEDIAN

RURAL OR URBAN OVER 45 MPH

(26' - 40' Between Travel Lanes)





SECTION A-A

* Median Barrier Required For 26' to 40' Width Between Travel Lanes
Minimum 2' Paved Between Barrier and MAL Shoulder for 26' Width
For Widths Greater than 26' and Up To 40'- Paving Optional
For Widths Greater Than 40' - Median Barrier Not Required

NOTES:

1. Flat Curve to Allow Design Vehicle to Enter Median Acceleration Lane Without Encroaching on Adjacent Lane
2. Inside Shoulder Extended for Runout Area
   Minimim Length - 300'
   Minimum Width - 10' (12' To Face of Barrier)
3. Median Barrier Treatment Concrete Barrier Shown Cable Barrier System May Be Optional (Final Placement and Layout With Project Design)

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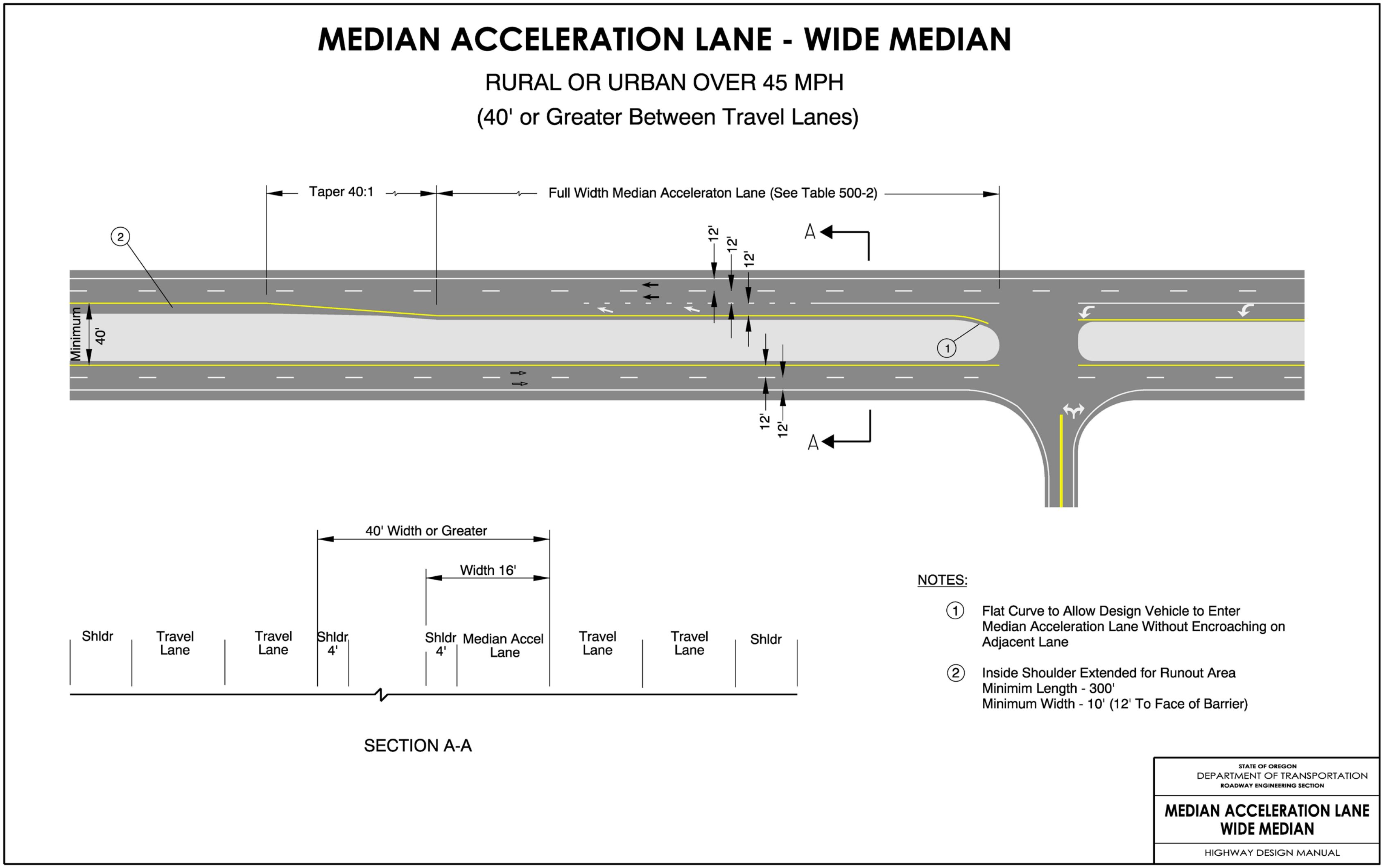
ROADWAY ENGINEERING UNIT

MEDIAN ACCELERATION LANE
NARROW MEDIAN

HIGHWAY DESIGN MANUAL

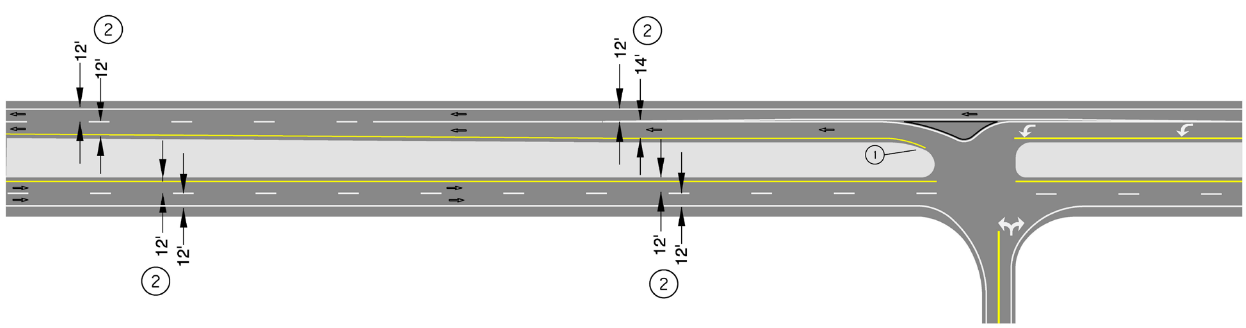
Figure 500-23: Median Acceleration Lane - Wide Median



506.15 Left Turn Add Lanes

A left turn add lane is a lane provided for vehicles turning left from a side road to accelerate and enter the main line traffic stream in a designated through lane. *A left turn add lane should not be confused with a median acceleration lane. Although they may serve similar functions, there is a distinct difference. A median acceleration lane requires the left turning vehicle to merge into the through lane of the main line traffic stream. Whereas a left turn add lane creates a new and separate through lane for the left turning vehicle to enter that is independent of the existing through travel lane on the main line highway*. This eliminates the need for the turning vehicle to merge into the existing through lane and creates a completely different operational characteristic from a median acceleration lane that reduces impacts on traffic in the existing through lane. ***Some form of physical separation between the add lane and the existing through travel lane should be provided for a length necessary to minimize speed differential between travel lanes. The first 600 feet should be a positive physical separation in the form of a raised separator or barrier, while the remaining length can be less physically separating in the form of rumble strips or a wide, solid paint stripe***. Figure 500-24 illustrates a left turn add lane configuration.

Figure 500-24: Left Turn Add Lane



1 Flat Curve to Allow Design Vehicle to Enter Median Add Lane Without Encroaching on Adjacent Lane

2 In Urban Lower Speed Locations, 11-foot Travel Lane Width May Be Appropriate

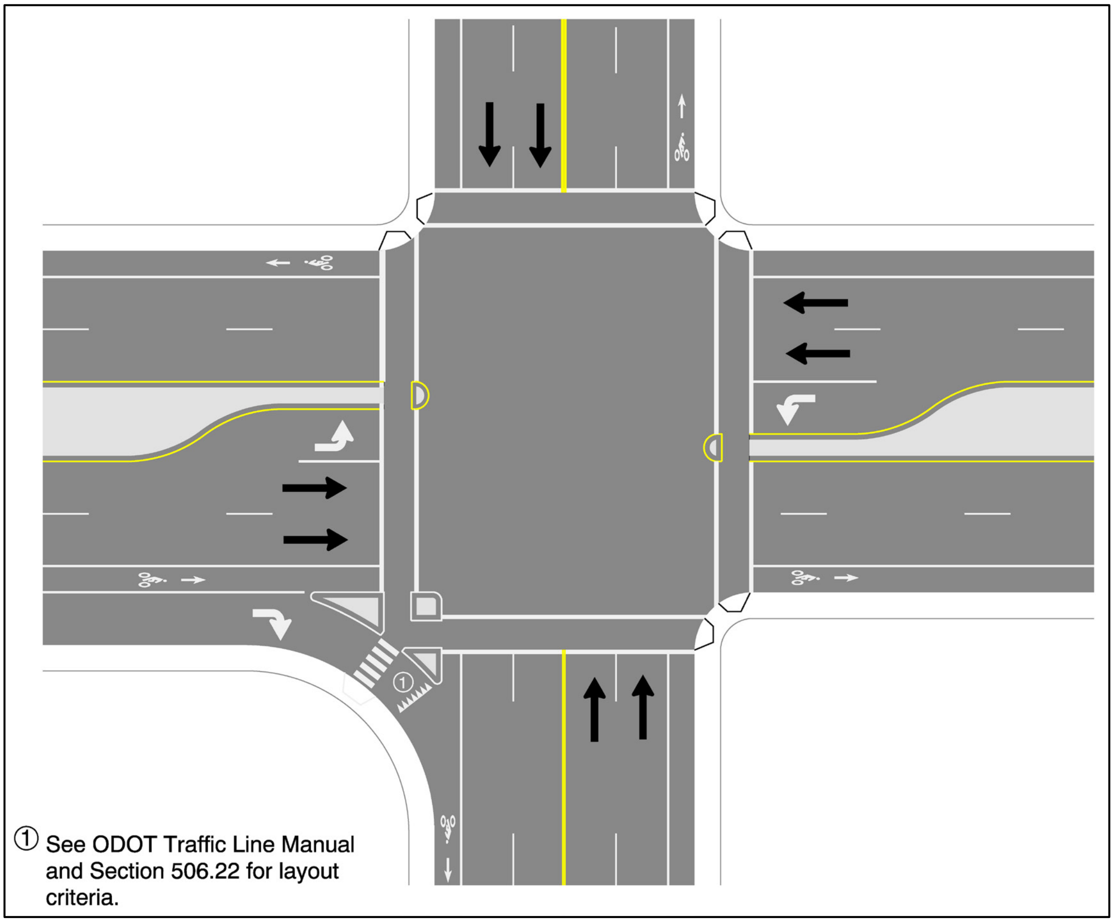
506.16 Channelization Islands

Channelization islands help to direct turning traffic through an intersection. Channelization islands are a tool to help decrease the exposed crossing area of very large intersections. These islands can provide a refuge area for crossing pedestrians and offer a location for signal poles and sign posts. *Where channelization islands are to accommodate poles or sign posts, the island should ideally have an area of at least 100 square feet.* **The minimum area shown on RD710 is 75 square feet.**

Channelization islands are also useful for decreasing the crossing distance of pedestrians. When intersections are very wide, pedestrians must cross very long distances which increases their exposure time to traffic, reduces safety, and reduces efficiency of the signal due to the time necessary to cover the crossing maneuver. *The designer should consider using channelization islands where crossing distances are greater than 6 lanes wide.* (Section 308 discusses raised medians and this section (Section 506.16) provides additional guidance on channelization islands for bicyclists and pedestrians). ***Channelization islands should be designed in conformance with Figure 500-25.*** Part 800 provides additional information regarding pedestrian crossings and channelization islands. Part 900 provides information regarding protected intersections and channelization layout.

In some rural locations, it may be advantageous to provide a moderate to higher speed right turn movement at major intersections. However, care must be taken at these locations to adequately provide facilities that protect pedestrians. Channelization islands could also be used in these instances. ***When channelization islands are installed at high speed, rural locations, care must be taken to place these islands with adequate offset distance from the through travel lane.*** *Figure 500-31 provides layout details for channelization islands.* **Adding raised channelization islands to intersections must be in compliance with ORS 366.215 and freight mobility needs.** See ODOT guidance document "Guidelines for Implementation of ORS 366.215, No Reduction of Vehicle-Carrying Capacity" and the "ODOT Highway Mobility Operations Manual".

Figure 500-25: Typical Multi-Lane Channelized Intersection



506.17 Curb Extensions

Curb extensions, also known as “bulb-outs,” are good tools to help reduce the pedestrian crossing distances in areas with on-street parking. Curb extensions also increase pedestrian visibility, help control vehicular speeds, and give a “downtown look” to an urban area. Curb extensions are generally appropriate within slower speed compact areas, such as Special Transportation Areas (STAs) or Traditional Downtown/Commercial Business Districts. Curb extensions are generally considered at intersections, but they can also be utilized with great benefit at mid-block pedestrian crossings as well.

The curb extensions still must be designed to accommodate the appropriate design vehicle. However, due to the speed, traffic characteristics, and importance of alternative modes in these areas, the level of accommodation of large vehicles is expected to be minimal. ***Curb extension design at proposed locations must meet the process and criteria outlined in ORS 366.215 and must meet freight mobility needs.*** See ODOT guidance document "Guidelines for Implementation of ORS

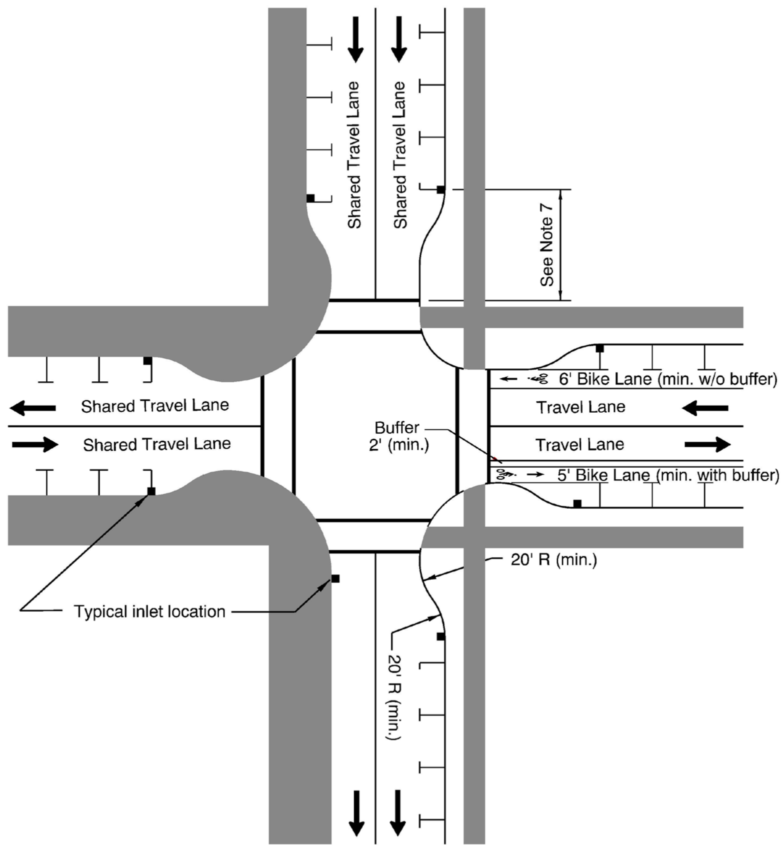
366.215, No Reduction of Vehicle-Carrying Capacity" and the "ODOT Highway Mobility Operations Manual".

Curb extensions should generally be constructed to the full width of the on-street parking. *However, when no bike lane is present, the curbside travel lane should be at least 14 feet wide from the left side lane line to the face of the curb at the maximum extension point.* Each curb extension design is different. Figure 500-26 contains several design concepts for consideration. Special consideration is required in many situations for addressing drainage in conjunction with curb extensions, especially in retrofit situations. **Curb extensions shall not block and should not narrow bicycle lanes. Adequate drainage shall be provided along the curb line with no ponding of water at the curb ramp entrance.** For additional information on curb extensions, see Part 800 for pedestrian design guidance.

ORS 811.550(17) requires parking to be 20 feet from a marked or unmarked crosswalk and the MUTCD indicates parking should be 30 feet from the crosswalk at signalized intersections. Curb extensions can be used to provide the pedestrian benefits listed previously in this section as well as provide compliance for the required distance from crosswalks to on street parking.

Figure 500-26: Curb Extensions

CURB EXTENSIONS



General Notes

1. Intersections on state facilities should be designed to accommodate the appropriate design vehicle with the SU as the minimum. Corner curb radii are normally no less than 33' in cases where vehicles are turning right onto a roadway without a bike lane. The introductions of bike lanes, one-way streets and different combinations of turning movements may reduce the curb radius requirements to as low as 16'. These radii should be confirmed by the appropriate vehicle turning template or computer-generated turning paths.

2. Other curb radii should be no less than 20' to accommodate street maintenance equipment. This radius may be reduced if approved by local authorities.

3. Curb ramps should be designed in accordance with Part 800 of the HDM and the RD900 series of standard drawings.

4. Storm water inlets should be placed at the point where the curb extension matches into the normal street section. Normally, 2 inlets are required, one at each end of the curb extension. Drainage may be required in the sidewalk area, depending on slopes and sidewalk design. Drainage may also be provided through the use of a slotted drain or a pipe through the curb extension.

5. Curb extension should be kept clear of obstructions that could obscure sight distance.

6. Curb extensions should not narrow bikelanes.

7. ORS 811.550(00) requires parking to be 20 feet from crosswalk for unmarked or marked crosswalks. MUTCD - 30 feet from crosswalk at Signalized intersection.

8. For bicycle facility selection, see Part 900.

9. For lane width options, see Part 300.

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CURB EXTENSIONS

HIGHWAY DESIGN MANUAL

506.18 Bicycle and Pedestrian Needs

The design of intersections must consider the needs of bicyclists and pedestrians. The level and amount of design effort required to ensure adequate design for these modes will vary among locations. ***Inclusive intersection designs keep the crossing distances and pedestrian exposure to a minimum. Pedestrians and motorists must be able to see each other clearly and understand how the other will proceed through the intersection.*** This can sometimes be difficult at major intersections that accommodate multiple turn lanes. When intersections become excessively large and complex, pedestrian safety is often at a higher risk. The roadway designer should provide mitigation measures to reduce the crossing distance to balance impacts for roadway users.

Providing pedestrians with a crossing that can be completed in one movement is preferred. *However, when pedestrians must cross an excessive number of traffic lanes or a combination of excessive traffic lanes and a large skew angle, consider an appropriately sized pedestrian median refuge to enable pedestrians to cross the street in two phases.* A right turn channelization island can also be considered to reduce the pedestrians' exposure to both through and right turning vehicles. Curb extensions are a treatment available to reduce the crossing distance for roadways with on-street parking. Median refuges and right turn channelization islands may be more appropriate in suburban locations, and curb extensions may be a more appropriate treatment in more compact areas such as STAs or Commercial Business Districts. However, any of these treatments could apply in a multitude of situations. A general rule of thumb is to consider pedestrian crossing treatments when the crossing distance exceeds 90 feet in typical urban environments such as Urban Business Areas (UBAs) or Commercial Corridors and 72 feet in compact densely developed areas such as STAs, Traditional Downtown, or Urban Mix contexts.

Use protected intersection design to provide safer intersection operations for all users. See Part 900 for guidance on protected intersections.

ADA requirements shall be met in every intersection design. Issues such as curb ramps, location of pedestrian and signal poles, obstructions, fixed objects, drainage, etc., need to be reviewed and designed to be accessible and accommodate all roadway and intersection users. Part 800 for Pedestrian Design and Part 900 for Bicycle Facility design provides additional information on intersection accommodation.

506.19 Intersection Design Affecting Pedestrians

There are several aspects of intersection design that impact the safety, comfort, and access needs of pedestrians. For each identified issue, measures that can be used to mitigate these effects will be proposed. In addition to the issues discussed below, see Part 800 for additional information about pedestrian design for intersections. The ODOT Traffic Manual is another resource available to roadway designers. Traffic control options for intersections are covered by the ODOT Traffic Section. Coordinate with the Region Traffic Section and the ETSB, Traffic Engineering Services Unit staff.

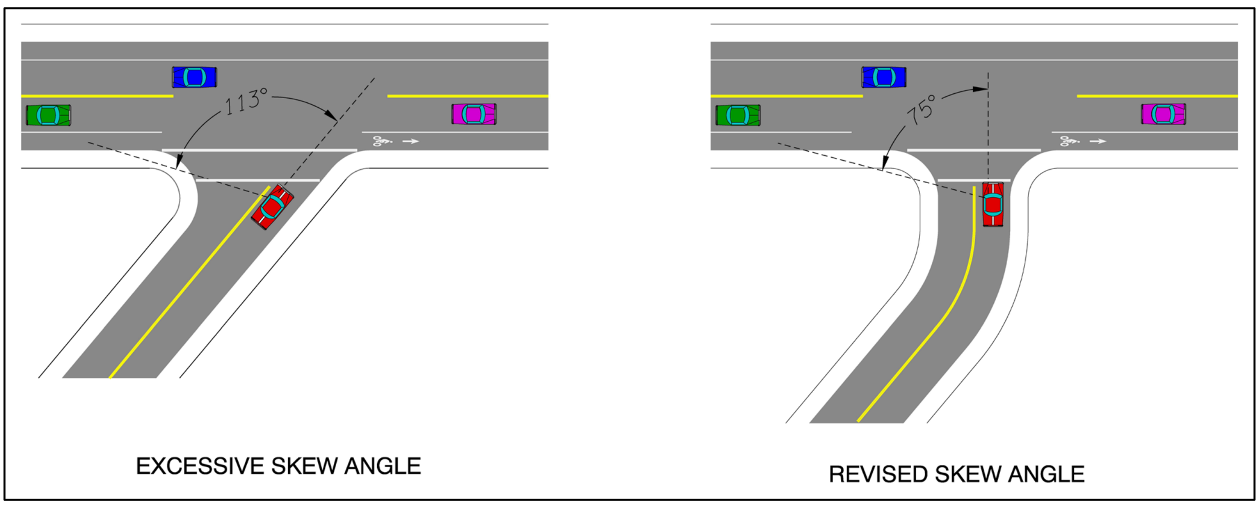
506.20 Excessive Skews

Skewed approaches have several negative effects for pedestrians:

1. They make the crossing longer;
2. They enable motorists to make a turn at high speeds;
3. They force entering motorists to look backwards for conflicts, so that a pedestrian approaching from the other direction is out of sight, and
4. They place crossing pedestrians with their backs to approaching traffic.

The best way to mitigate for a skew is to reconfigure the intersection at, or close to, a right angle. If sufficient right of way is not available for total reconfiguration, the negative effects can be mitigated with a curb extension in the flat-angle corner(s). Figure 500-27 shows an example of an intersection with excessive skew and the intersection reconfigured with improve skew angle. If a curb extension isn't feasible, then use the tightest possible radius in the flat-angle corner(s).

Figure 500-27: Skew Angle and Field of View



506.21 Long Crosswalks

Long crosswalks are a problem for all road users for several reasons:

1. The pedestrian is exposed to conflicts longer;
2. It is difficult for some people to see pedestrian signals if they are too far away, and
3. The capacity of the intersection is reduced if the signal cycle is governed by the pedestrian crossing time. ***However, operational needs must be balanced against pedestrian access needs and pedestrian safety.***

Several methods may be considered, individually or jointly, to reduce crosswalk lengths:

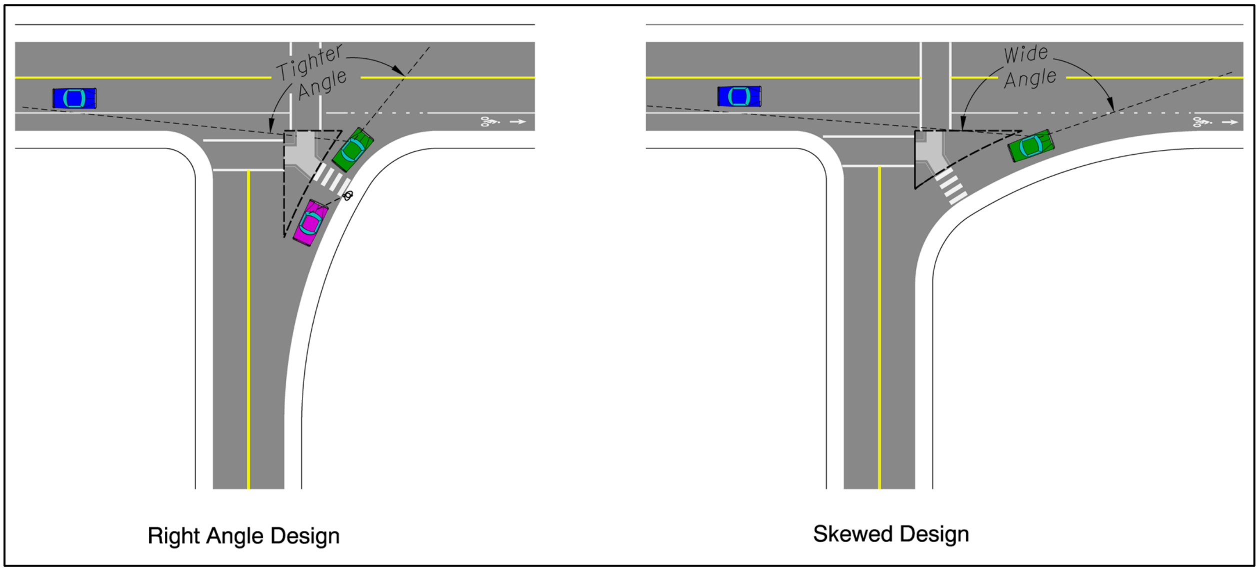
1. Narrow the cross-section;
2. Provide curb-extensions on streets with parking;
3. Reduce the skew of the intersecting street, and
4. Minimize curb radius.

If the overall crosswalk length cannot be reduced, or the above techniques still do not provide sufficient reductions, then consider placing a refuge island(s) to enable the pedestrian to cross in two or more phases. ***Pedestrian median refuges are strongly recommended when crossing more than 6 lanes. Pedestrians should not be forced into a two-phase crossing; rather, the option should be available should they be stranded on a refuge island. Always provide a pedestrian push-button on islands.*** The Signal Design Manual can provide guidance for crossings at signalized intersections. Consult the Region Traffic Section and the Technical Services Traffic Unit when considering the installation of pedestrian refuge islands.

506.22 Island Geometry

An island placed between a slip lane and through traffic can offer pedestrians a refuge, *but if it is poorly designed, the geometry can encourage drivers to make turns at high speeds without looking for pedestrians.* This can be mitigated by a design that brings the motorist to the intersecting street at close to a right angle, rather than a skew. This forces the driver to slow down and enables the driver to see the crossing pedestrian. Figure 500-28 shows an example of a reconfigured right angle design and a skewed, flat angle design. The type of design chosen varies depending upon the right turn vehicle accommodation. *In many cases the presence of large trucks creates challenges for the use of this treatment. See Section 502.1 and Figure 500-3 for more information on large vehicle accommodation and design. Also see ODOT guidance document "Guidelines for Implementation of ORS 366.215, No Reduction of Vehicle-Carrying Capacity" and the ODOT "Highway Mobility Operations Manual".*

Figure 500-28: Island Geometry (Right Turn Bypass)



506.23 Corner Radii

Large corner radii present several problems for pedestrians:

1. They make the crossing longer;
2. They enable motorists to make a turn at a potentially higher speed, and
3. They make it very difficult to line up the sidewalks, crosswalks and curb ramps.

Designers should try various design options to minimize the corner radii at intersections in urban areas. Refer to the method described in Section 506.9 Turning Radii.

Choosing the appropriate radius is often dependent on factors other than strict interpretation of design parameters. For example, it may be acceptable to design to a tight radius on approach streets with very little truck traffic, even if that means that the occasional truck may have to encroach into traffic to make a turn. Where there is a higher volume of truck traffic turning, a balance needs to be maintained between a large enough radius to accommodate truck turning, but a small enough radius to keep speeds of smaller turning vehicles low; thereby, minimizing impacts to pedestrians and bicyclists. In some locations, it might be appropriate to install an apron to minimize turning radii and accommodate the necessary vehicles. Exhibit 500-1 illustrates the use of an apron to minimize turning radius for passenger vehicles, but also allow bus and truck turning movements. When installing an apron, ADA requirements must be met. *The use of aprons must be considered carefully for overall impacts to safety and operations for all road users.*

Exhibit 500-1: Apron to Accommodate Bus Turning and Minimize Radius for Passenger Vehicles

506.24 Crosswalk and Ramp Placement

Crosswalk and curb ramp placement becomes a concern when an intersection is skewed, or if the corner radii are too large, especially with curb-tight sidewalks. The pedestrian expects the sidewalk, the curb ramp and the crosswalks to be in a reasonably straight line. The natural crossing point will be a continuation of the pedestrian zone.

Again, large corner radii create very long crosswalks. The designer may then be tempted to move the crosswalk away from the intersection, where the crossing is shorter, and crosswalks and curb ramps are perpendicular to the curb. This creates a new problem, as the crosswalk is offset from the intersection. The crossing pedestrians may not be visible to turning motorists, or pedestrians may ignore the crosswalk markings and walk where they are less inconvenienced. In other circumstances, squaring up the crossing may be the appropriate treatment. The best solution is to tighten up the intersection as much as possible.

In most instances, the best design will be arrived at through an iterative process. Imagining the natural path a pedestrian will take, while anticipating the various vehicle turning movements that may conflict with a pedestrian will help a designer reach optimal visibility of pedestrians and reasonable crossing distances. Examining driver and pedestrian expectations where pedestrian/vehicle conflicts may occur will help a designer better accommodate pedestrian crossings.

Another consideration is trying to ensure that sidewalks are separated with a buffer strip. This has two advantages: the extra separation will place the sidewalks between the offset crosswalk and the curb-tight crosswalk described above, and a curb ramp traced through the buffer strip will more effectively channel pedestrians to the right crossing point. For additional information, Part 800 provides guidance for pedestrian design and Part 900 provides information on protected intersections.

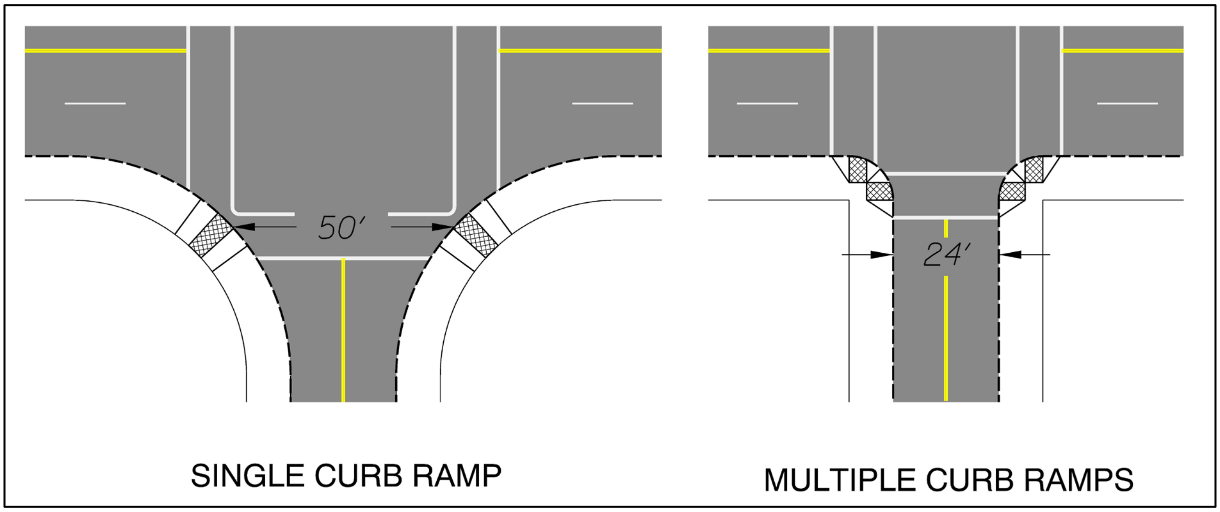
506.25 Curb Ramps - Placement and Number

U.S. Access Board guidance on compliance with the Americans with Disabilities Act (ADA) recommends two curb ramps at each corner of an intersection on new construction, and reasonable efforts should be made to install two curb ramps on all projects. **To the greatest extent feasible, provide a separate curb ramp for each intersection crosswalk location. The use of a single curb ramp on a corner that serves both directions requires a design exception.**

An advantage to utilizing two curb ramps is the ability to align curb ramp runs between the crosswalk and the adjacent sidewalk pedestrian accessible route and pedestrian zone. This allows pedestrians a straight path to follow to reach the sidewalk, rather than having to deviate from the crosswalk alignment to find the single curb ramp located at the apex of the corner. Providing two curb ramps makes it easier to construct the curb ramp run perpendicular to the curb, as required. However, on corners with larger radii, generally radii greater than 30 feet, placing two curb ramps may make it difficult to align everything correctly. In these situations, unique solutions such as utilizing shared components of a curb ramp can be a benefit. For example, a shared turn space (level landing), or a shared ramp run that is used jointly for each curb ramp to access the crosswalk (see Option “CC-3” on RD936) will bring the natural travel paths of pedestrians closer to the pedestrian zone and connecting crosswalk. Two curb ramps enable people in wheelchairs and other mobility aids, and those with low vision to enter a crosswalk directly in a straight line, without having to turn in the roadway. Figure 500-29 compares the number of curb ramps provided at an intersection corner based on corner radius, crossing distance, and location. Regardless of radius, the designer should strive to place two curb ramps for each corner where it is feasible. The use of a single curb ramp on a corner requires an approved design exception.

The drawings in Figure 500-29 are for illustrative purposes for discussion about the number of curb ramps and placement. Actual curb ramp design requires greater detail. Whatever the final design, the designer needs to provide the most optimal method available to ensure continuity for people with disabilities to traverse the distance between the crosswalk and the sidewalk. See applicable Oregon Standard Drawings for accessible island, accessible sidewalk and accessible curb ramp options and design. See Part 800 for additional information about accessible design and ODOT design practices.

Figure 500-29: Crosswalk Ramp Placement



506.26 Signal Pole and Push Button Placement

Signal poles must be placed in a location where they do not interfere with pedestrians' path of travel. They must be placed in a location that all pedestrians are able to conveniently reach and activate the signal control push buttons. There is placement criteria for accessibility that must be followed, including reach range and landing requirements to activate the push button. The designer works with the Region Traffic Unit and the Technical Services, Traffic Section concerning placement of signal poles and push buttons. The Signal Design Manual provides extensive detailed information and guidance for signal pole, pedestal, and push button placement.

In general, placing the poles correctly is made easier with tight corner radii, sidewalks separated with a buffer strip, and two curb ramps per corner. As the radius increases, it becomes more difficult to place the poles and pedestals out of the pedestrian zone and keep the push button within the appropriate reach range. **In all locations, pedestrian push buttons must be installed to meet accessibility requirements.** See Sections 5.4 and 5.5 of the ODOT Traffic Signal Design Manual for guidance on signal pole and push button placement. **Under no circumstances shall pedestrian push button poles be placed in a curb ramp run for new construction.**

This section is a general overview for signal poles and pushbutton placement to help the roadway designer understand conflicts and accessibility requirements. See the ODOT Traffic Signal Design Manual as well as the MUTCD, 4E.08 for additional detailed information on signal pole and push button pole placement requirements. Signal pole and push button placement is a specialized design consideration. Consult Region Traffic and the Technical Services, Traffic Signal staff for appropriate placement of signal poles and equipment.

506.27 Free-Flow Acceleration (Add) Lanes

This type of intersection treatment should be avoided in urban areas. ***Free-flow acceleration lanes, often called "slip lanes", are generally not allowed for urban at-grade intersections.*** They create an unexpected condition for both pedestrians and cyclists. Free-flow acceleration lanes are different than at-grade right-turn acceleration lanes described in Section 506.13. A free-flow acceleration lane provides a lane for traffic to make the turn and enter the acceleration lane without stopping. This implies priority for the turning vehicle over other roadway facility users and is generally not appropriate in urban locations. *Use of free-flow lanes is strongly discouraged where pedestrians and bicyclists are expected to cross the lane.*

If a free-flow acceleration or add lane is provided for capacity reasons, then make every reasonable effort to create conditions that make any adjacent crossings safer and easier for pedestrians and cyclists. Crossings should occur prior to vehicle acceleration locations where vehicle speed is low. Adequate sight distance must be provided for a driver to see pedestrians and bicyclists crossing the lane.

Most of the design principles offered in previous sections on right turn lanes would apply to free-flow lanes also: tighten the turning radius, narrow the lane, and keep the angle of approach as close to a right angle as possible. These three elements combined will force drivers turning right to slow down and look ahead, where pedestrians and bicyclists may be present, before turning and accelerating onto the roadway.

Section 507 Signalized Intersections

Signalized intersection design will need to consider the additional issues to the design standards for general intersection design that were discussed in Section 506. Specific roadway design items of interest at signalized intersections include left turn lanes, right turn lanes, bicycle accommodation and pedestrian needs. *It will be necessary for the designer to coordinate with the Region Traffic Unit and the Technical Services, Traffic and Roadway Sections to meet these specific design needs.*

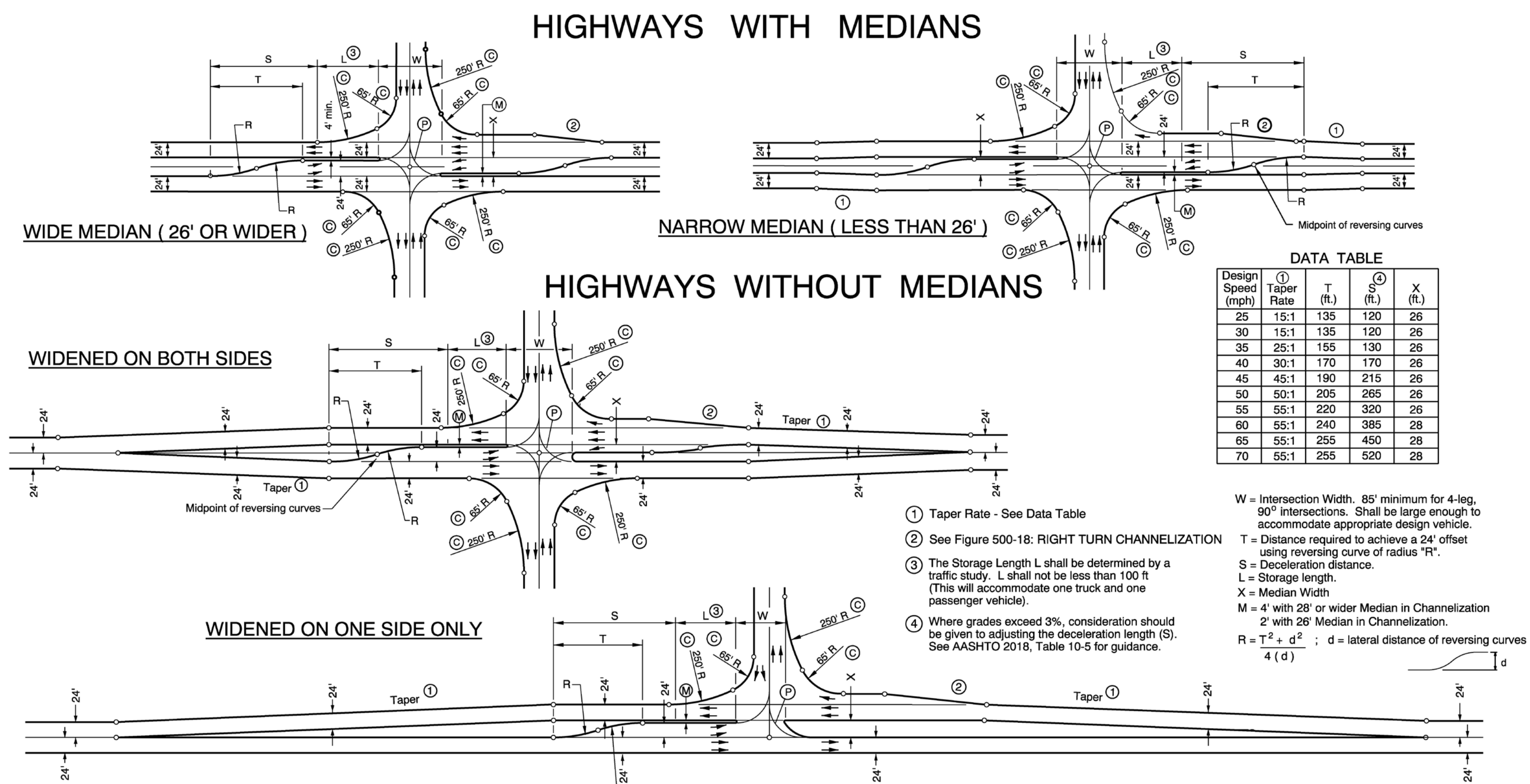
507.1 Left Turn Lanes

Most signalized intersections will have left turn lanes. *When left turning traffic is allowed from a two-way highway at a signalized intersection, a left turn lane should be provided.* Providing a traffic signal phase for left turning traffic is determined by the Region Traffic Engineering Section and the Technical Services, Traffic Section (see "ODOT Traffic Signal Policy and Guidelines").

When the left turning volume is very large, a single left turn lane may not be able to operate at an acceptable level. In these instances, a dual left turn lane may be needed. ***Requests for dual***

left turn lanes must be approved by the State Traffic Engineer (see OARs 734-020-0135 and 0140 for criteria). ***When designing dual left turn lanes, there must be dual receiving lanes on the connecting roadway with adequate length downstream prior to any merge points.*** The designer must determine the appropriate design vehicles to use for side-by-side operation through the turning movement. *In rare locations, like at freeway ramp terminals leading to truck stops or warehousing districts, that may need to be two WB-67 vehicles making the turn simultaneously. However, in most locations, a WB-67 and an SU vehicle side-by-side is adequate for design. In other locations where truck volumes are low, an SU vehicle and a passenger vehicle may be sufficient. Dual left turn lanes should be designed in conformance with* Figure 500-30. *Consult the Region Traffic Section when considering the design of a dual left turn lane as well.* Figure 500-31 illustrates channelization, island and intersection details.

Figure 500-30: Dual Left Turn Channelization



DATA TABLE

Design Speed (mph)	① Taper Rate	T (ft.)	④ S (ft.)	X (ft.)
25	15:1	135	120	26
30	15:1	135	120	26
35	25:1	155	130	26
40	30:1	170	170	26
45	45:1	190	215	26
50	50:1	205	265	26
55	55:1	220	320	26
60	55:1	240	385	28
65	55:1	255	450	28
70	55:1	255	520	28

① Taper Rate - See Data Table

② See Figure 500-18: RIGHT TURN CHANNELIZATION

③ The Storage Length L shall be determined by a traffic study. L shall not be less than 100 ft (This will accommodate one truck and one passenger vehicle).

④ Where grades exceed 3%, consideration should be given to adjusting the deceleration length (S). See AASHTO 2018, Table 10-5 for guidance.

W = Intersection Width. 85' minimum for 4-leg, 90° intersections. Shall be large enough to accommodate appropriate design vehicle.
T = Distance required to achieve a 24' offset using reversing curve of radius "R".
S = Deceleration distance.
L = Storage length.
X = Median Width
M = 4' with 28' or wider Median in Channelization
2' with 26' Median in Channelization.

$R = \frac{T^2 + d^2}{4(d)}$; d = lateral distance of reversing curves

NOTES:

For details on shoulders at channelized intersections, curbed islands, and skewed intersections see Figure 500-19

Use standard shoulder width through channelized section. For stand alone safety projects, the adjacent shoulder width may be used with a minimum of 4' shoulder width for bicycle accommodation.

Ⓒ The smallest radius that will accommodate the appropriate design vehicle should be used. Intersections on Route Map 7 with major truck movement shall "accommodate" the Interstate Design Vehicle. Where it is necessary to "design for" the design vehicle, two-centered curves minimize area of pavement. Vehicle templates or computer generated paths should be used to determine clearances. The HDM Part 600 discusses "designing for" vs "accommodating" the design vehicle. In most cases, the intersection should only "accommodate" the design vehicle since tighter curb returns and thus smaller intersections are generally safer.

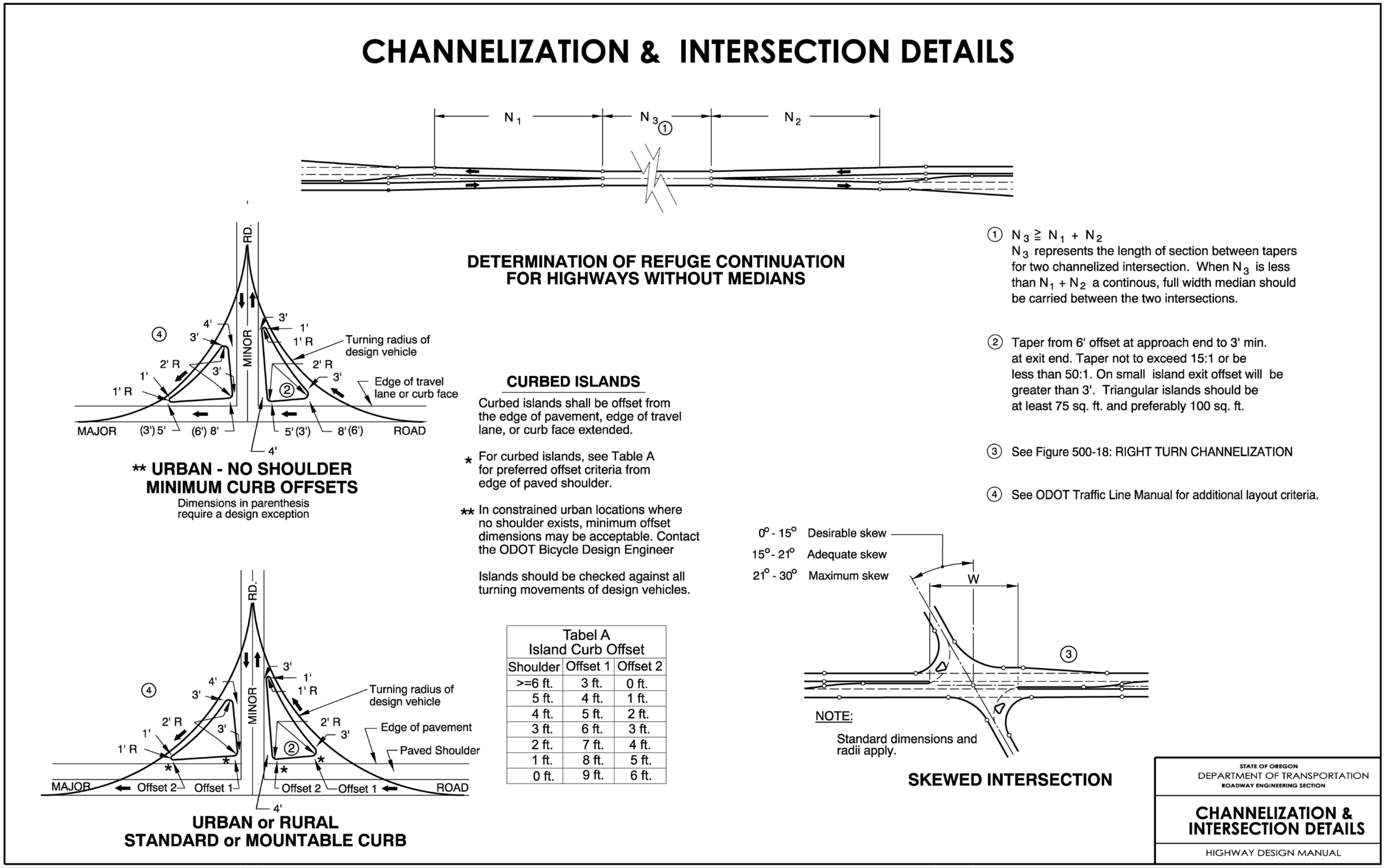
Ⓟ Inside swept path of appropriate design vehicle. Vehicle templates or computer generated paths should be used to determine the intersection width "W". This path must have a minimum 2' offset from the lane lines of opposing direction traffic.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING SECTION

DUAL LEFT TURN CHANNELIZATION & INTERSECTION DETAILS

HIGHWAY DESIGN MANUAL

Figure 500-31: Channelization Island & Intersection Details



Tabel A
Island Curb Offset

Shoulder	Offset 1	Offset 2
>=6 ft.	3 ft.	0 ft.
5 ft.	4 ft.	1 ft.
4 ft.	5 ft.	2 ft.
3 ft.	6 ft.	3 ft.
2 ft.	7 ft.	4 ft.
1 ft.	8 ft.	5 ft.
0 ft.	9 ft.	6 ft.

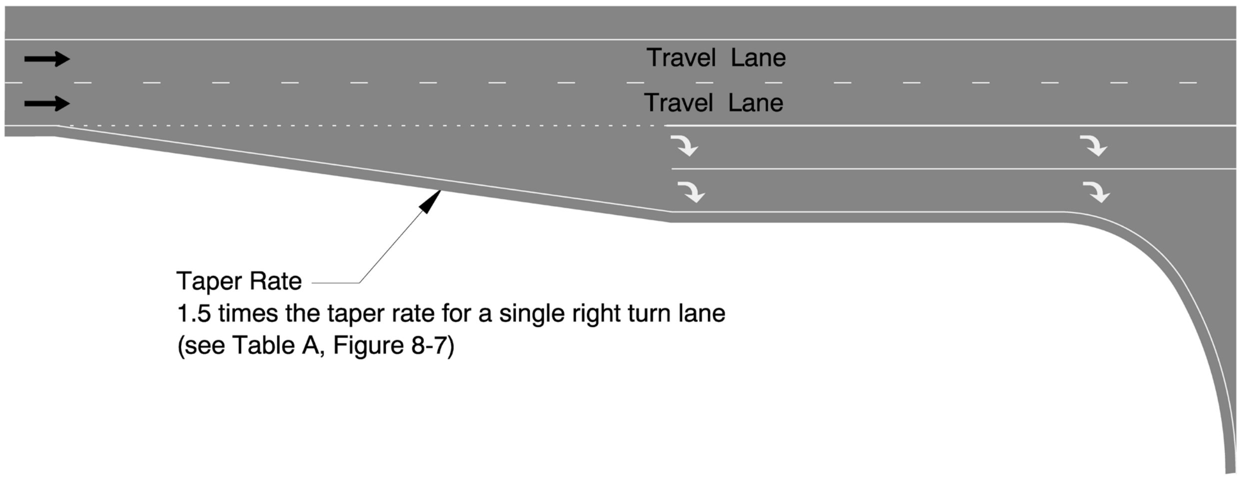
507.2 Right Turn Lanes

There are no specific warrants for installation of a right turn lane at a signalized intersection. A rule of thumb is to install a right turn lane when peak hour right turn volume is 200 or more. *However, adding a right turn lane increases pedestrian crossing distances and adds complexity for bicycle facilities. Installation of a right turn lane at signalized intersections should be justified by engineering analysis.* Consult the Region Traffic Section and the Transportation Planning Analysis Unit (TPAU) when considering the addition of a right turn lane. *In some instances, removal of an existing right turn lane may be preferred for overall operation of a signalized intersection for all road users.*

When a right turn lane is installed at a signalized intersection, it is critical to the operation of signalized intersections that adequate storage length for right turning vehicles (out of the through traffic lanes) be provided. **The storage length needs to accommodate the 95 percent queue distance through the design life of the project.** The 95 percent queue length means that there is only a 5 percent probability that the actual volume of vehicles will exceed the storage available. ***In areas where obtaining the 95 percent queue distance is impractical, the designer should provide as much storage as possible. Consider shortening the entrance taper to lengthen the available storage if possible.*** **Any exception to providing 95 percent queue distance requires approval from the State Roadway Engineer.** For individual intersection or operational projects, contact the Region Traffic Engineering Unit to determine the appropriate storage lengths needed. For complex or environmental study projects, the Transportation Planning Analysis Unit (TPAU) can be contacted to help determine the appropriate storage lengths or give guidance or technical help on the particular project or methodology. At some intersections, right turn demands might be so large that dual right turn lanes may be necessary. ***The Analysis Procedures Manual, Region Traffic, and the Technical Services Traffic Engineering Section must be consulted and the approval of the State Traffic Engineer obtained prior to installation of dual right turn lanes*** (see OARs 734-020-0135 and 0140). Where dual right turn lanes are required, follow the guidelines shown in Figure 500-32. Dual right turn lanes can create additional crossing issues for bicycle and pedestrian movements. ***When dual right turn lanes are proposed, bicycle and pedestrian movements must be considered and adequately addressed.*** Contact the ODOT Bicycle and Pedestrian Design Engineer or the project resource for active transportation for information about providing appropriate facilities.

In addition to bicycle and pedestrian considerations at dual right turn lane locations, the designer also must determine the appropriate design vehicles to use for side-by-side operation through the turning movement. *In rare locations, like at freeway ramp terminals leading to truck stops or warehousing districts, that may need to be two WB-67 vehicles making the turn simultaneously. However, in most locations, a WB-67 and an SU vehicle side-by-side is adequate for design. In other locations where truck volumes are low, an SU vehicle and a passenger vehicle may be sufficient. When considering dual right turn lanes as an option*, consult the Region Traffic Section for input. When designing dual right turn lanes, there must be two lanes on the connecting roadway to turn into and there must be adequate length provided downstream before any lanes merge.

Figure 500-32: Dual Right Turn Channelization



507.3 Bicycle and Pedestrian Needs

Signalized intersections must provide marked pedestrian crossings at all approaches and provide bicycle connectivity and continuity. There may be some locations where full access may not be appropriate. ***Locations where exceptions to full access may be considered are:***

1. Intersections that include multiple left or right turn lanes,
2. Intersections with one or more legs being one-way roadways, and
3. Intersections that are a 'T' configuration.

However, even at these locations, bicycle and pedestrian needs and movements must be addressed and accommodation is expected. The idea is to only close a crossing where there is a safety concern for pedestrians. ***Only the State Traffic Engineer can close a legal crosswalk.*** Contact the Region Traffic Section and the Traffic Engineering Section of Technical Services early in the project to determine the appropriate pedestrian crossing locations.

Section 508 Unsignalized Intersections

This section covering unsignalized intersection design is intended to enhance the discussion about general intersection design criteria covered in Section 506. *Left turn lanes, right turn lanes, bicycle access and pedestrian movements will need to be specifically considered and accounted for when designing unsignalized intersections.* The level and amount of design effort required to ensure adequate design for these modes will vary among locations. Because of the complexity of urban areas, a higher level of effort is needed to ensure that these design needs are adequately addressed.

508.1 Left Turn Lanes

Left turn lanes at unsignalized intersections must meet the siting criteria to justify installation. Regardless of the funding source, the Region Traffic Engineer must approve all unsignalized channelized left turn lanes. The designer consults with the Region Traffic Unit in locations where left turn lanes are being considered. For information about siting criteria for left turn lanes, see the ODOT Analysis and Procedures Manual (APM).

https://www.oregon.gov/odot/Planning/Pages/APM.aspx

508.2 Right Turn Lanes

Unsignalized intersections and private approach roads must meet the installation criteria prior to constructing a right turn lane. Regardless of the funding source, the Region Traffic Engineer must approve all unsignalized right turn lanes.

Since the right turning vehicles only have to yield to pedestrians and bicyclists at unsignalized intersections, there is no need to provide vehicle storage at an unsignalized right turn lane. ***The one exception is where vehicular storage may be required where the right turn lane is next to an at grade railroad crossing.*** For information about siting criteria for right turn lanes, see the ODOT Analysis and Procedures Manual (APM).

https://www.oregon.gov/odot/Planning/Pages/APM.aspx

508.3 Bicycle and Pedestrian Needs

Bicycle movements must be considered at all unsignalized intersections. There are a variety of methods available to provide adequate bicycle connectivity and continuity at these types of locations. For information, see the "Oregon Bicycle and Pedestrian Design Guide". Part 900 provides guidance for bicycle facility selection and bicycle access requirements.

By law, every intersection is a legal crossing location for pedestrians. *This is true whether the crossing is marked or unmarked. Therefore, it is important to ensure that pedestrian needs are included in the intersection design, particularly in urban areas.* See the ODOT Traffic Manual for standards, guidelines, and processes related to marking crosswalks. Part 800 provides guidance on pedestrian design requirements and ADA compliance.

Section 509 Roundabouts

509.1 General

This section provides basic information and site criteria on both single lane and multi-lane roundabouts. Please contact the Technical Services, Traffic and Roadway Sections for additional design criteria and recommendations.

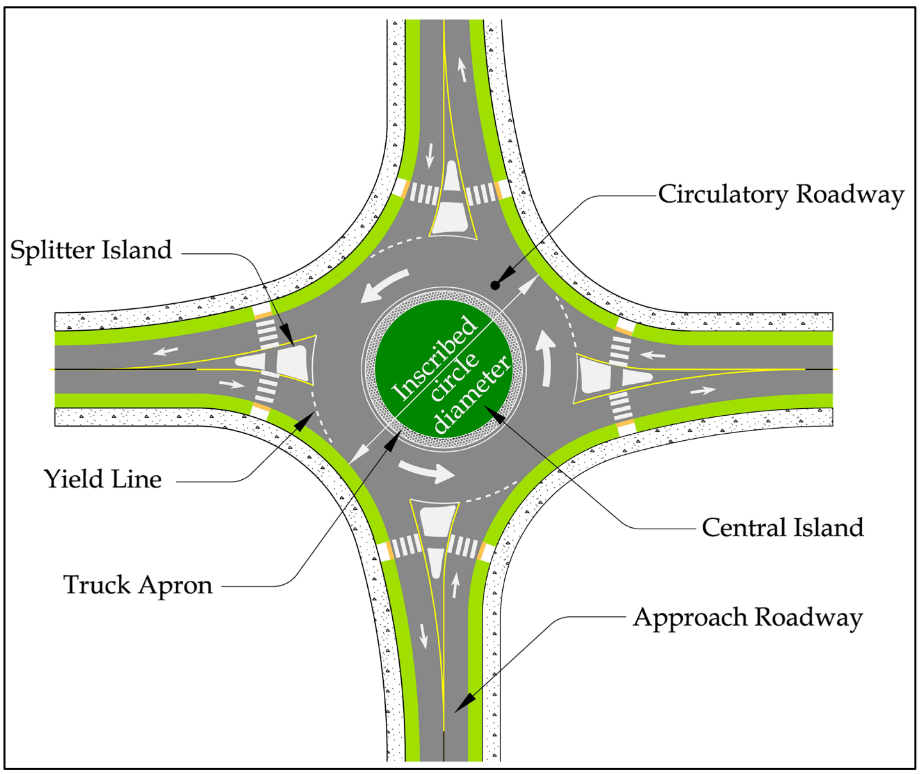
Traffic signals, stop signs and modern roundabouts are all forms of intersection control. Signal control and stop control are more established forms of intersection control and are well known to motorists, pedestrians and bicyclists. Signal control and stop control function by separating out individual traffic movements at an intersection in physical and temporal space. Each road user takes a turn or is delegated time and reasonable opportunity to move through the intersection space in sequence. However, intersections controlled by signals and stop signs do not always afford the most efficient or safest operation. When traffic volumes are low, signals can cause unnecessary delay by stopping traffic flow when conflicts do not exist. When traffic volumes are high, stop signs can cause long queues and extended delay. In addition, when motorists, pedestrians or bicyclists make mistakes or push the limits at signalized or stop controlled intersections, the results often cause severe injury or fatal crashes.

Modern roundabout controlled intersections have the potential to function much more efficiently and safely than signal controlled or stop sign controlled intersections because they do not stop traffic flow unnecessarily. By design, roundabouts allow for more consistent flow by slowing all vehicles through the intersection. By reducing delay, they improve vehicle fuel efficiency and reduce overall vehicle emissions at the intersection. They also function well during power outages or severe storm conditions. Modern roundabouts are an effective intersection control option on evacuation routes.

Modern roundabouts can also be safer than signalized or stop controlled intersections. By reducing conflict points, reducing speeds, and keeping traffic flowing in the same direction, both crash frequency and severity have been shown to be reduced when compared to other intersection control types. Roundabouts have been shown to be safer for pedestrians and bicyclists as well. By design, roundabouts lower vehicle speeds. Lower vehicle speeds translate to less kinetic energy transfer between vehicle-to-vehicle crashes, vehicle-to-bicycle crashes, and vehicle-to-pedestrian crashes. As a result, if a crash does occur in a roundabout, the severity is greatly reduced lessening the potential for a fatality or serious injury. Roundabouts are an effective tool when designing from a Safe System approach and part of an effective strategy to reduce fatalities and serious injuries at intersections.

Some people, including motor vehicle drivers, pedestrians, and bicyclists are unsure how to use roundabouts because they are less prevalent than signals and stop signs. As a result, they approach roundabouts with concern, both when discussing proposed installations and when encountering one on the highway. In some cases, drivers remember circular intersections of the past that were called “traffic circles” or “rotaries”. Many of these older circular intersections did not function well. As a result, many drivers have negative impressions of circular intersections that carry over to the present. By their design, however, modern roundabouts eliminate the undesirable design features of older traffic circles or rotaries and create an efficient and effective intersection control option with specific characteristics. The distinctive characteristics of a modern roundabout that separate it from a traffic circle or rotary include a raised central island with a circulatory roadway, raised splitter islands at the entry to introduce deflection to the vehicle path, and yield control for approaching vehicles. In older style circular intersections, circulating traffic yielded to the entering traffic and caused capacity problems that eventually leads to intersection lock-up at peak times. In various locations around the United States, operations at many of the original traffic circles and rotaries have been improved by incorporating some of the modern roundabout concepts into them where feasible. In some locations, the older style traffic circles have been removed entirely. Figure 500-33 details several major roundabout elements.

Figure 500-33: Elements of a Modern Roundabout



Studies have shown, even in communities where the initial majority viewpoint concerning the installation of roundabouts was negative, once roundabouts were installed and the community became used to driving them, the roundabouts have become a popular form of safe and effective intersection control and the community viewpoint changed to positive for the installation of roundabouts.

509.2 Overview

Roundabouts have been proven as a viable alternative to traffic signals at many intersections. Several studies comparing roundabouts to traffic signals or two-way stop-controlled intersections have demonstrated consistent results in determining that roundabouts can provide significant safety improvements. Their combined findings indicate:

1. Reduction of fatalities by more than 90 percent;
2. Reduction of injuries by up to 75 percent;
3. Reduction of all crashes by a third or more; and
4. Increases in pedestrian and bicyclist safety due to slower vehicle speeds.

Additional information concerning roundabouts and their safety performance can be found through information provided by the Federal Highway Administration website “FHWA Safety - Roundabouts” and through research results from the Insurance Institute for Highway Safety (IIHS).

All roundabouts greatly reduce conflicts at intersections and increase safety when compared to signal controlled or stop controlled intersections. However, due to differences in inherent characteristics of single lane and multi-lane roundabouts, there are differences in the potential safety improvements between them. Both single lane and multi-lane roundabouts reduce fatal and serious injury crashes. Single lane roundabouts have greater reduction in intersection conflict points than multi-lane roundabouts and, therefore, tend to have greater reduction in overall crash rates than multi-lane roundabouts.

Since there is more than one travel lane in a multi-lane roundabout, multi-lane roundabouts have the potential for sideswipe crashes that single lane roundabouts do not have. However, since speeds are slow, these crashes are generally less severe than the higher speed “T-bone” and head-on crash types that occur at signalized or stop controlled intersections. Therefore, even though multi-lane roundabouts may have a greater preponderance of side-swipe crashes than a single lane roundabout, they are still a safer alternative than a multi-lane signalized intersection because the severity of crashes is greatly reduced, while providing the necessary intersection capacity.

There are three conflict types that can occur at multi-lane roundabouts that do not occur at single lane roundabouts, and they can lead to sideswipe crashes. They are categorized as:

1. Driver fails to maintain lane position through the roundabout (Note: ORS 811.292 and ORS 811.370 have provision for “commercial motor vehicles” to operate outside a single lane in a multi-lane roundabout when necessary.)

2. Entering driver fails to yield properly and enters next to a vehicle exiting the roundabout.
3. Driver turns or exits from the incorrect lane and crosses the path of a vehicle in the outside lane.

These types of driver error are not unique to roundabouts and similar errors can also occur at conventional intersections. However, with good roundabout geometric design consistent with appropriate entry and exit angles, vehicle deflection and sight distance as well as effective striping and signing, the first two can be minimized thereby further improving safety over conventional, multi-lane intersections.

Along with the potential safety benefits they provide, roundabouts can also reduce congestion and delay. They have been shown to be efficient during both peak and non-peak hours. Other distinct advantages of roundabouts include the following:

1. Reduced pollution and fuel use through smoother flow and fewer stops;
2. Significant life-cycle cost savings when compared to traffic signals due to no signal equipment installation and reduced maintenance costs; and
3. Can provide traffic calming and general speed reduction, while supporting urban and rural community values through quieter operation and by providing a traffic control solution that is both functional and aesthetically pleasing.

As stated earlier in this section, some features of multi-lane roundabout design are significantly different from single lane roundabout design and some techniques used in single lane roundabout design may not directly transfer to multi-lane roundabout design. However, several principal objectives should be achieved when designing any roundabout. The following principles are the goal of roundabout designs:

1. Provide slow entry speeds and consistent speeds through the roundabout utilizing vehicle path deflection.
2. Provide the appropriate number of lanes and lane assignments to achieve adequate capacity, lane volume balance and lane continuity for necessary vehicle movements.
3. When determining number of lanes needed, a 20-year analysis is not always appropriate. Adding lanes too soon in a roundabout's life can reduce the overall safety benefits roundabouts afford. Consider staged design to achieve maximum safety performance. Staged design should consider right-of-way needs for future lanes.
4. Provide smooth channelization that is intuitive to drivers that results in vehicles naturally using the intended lanes.
5. Provide adequate design and accommodation for all vehicle types expected to use the roundabout, including freight and transit vehicles.
6. Design to include the needs of pedestrians and bicyclists.

7. Provide appropriate sight distance and visibility for driver recognition of the intersection and potential conflicts with other roadway users both motorized and non-motorized.

The Transportation Research Board (TRB) and the FHWA have published a useful guidance document entitled NCHRP Report 1043, Guide for Roundabouts. It can be found on the TRB/NCHRP website.

For proposed roundabouts on state highways in Oregon, staff should familiarize themselves with FHWA guidance documents, the Oregon Highway Design Manual, including this section, Section 509 Modern Roundabouts, the Roundabout Selection Criteria And Approval Process (Section 509.3 of the HDM and Section 403 (Roundabouts) of the ODOT Traffic Manual) as well as pertinent sections of the Analysis and Procedures Manual (APM) published by TPAU.

Before proceeding to the Roundabout Selection Criteria and Approval Process, a thorough alternatives analysis should have been completed in the form of an Intersection Traffic Control Study showing that a roundabout is a viable alternative when compared to other types of intersection traffic control. Refer to the Intersection section of the ODOT Traffic Manual for more detail on how to conduct this type of analysis. Capacity for the proposed roundabout should be analyzed for the appropriate peak hour flow(s). However, roundabouts have proven to provide greater traffic flow and can still function well at Vehicle to Capacity Ratios (V/C) of 0.90 and even as high as 0.95 for short periods of time.

If traffic analysis based on a 20-year projection shows the need for additional lanes in a roundabout, it is important to understand when the additional lanes will be needed. Building extra lanes at the outset that are not needed can have negative impacts on the safe operations of the roundabout in the interim until the lanes are truly needed. Keeping roundabouts to single lane operation for as long as possible and phasing additional lanes when needed is best practice. If analysis shows the single lane will function for many years, it is advisable to start with a single lane roundabout and add lanes when, or if, operation reaches a V/C of 0.90.

509.3 Roundabout Selection Criteria and Approval Process

Roundabouts are proposed for a variety of reasons including safety improvements, operation improvements, community livability, traffic calming, aesthetic gateway treatments, etc. ***The State Traffic Engineer has been delegated the authority to approve the installation of roundabouts on State Highways in consultation with the State Roadway Engineer.*** Requests for roundabout evaluations are a collaborative process between the Region Traffic Unit and Region Roadway Unit. ***All roundabout requests sent to the State Traffic Engineer and State Roadway Engineer for consideration shall be jointly sent by the Region Traffic Manager and Region Roadway Manager, accompanied by an Engineering Investigation that includes***

purpose, need and intent of installation of the proposed roundabout. In addition, the Engineering Investigation shall address the considerations as described in the following discussion.

Once the State Traffic Engineer receives a request, the Traffic and Roadway Sections will coordinate a review with other technical staff from Technical Services and the Transportation Planning Analysis Unit (TPAU) to make a recommendation to the State Traffic Engineer. Analysis is performed to evaluate the roundabout option in relation to other traffic control options. This is an Intersection Control Evaluation (ICE) and may follow FHWA guidelines grounded in safety analysis. Refer to Section 400.0 of the ODOT Traffic Manual for intersection control evaluations. If the information provided is insufficient or not appropriate in methodology (see the ODOT Analysis Procedures Manual (APM))as determined by the Department) the State Traffic Engineer may request further analysis.

The approval process for roundabouts is divided into two phases: Conceptual Approval and Design Approval. ***The State Traffic Engineer will make the decision whether roundabouts will receive Conceptual Approval and move to the Design Approval phase in consultation with the State Roadway Engineer. Conceptual Approval must follow ODOT procedures that assure the roundabout can accommodate freight movement on the highway.*** (Refer to ODOT's Mobility Engagement Guidance for Intersection Improvements and Roundabouts.) This requires the Region to engage with the Mobility Advisory Committee to seek the following through the freight mobility committee review process (ORS 366.215; OAR 731-012):

- An agreement with the Mobility Advisory Committee on roundabout sizing. See ODOT Directive DES 02.
- Stakeholder Forum support for proposed reductions in Vehicle-Carrying Capacity (if applicable): Refer to ODOT's ORS 366.215 Implementation Guidance.

The State Roadway Engineer will make the final decision on the approval of the geometric design in the Design Approval phase. Consult with the Statewide Mobility Program and the Region Mobility Liaison for additional guidance.

Conceptual Approval will constitute official approval under the Delegated Authorities of the State Traffic Engineer for a roundabout to be used as traffic control at a particular intersection. For Conceptual Approval, an Intersection Traffic Control Study addressing all pertinent considerations described in this section will be required. ***In addition, a Conceptual Design of the intersection shall be submitted to the State Traffic Engineer for review by Traffic and Roadway Engineering Sections staff. Conceptual Approval will not be granted until staff in the Traffic and Roadway Engineering Sections verify that the region has followed the ODOT procedures related to*** roundabout sizing (ODOT Directive DES 02) and, if applicable, reductions in ***vehicle carrying capacity*** subject to a Stakeholder Forum review (*ORS 366.215; OAR 731-012*). See Section 403.0 of the ODOT Traffic Manual for conceptual approval requirements.

Design Approval will constitute the final approval phase of the roundabout at a particular intersection. The geometrics of roundabout designs (including channelization plans) must be submitted to the State Roadway Engineer for review and approval.

The Department has developed a list of considerations that should be addressed in the Engineering Investigation that is submitted for proposed roundabout locations. These considerations should not be interpreted as roundabout warrants, nor should they be considered pass/fail criteria for installation of a roundabout. These have been identified as important considerations to evaluate when proposing roundabout intersections on state highways.

1. Freight Mobility needs should be sufficiently defined and addressed prior to Conceptual Approval.
2. Motorized user mobility needs must be balanced with the mobility needs of non-motorized road users. The ability for bicyclists and pedestrians to safely move through the roundabout intersection is equally important as the mobility needs of motorized vehicles. Designers are encouraged to first utilize separated bicycle facilities with their roundabout designs where applicable and appropriate. At a minimum, bicyclists are given the option to use either the circulating roadway with other vehicles or the pedestrian crosswalks outside the circulatory roadway. Special design considerations are needed for the pedestrian crosswalk at the entrances and exits on all legs of the roundabout where vehicles are either decelerating to enter the roundabout or accelerating to exit the roundabout. Multi-lane roundabouts, like other multi-lane intersections, have potential for "multiple threat" conflicts between vehicles and pedestrians, particularly low vision and blind pedestrians. The Public Rights-Of-Way Accessibility Guide (PROWAG) has identified the need for pedestrian-activated crossing capability at multi-lane roundabouts. Although not explicitly required at this time, rulemaking is proposed, and it is prudent to design a multi-lane roundabout for easy installation of the necessary equipment in the future. Crosswalk placement, striping, installing conduit as well as identifying and reserving necessary equipment locations even though final installation of all the equipment is not necessary at this time, is good design practice and can save money in the future. Generally, Rectangular, Rapid Flashing Beacons (RRFB) are being installed at multi-lane roundabout entrances on state highways.
3. Roundabout design should consider the needs and desires of the local community including speed management and aesthetics.
4. Intersection safety performance is a primary consideration when pursuing a roundabout for intersection control. Predicted reductions in fatal and serious injury crashes is compared with other types of intersection control such as traffic signals or other alternatives supported by crash modification factors (CMF) from the AASHTO Highway Safety Manual.

5. Roundabout entrance geometry, circulating geometry and exit geometry is designed to allow the design vehicle to traverse the roundabout in a reasonable and expected manner commensurate with best design practices as shown in NCHRP Report 1043, Guide for Roundabouts and the HDM. This design utilizes a representative template of the design vehicle, and the vehicle path is demonstrated using computer-generated path simulation software.
6. Roundabouts should meet acceptable v/c ratios for the appropriate Design Life. Analysis considers when in the Design Life the roundabout will most likely reach capacity. Roundabouts can still function well at V/C values of 0.90. Building a roundabout too large for initial operations can negatively impact safety performance (See subsection 1206.3 Design Guidelines regarding design life for possible exceptions to this consideration.)
7. Roundabouts proposed for the state highways with posted speeds higher than 35 mph will require special design considerations (e.g., possibly longer splitter islands, specific landscaping, possibly reversing curve alignments approaching the roundabout, etc.) to transition the roadside environment from higher to lower speeds approaching the roundabout intersection. A roundabout needs to be seen by approaching drivers and in higher speed locations needs a higher level of conspicuity.
8. For roundabouts with more than 4 approach legs, special design considerations should be made for the layout of the approach legs.
9. Roundabout proposals should address how roundabout operations would impact the corridor immediately upstream and downstream from the roundabout intersection. (If the proposed roundabout is in a location where exiting vehicles would be interrupted by queues from signals, railroads, draw bridges, ramp meters, or by operational problems created by left turns or accesses, these problems should be addressed by the Engineering Investigation.

For brevity, the following is summarized from the ODOT Traffic Manual, Section 403, Roundabouts, and is included in a bulleted, step-wise listing. For the full text, reference the ODOT Traffic Manual.

Steps in the Roundabout Selection Criteria and Approval Process include:

1. Perform an engineering Investigation including a comprehensive Intersection Traffic Control Study. In addition to site specific intersection data, the investigation should include comparisons of intersection control types (i.e., stop controlled, signal controlled, roundabout, etc.)
2. Determine design Life – generally 20 years for STIP projects and 10 years for development review.
3. Submit a scaled Conceptual Design of the proposed roundabout to the State Traffic Engineer for approval including roundabout type, geometry, topography, influence

area, approximate right-of-way required as well as other pertinent design information and impacts. Figure 500-33 illustrates major design elements of a roundabout.

4. After Concept Design Approval has been obtained, submit a refined Design Package to obtain Design Approval from the State Roadway Engineer. This Design Package should include:

    a. Channelization plans, completed per the Department's guidance for roundabout pavement markings found in the Traffic Line Manual and for splitter islands found in the Highway Design Manual.

    b. A summary of the documented design decisions including

        i. how the requirements of Highway Division Directive DES 02 have been net, or

        ii. How the OAR 731-012 process (Reduction of Vehicle Carrying Capacity) has been met.

    c. Identified deviations from design standards where design exceptions might be needed.

    d. Roundabout geometric data, including:

        - Approach, entry, exit, and circulating design speeds for all approach legs including any bypass legs for right-turning vehicles. (Bypass legs should be designed for speeds no more than 5 mph greater than the design speed of the circulatory roadway in order to accommodate bicycles and pedestrians crossing the bypass leg);
        - The design vehicle for each movement and accommodations for other special vehicles (e.g., permitted loads, farm equipment, etc.);
        - A table or drawing summarizing the roundabout design details, including inscribed diameter, central island diameter, truck apron designed to accommodate the appropriate design vehicle for the roundabout, and cross slope of the circulating roadway;
        - Detailed drawings showing the fastest path for each movement, with speed and radius for each curve;
        - A table summarizing stopping and intersection sight distance on each leg; and
        - Computer generated (AutoTurn) paths showing design vehicle and largest oversize vehicle movements (The Highway Division Directive DES 02 process will help identify the oversized loads that could be expected).

5. Detailed drawings of the splitter islands on each leg. These should include pedestrian and bicycle accommodation, ramps, etc.

6. Preliminary signing and illumination plans.

509.4 Design Considerations

It is the intent of the Department to ensure that the geometric design of roundabouts adheres to principals that encourage lower speeds where appropriate and improves safety for all users. These principals will also have traffic-calming benefits on the road system. It must be recognized that the design of a roundabout is an iterative process. Geometric layout may need to be refined several times before capacity and safety requirements can be achieved. Engineering judgment will be required to refine the layout. Each roundabout has its own unique requirements.

The following discussion presents some basic design considerations for modern roundabouts. Additional design details and layout considerations can be obtained through consultation with the Roadway Engineering Section of Technical Services. **Roundabout designs on the state highway system shall use NCHRP Report 1043, Guide for Roundabouts and the HDM to determine design criteria and compliance with design standards. Where design considerations may conflict, the ODOT Highway Design Manual criteria will be used to resolve the conflict.**

509.5 Design Vehicle

When designing intersections on the state highway system, ODOT makes a distinction between "designing for" and "accommodating for" large vehicles. The typical design vehicle for intersections on state highways is the WB-67 class Interstate Truck also known as the Interstate Design Vehicle. Vehicles larger than the WB-67 class are accommodated as necessary. In the design of roundabouts, as with other highway facilities, layouts should provide accommodation for the largest vehicles likely to use the facility. The primary consideration for designing a roundabout to allow large vehicles to satisfactorily traverse it is to select both the appropriate design vehicle and, if necessary, the appropriate accommodation vehicle. Once the vehicles have been selected, the necessary design for entrance geometry, circulating geometry and exit geometry can be provided.

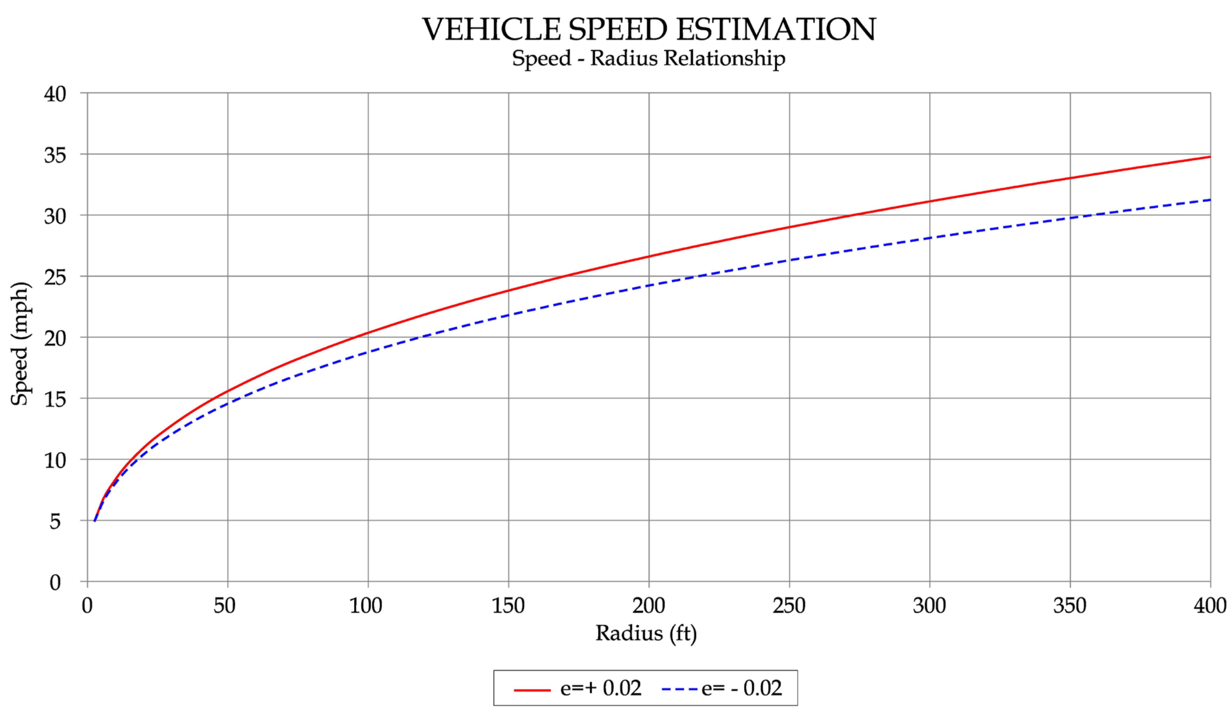
When designing a roundabout on the state highway system, the designer:

1. ***Shall coordinate with the ODOT Statewide Mobility Program and appropriate highway user groups to determine type and frequency of large vehicle traffic expected to use the roundabout.***
2. ***Shall use a WB-67 Interstate Truck as the design vehicle, unless it has been determined through coordination with the ODOT Statewide Mobility Program and appropriate highway user groups that a smaller vehicle is acceptable.***

3. ***Shall consider and accommodate as necessary, based on conversations with the ODOT Statewide Mobility Program and appropriate highway user groups, the need of over-dimensional vehicle passage through the roundabout.***
4. **Shall design entrance geometry, circulating geometry and exit geometry for all roundabouts, single lane and multi-lane, to allow the design vehicle to traverse the roundabout in a reasonable and expected manner commensurate with best practices as shown in NCHRP Report 1043, Guide for Roundabouts and the HDM.** *It is also important to remember that ORS 811.292 and ORS 811.370 have provision for "commercial motor vehicles" to operate outside a single lane in a multi-lane roundabout when necessary.*
5. ***Shall design the roundabout using representative templates for the design vehicle and for any vehicles being accommodated with the design. This design will utilize the representative templates to demonstrate vehicle accommodation and vehicle pathway through the roundabout by using computer generated path simulation software.***
6. ***Shall coordinate with the ODOT Statewide Mobility Program and other highway user groups throughout the design process to ensure all roundabout user expectations are being considered, including bicycle and pedestrian needs.***

509.6 Design Speed and Target Speed

Figure 500-34: Estimated Vehicle Speed and Radius Relationship – Fastest Path



Highway designers generally use a selected design speed when designing roadway elements for a project. However, in the traditional sense of highway design, the term design speed doesn't necessarily relate well to roundabouts. Controlling speed plays an important part for safety at roundabouts. Roundabouts are purposely designed so that traveling speeds are restricted to a low and consistent speed through the roundabout. Figure 500-34 demonstrates estimated vehicle speeds based on the relationship of path geometry in the terms of radius and superelevation to corresponding theoretical velocity when calculating fastest paths through a roundabout. Superelevation for the path through a roundabout is considered to be a typical positive two percent at entrance and exit and a typical negative two percent along the circulating roadway. Table 500-4 is a tabular form of the path speed/radius relationship based on 25 foot increments in radius and the typical positive and negative two percent superelevation. The vehicle speed values shown on the graph in Figure 500-34 and in Table 500-4 are determined by utilizing the simplified equations shown in NCHRP Report 1043, Guide for Roundabouts where:

$\boldsymbol{V = 3.4415R^{0.3861}}$ for e= +2%

and

$\boldsymbol{V = 3.4614R^{0.3673}}$ for e= -2%.

These simplified forms are derived from the basic equation for velocity and minimum radius from the AASHTO Green Book;

$$\boldsymbol{V = \sqrt{15R(e+f}}$$

They are only valid for superelevation values (e) of +2% and -2%. Side Friction Factor (f) varies with speed as shown in Figure 3-6 (Side Friction Factors Assumed for Design) in the AASHTO Green Book and is accounted for in the equations. In an actual design, if superelevation is greater or less than the assumed positive and negative two percent shown in Figure 500-34 or Table 500-4 then theoretical fastest path speeds for the specific design will need to be calculated using the AASHTO minimum radius equation. Design superelevation (e) and friction factor (f) values can be obtained from the 2011 AASHTO Figure 3-6, Side Friction Factors Assumed for Design.

Table 500-4: Speed to Radius Relationship

Radius (ft.)	V(+2%) (mph)	V(-2%) (mph)
25	12	11
50	16	15
75	18	17
100	20	19
125	22	20
150	24	22
175	25	23
200	27	24
225	28	25
250	29	26
275	30	27
300	31	28
325	32	29
350	33	30
375	34	31
400	35	31

Speed (V), Radius (R) Relationship Equations:

Equation 500-1: Speed Radius Relationship

$$\boldsymbol{V = 3.4415R^{0.3861}} \qquad \text{For e= 2\%} \qquad \text{(NCHRP Report 1043, Equation 9.3)}$$

Equation 500-2: Speed Radius Relationship

$$\boldsymbol{V = 3.4614R^{0.3673}} \qquad \text{For e= -2\%} \qquad \text{(NCHRP Report 1043, Equation 9.4)}$$

Equation 500-3: Speed Radius Relationship

$$\boldsymbol{V = \sqrt{15R(e+f)}} \qquad \text{(AASHTO Minimum Radius)}$$

The design speed of the roundabout intersection should not be confused with the design speed of the highway. In many cases, the design speed of the approaching roadway may be greater than the speed for which the roundabout will be designed. Therefore, it is advantageous to use the term target speed when designing the roundabout layout. This will eliminate confusion with the approach road design speed. For roundabouts, target speed is considered the speed of the “fastest path” of a vehicle through the roundabout. This is also called “geometric speed” in NCHRP Report 1043, Guide for Roundabouts.

There are five critical path radii used to determine fastest path movements through a roundabout. The fastest path of a vehicle is a theoretical analysis of entrance radius (R_1), the circulating radius (R_2), exit radius (R_3), left turn radius (R_4) and right turn radius (R_5). Figure 500-35 denotes the five critical radii that determine fastest path calculations for a roundabout. Figure 500-36 and Figure 500-37 demonstrate the method and assumptions used to calculate a fastest path through a single lane roundabout and a multi-lane roundabout respectively.

On the state highway system, maximum theoretical entry approach speeds for single lane roundabouts should be 25 mph. For multi-lane roundabouts maximum theoretical entry approach speeds should be limited to 30 mph. Target speeds for single lane roundabouts should be between 15 and 20 mph and between 20 and 25 mph for multi-lane roundabouts. Theoretical speeds through the roundabout (entry, circulation, exit) should be kept consistent with no greater differential than 10 mph to 15 mph maximum between entry and exit. For smaller diameter roundabouts found on local jurisdiction highways, these theoretical speeds may need to be reduced to fit the smaller design.

A safely designed roundabout should have geometry that accommodates all traffic movements at the chosen approach and target speeds, thereby maximizing safety benefits and minimizing the area needed for installation.

Figure 500-35: Five Critical Path Radii for Fastest Path Analysis

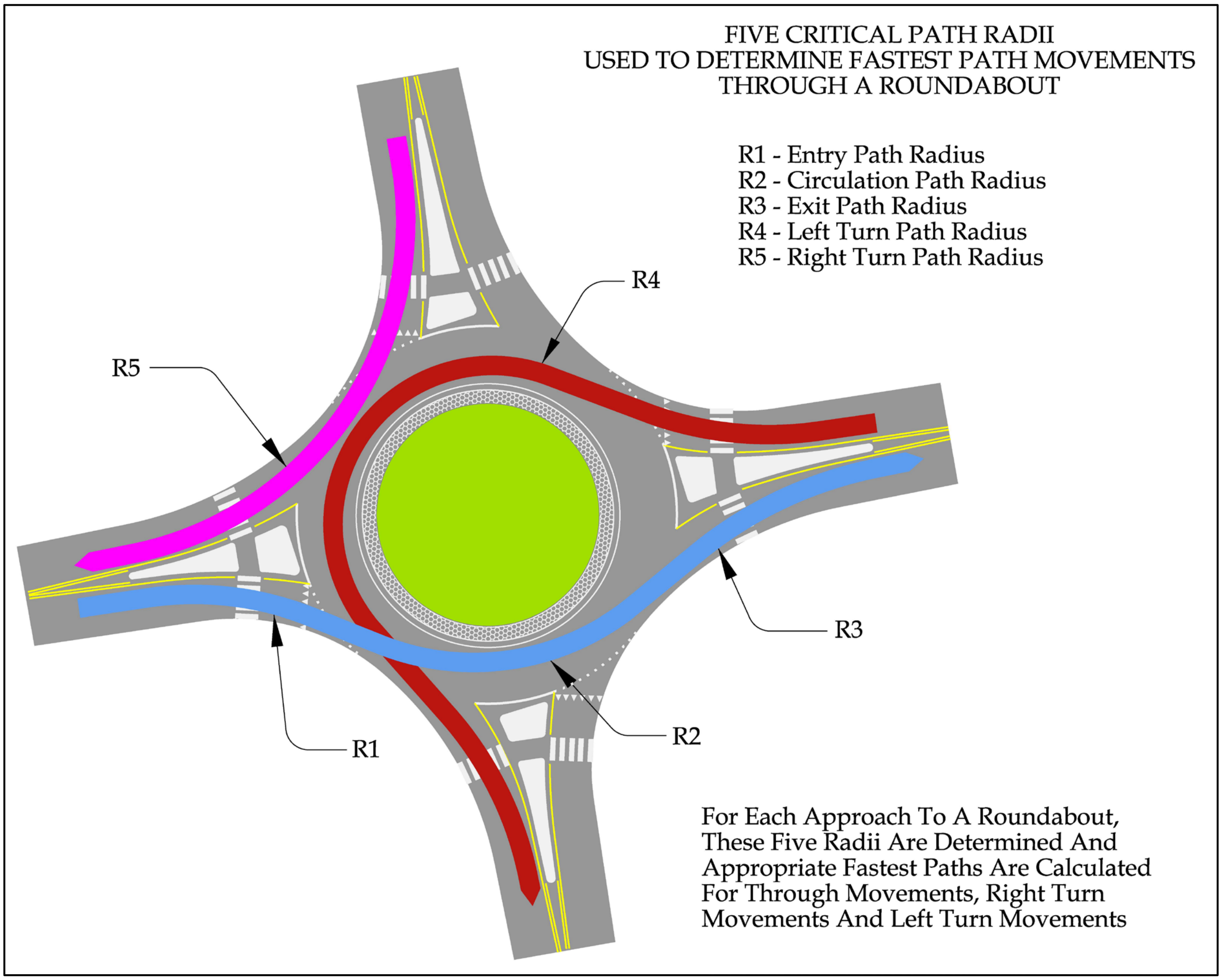


Figure 500-36: Fastest Vehicle Path through a Single Lane Roundabout

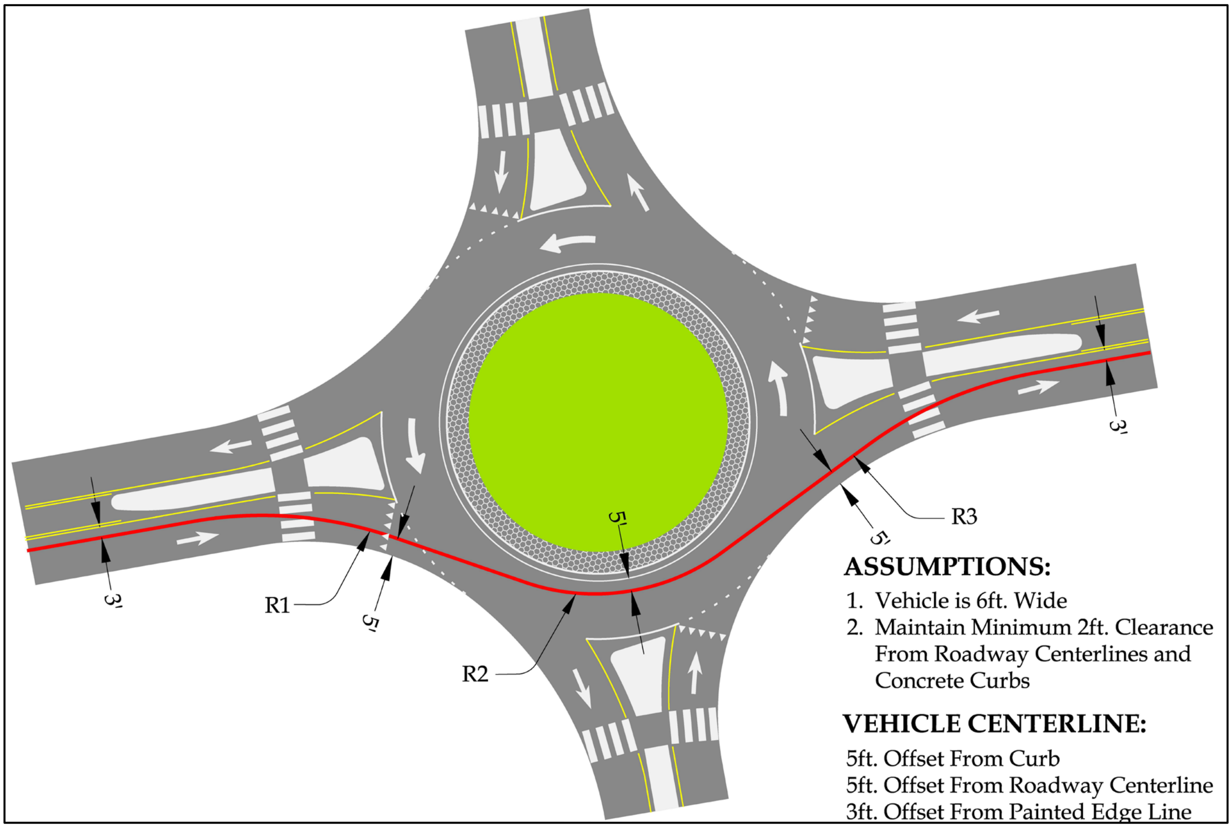
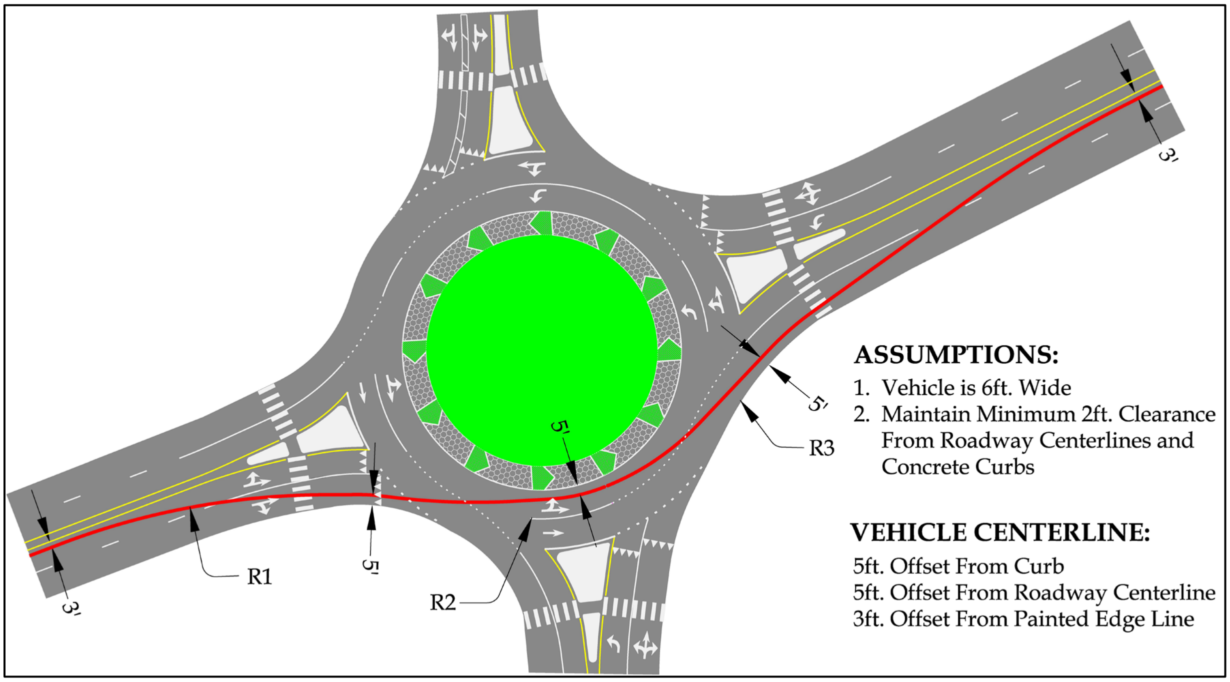


Figure 500-37: Fastest Vehicle Path through a Multi-Lane Roundabout



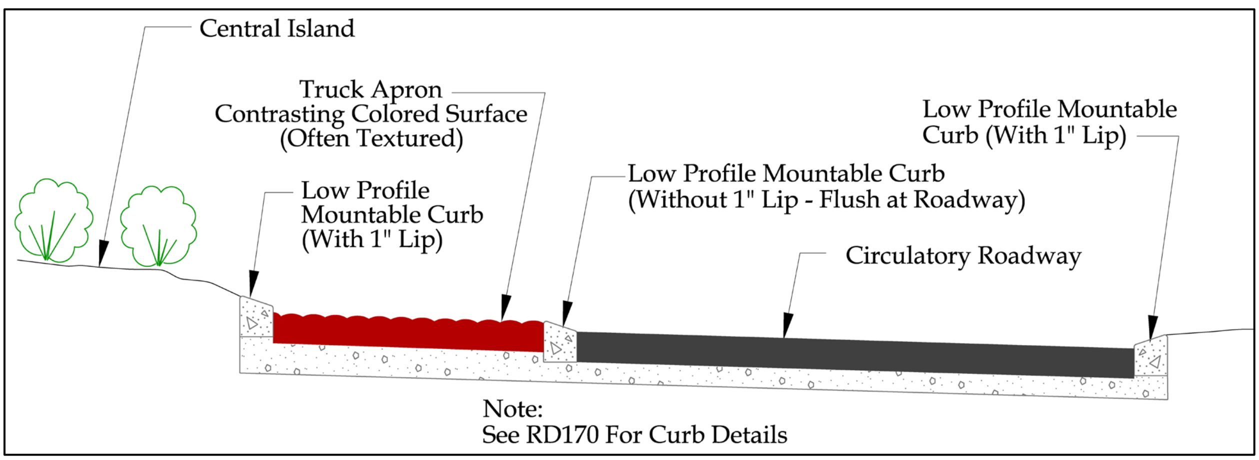
509.7 Inscribed Circle and Central Island

The inscribed circle is the outside edge of travel of the circulatory roadway. The central island is the raised area surrounded by the circulatory roadway. There are two areas of a central island, the mountable truck apron and the non-traversable center raised area. Figure 500-38 shows a typical cross-section of a roundabout including the basic elements of the truck apron, circulating roadway and central island.

Low profile mountable curbing is used for roundabouts on the state highway system. ***For truck aprons or where it is anticipated that trucks will need to mount the curb to maneuver through a roundabout, the low-profile curb is installed <u>without</u> the 1-inch lip and the edge of the slope is flush with the roadway finish surface. On splitter islands approaching the roundabout, the low-profile curb is generally installed with the 1-inch lip at the roadway finish surface. However, if there are locations along the splitter island where it is intended for large or over-sized vehicles to mount the curb to traverse the roundabout, the curb can be installed without the lip and flush with the roadway finish surface. See RD170 for curb details at roundabouts on the state highway system.***

It is important to maintain color differentiation between roadway areas, apron areas and splitter islands. This helps drivers see and understand the different areas of a roundabout and where they should be driving. It is strongly recommended to use red brick coloring for concrete truck apron and splitter island surfaces if using concrete as the traveled lanes near and inside the roundabout. This will provide strong color differentiation when either concrete or asphalt is used for the roadway surfacing. Patterning the apron and the splitter island surfaces is also recommended. Patterning discourages passenger vehicles from using the apron area unless necessary.

Figure 500-38: Typical Roundabout Cross-Section Elements



The Interstate Design Vehicle (WB-67 class truck) is the standard design vehicle for roundabouts on the state highway system. *Vehicles larger than a WB-67 vehicle will be*

accommodated at roundabouts where necessary as determined through conversation with the ODOT Statewide Mobility Program and appropriate highway user groups.

The truck apron is a key roundabout design element to provide passage and accommodation of the design vehicle and larger vehicles through the roundabout. Encroachment onto the truck apron is permitted and encouraged for large vehicles to effectively traverse a roundabout; however, vehicles smaller than the Interstate Design Vehicle may be accommodated without encroachment.

To minimize circulatory roadway width for single lane roundabouts, some states use the design philosophy that the circulatory roadway should be only wide enough to allow passage of a standard bus, fire truck, or ambulance without using the truck apron and therefore, all larger vehicles would use the truck apron for off-tracking. This is good design practice to minimize the circulatory roadway width, reduce cost, reduce impacts to adjacent properties, and provide a more comfortable ride for passengers.

Design each roundabout to fit the location needs and to provide the most appropriate design elements for the traffic stream expected to use it. In the case of mini-roundabouts or compact roundabouts, the central island may need to be mounted by all larger vehicles. In rare, single lane locations where high proportions of heavy vehicles are expected, the design of adequate circulatory roadway width with minimal use of the truck apron might be appropriate. It is anticipated that locations with wider circulating lane width would be the exception as a special case.

Increasing circulatory roadway width or inscribed diameter to accommodate large vehicles within the circulatory roadway will generally increase the fastest path speeds through the roundabout for smaller vehicles, thereby potentially negating some of the safety benefits afforded by roundabouts. *A balance must be maintained between accommodating large vehicles and the safe, effective passage of general traffic for which the roundabout is intended.*

NCHRP Report 1043, Guide for Roundabouts lists ranges of acceptable inscribed diameters for both single lane and multi-lane roundabouts. See Table 500-5 for inscribed diameters suggested in NCHRP Report 1043.

For general design parameters on the state highway system, the inscribed circle diameter for a single lane and multi-lane roundabouts accommodating the Interstate Design Vehicle generally follows the inscribed circle diameter of the NCHRP Report 1043. For Oregon state highways, ORS 366.215, OAR 731-012, and directive DES-02 must also be considered and appropriate procedures followed when determining the design inscribed diameter of a roundabout. Table 500-5 provides guidance for inscribed diameters. For roundabouts proposed on a reduction review route, the OAR 731-012 process leads to a record of support and documents collaboration with interested parties. See Oregon Revised Stature 366.215 Implementation Guidance for more information. On non-reduction review routes, the DES-02 process provides agreement of the roundabout being "properly sized".

If a smaller vehicle than a WB-67 class vehicle has been deemed the appropriate design vehicle, a smaller inscribed diameter may be acceptable. **Using inscribed diameters smaller than the minimums described above require design concurrence and/or design exceptions. Contact the Technical Services, Roadway Engineering Section for guidance.**

In addition to design vehicle considerations, there are many other factors to consider when determining the inscribed diameter for a proposed roundabout. There may be locations where a smaller inscribed diameter is appropriate to accomplish overall intersection control goals. These locations should be considered on a case-by-case basis and designed accordingly to achieve the necessary intersection control. These designs may be based on a smaller design vehicle if deemed appropriate through conversation with the ODOT Statewide Mobility Program and the requisite highway user groups.

If a WB-67 class vehicle is the design vehicle and a smaller diameter is proposed, then the truck apron may need to be widened for accommodation. However, widening the truck apron will reduce the central Island diameter and may create undesirable visibility and sight lines across the roundabout. In lower speed, urban locations, this may not be a substantial consideration.

Table 500-5: Roundabout Inscribed Diameters

ROUNDABOUT INSCRIBED DIAMETER					
	NCHRP Report 1043			ODOT Range	
Design Vehicle	**Single Lane	Multi-Lane 2-Lane	Multi-Lane 3-Lane	**Single lane	Multi-Lane (2-Lane)
WB-67	120 ft. - 180 ft.	140 ft. – 180 ft.	190 ft. - 240 ft.	*130 ft. -180 ft.	*175 ft. – 220 ft.
SU-30 BUS-40 WB40/ WB-50	65 ft. - 130 ft.	135 ft. – 160 ft.	190 ft. - 240 ft.	*95 ft. -130 ft.	*165 ft. – 220 ft.

* Design exception required for smaller inscribed diameters

** Mini-roundabouts and compact roundabouts are special cases of single Lane designs and have general diameters from 45ft. – 90ft. and from 65ft. – 120ft. respectively

In addition to the inscribed diameters shown in Table 500-5, there are inscribed diameter ranges of smaller diameters that can be utilized in certain locations to meet operation and safety needs with minimal to no right-of-way acquisition. Depending on diameter and agency terminology, these types have been termed “mini-roundabout” or “compact roundabout”. In general, mini-roundabouts fall into a diameter range of 45 ft. to 90 ft. and compact roundabouts are considered in the 90 ft. to 130 ft. range. These are generally used on city or county roadways with minimal or no large vehicle traffic.

For the needs and vehicles that utilize the state highway system, there are few places where these smaller diameter roundabouts would be appropriate. However, there may be some locations where a mini or compact roundabout would work well on the state system and these two additional types of roundabouts should not be arbitrarily dismissed. The safety benefits afforded by roundabouts, even small diameter ones, are well documented. Roundabouts should be considered whenever intersection safety improvements are considered. If a smaller inscribed diameter roundabout is proposed for a design, contact the Technical Services Roadway Engineering Unit for guidance. In the right location and with proper design, mini and compact roundabouts can provide safe and efficient intersection traffic control for minimal cost.

509.8 Roundabout Cross Section

Once the inscribed diameter has been established, circulatory roadway width and truck apron width can be determined. The circulatory roadway is the area between the outside curb and the truck apron. This is the area where the majority of traffic will traverse the roundabout. For single lane roundabouts, circulatory roadway widths should provide adequate width for most vehicles to comfortably maneuver through the roundabout, provide for some off-tracking of larger vehicles up to the design vehicle, but not be so wide that drivers may feel there is more than one lane in the roundabout.

Circulatory roadway width is based on the number of entering lanes and the turning requirements of the design vehicle. Generally, the circulating width should be at least as wide as the maximum entry width and in some cases, it may be appropriate to increase the width up to 120 percent of entry width.

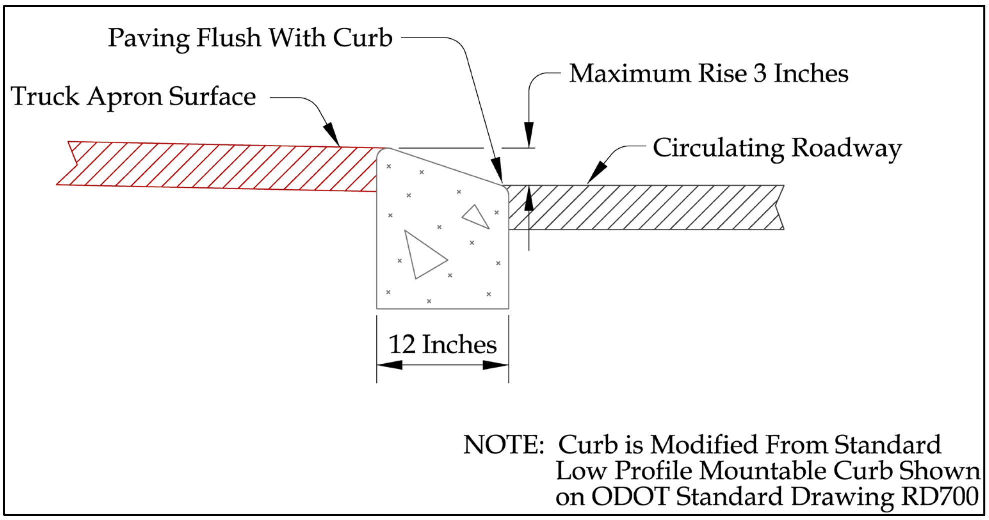
The recommended circulatory roadway width for a single lane roundabout on the state highway system is 21 feet, excluding the truck apron width. For multi-lane roundabouts, the suggested circulating width is 14 feet to 16 feet per lane or 28 feet to 32 feet for a two-lane roundabout on the state highway system. The suggested circulatory roadway widths are based on general design characteristics. Circulating widths should be checked using design vehicle turning characteristics and overall intersection control parameters governing the intended need for the roundabout installation. Larger diameters and wider lanes tend to increase circulating speeds which could jeopardize the intended speed control of a roundabout.

Central island truck aprons are an integral design element of a roundabout that provides accommodation for large vehicles while maintaining deflection and design controls for general traffic to achieve effective roundabout design at an intersection. A truck apron is generally designed in such a way that when traversed by a passenger car, it would feel uncomfortable but not unsafe. **Truck aprons shall be designed to allow for efficient transition to and from the circulatory roadway for large vehicles. Modified, low profile curbs no higher than 3 inches shall be used for delineation and transition between the circulatory roadway and the truck apron.** ***For some designs with specific needs, the total rise of the modified low profile curb***

could be lowered to 2 inches to facilitate specific vehicles. However, this is not a standard curb cross-sectional shape and will potentially require additional hand work to form and construct. This can increase cost and construction complexity. **Curbs for the truck apron shall be installed flush with the circulatory roadway.** See Figure 500-39. For full curb design at roundabouts. (See Standard Drawing RD170.)

As discussed in Section 509.7, it is important to maintain color differentiation between roadway areas, apron areas and splitter islands. ***It is strongly recommended to use red brick coloring for concrete truck apron and splitter island surfaces.*** This will provide strong color differentiation when either concrete or asphalt is used for the roadway surfacing. Patterning the apron and the splitter island surfaces is also recommended. Patterning generally discourages passenger vehicles from using the apron area unless necessary. (See Figure 500-38, Typical Roundabout Cross-Section Elements.)

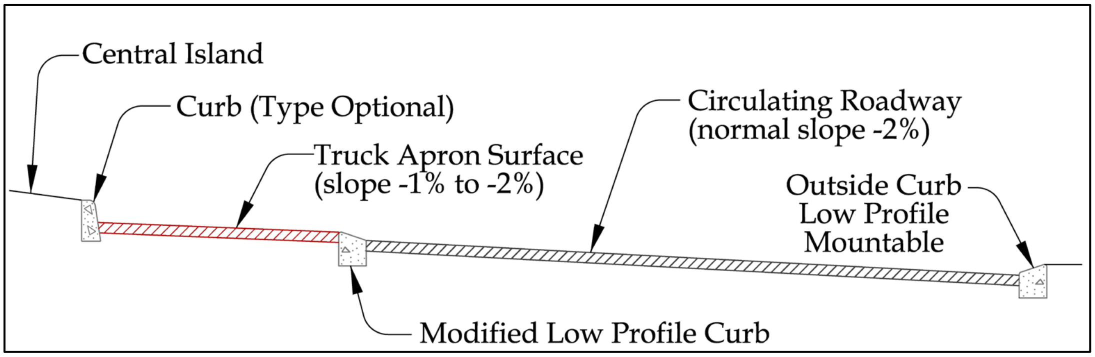
Figure 500-39: Truck Apron Modified Low Profile Mountable Concrete Curb



Truck apron width is determined by turning requirements of the design vehicle and other large vehicles being accommodated through the roundabout. Vehicle paths can be simulated using computer software to determine off-tracking needs. *Typical truck apron widths range from 10 feet to 20 feet, but wider aprons can be used to accommodate specific vehicle movements as needed. Central islands and truck aprons do not need to be limited to a circular shape. While this is the typical configuration, they can be shaped to meet turning movement needs.* Figure 500-42 illustrates a non-circular central island.

In general, past design practice set cross-slope of the truck apron at 2 percent from the roundabout center to the apron curb (-2 percent). However, more recent design philosophy is leaning to utilizing a 1 percent cross-slope to better accommodate specific large vehicle combinations. Truck apron cross-slope needs to be carefully determined to not introduce undesirable dynamics to large vehicles as they traverse the apron. This is particularly true when accommodating low–boy trailers, oversize loads, loads with high centers-of-gravity or loads that can shift, like bulk liquid loads. Low-boy trailers can pose problems with the vertical profile between the apron and the circulating roadway. Some low-boy trailers have only six inches of clearance from the ground to the bottom of the trailer frame. Truck apron cross-slope should be only as steep as necessary to provide adequate drainage. Smooth transitions between the circulating roadway and the apron are crucial to effective design and in most all cases should not be greater than 2 percent in differential slope.

Figure 500-40: Typical Truck Apron and Circulating Roadway Cross-Slope



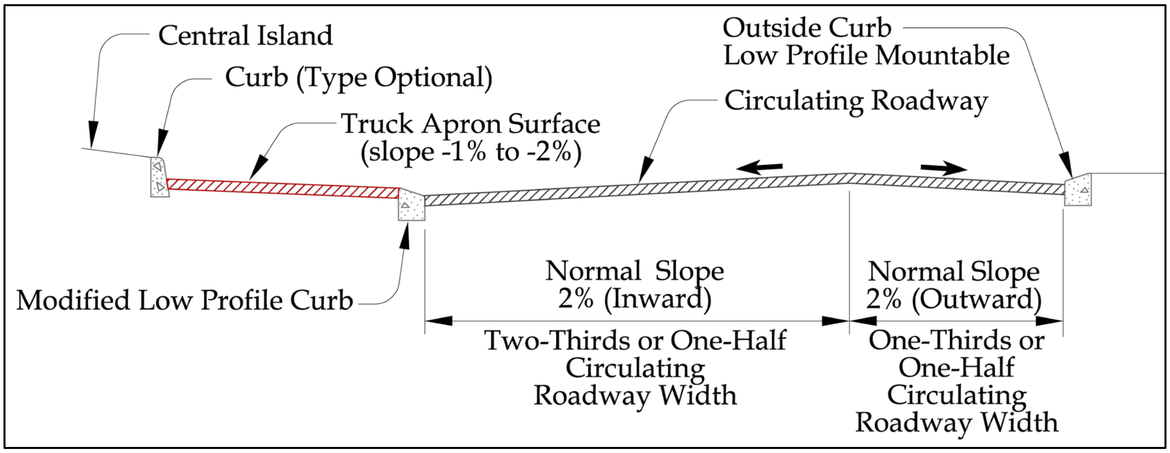
Cross-slope of the circulating roadway is also usually at 2% outward (-2%) keeping the truck apron and circulating roadway relatively parallel with each other. Figure 500-40 Illustrates typical truck apron and circulating roadway cross-slope. Advantages to this cross-slope design include:

1. Raising the central island and improving its visibility,
2. Lowering circulating speeds by introducing adverse superelevation,
3. Minimizing breaks in the cross-slope of the entrance and exit lanes. And
4. Helping drain surface water to the outside of the roundabout minimizing the drainage system.

In the past, significantly altering the cross-slope relationship between the truck apron and the circulating roadway was generally not an accepted practice. However, more recent research and analysis investigating varying this relationship from the typical -2% across the truck apron and circulatory roadway has shown there may be some benefit to certain vehicle movements through roundabouts, as well as potential drainage benefits.

Some agencies have opted to slope the truck apron inward toward the central island. In locations subjected to high incidence of precipitation, this option can reduce runoff across the circulating roadway. This can also have a beneficial effect of less ice buildup on the circulating roadway in colder climates. Depending on adjacent geometry of a particular roundabout, sloping the truck apron inward can also have a positive effect in minimizing the potential for load shifting. However, sloping the circulating roadway inward may require additional drainage for storm water removal.

Figure 500-41: Truck Apron and Crowned Circulating Roadway Cross-Slope



Some agencies are developing roundabout geometries that include a crown section on the circulating roadway. In this option, the inner portion of the circulating roadway is sloped inward towards the truck apron and the outer portion is sloped outward away from the truck apron. The crown section is usually divided into two-thirds of the circulating roadway width sloping inward and one-third sloping outward. The roadway width could also be divided in a half inward and a half outward scenario. Figure 500-41 illustrates the crowned circulating roadway concept.

Agencies that are developing these alternative cross-sections feel they may be of benefit in accommodating oversize and overweight vehicles at roundabouts. The theory is to minimize vertical movement as a large vehicle transitions on and off the truck apron. Disadvantages to using a crowned circulating roadway section are:

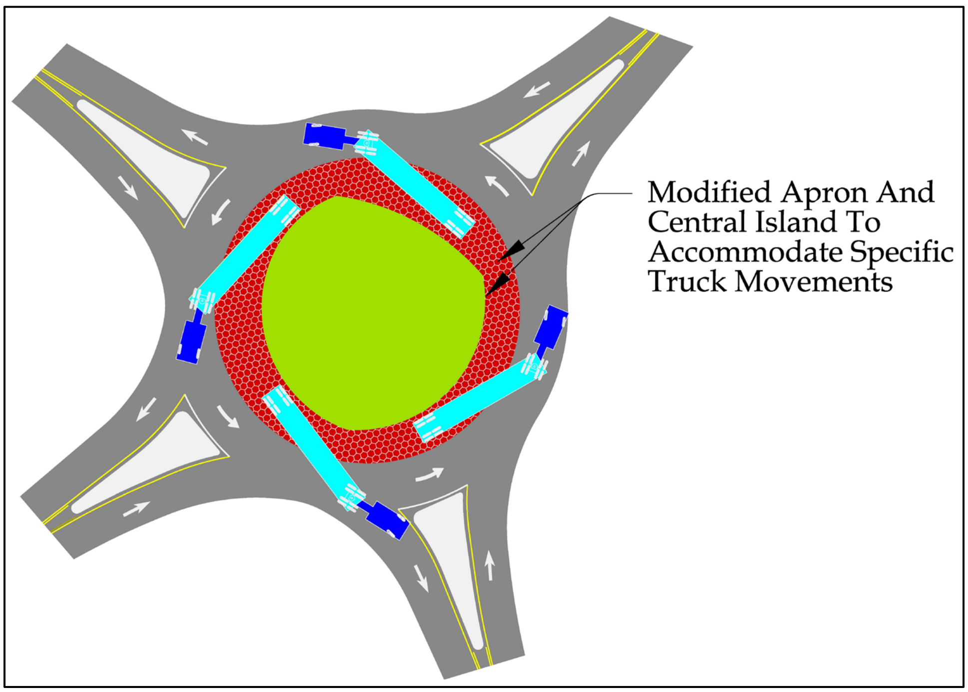
1. More inlets are required to handle the drainage, and the drainage system is more complex with the potential for increased maintenance.
2. The crown section introduces a break point in the vehicle path at entrances and exits that must be adequately blended for both comfort and clearance problems for low ground clearance vehicles.
3. Sloping the circulating roadway inward reduces or eliminates the adverse superelevation of the fastest path through the roundabout. This can increase some vehicle speeds on the circulating roadway.

The alternative roundabout cross-sections discussed in this section are not the preferred cross-section for roundabouts on the state highway system in Oregon. They are discussed here because some agencies are using them, and they seem to have benefits in certain locations. However, their use is not wide spread, and more information is needed to understand if there are unforeseen negative impacts.

However the cross-section of a roundabout is designed, the vertical profile that a vehicle traversing a roundabout follows is a critical piece of the overall roundabout design. Designers must analyze the design profile for the paths of all vehicles that will be using the roundabout. This is particularly important for large vehicles that will need to utilize the truck apron and for low-boy trailers with limited ground clearance. The vertical clearance can be checked by drawing a chord across the truck apron in the position of the trailer's swept path. It is also important to analyze vertical clearance along the circulatory roadway itself. In some cases, the warping of the profile to blend transitions at exits and entrances can create high spots that a turning trailer may contact under dynamic loading or twisting of the trailer frame.

The truck apron is a critical element of a roundabout and there is no set truck apron width. It needs to be wide enough to accommodate appropriate vehicle movements. A 10 foot to 15 foot width is a good starting point. Large vehicles making left (270 degree) turns will generally have the greatest off-track. Apron width may need to be increased to accommodate this movement for some vehicles. Truck aprons and the corresponding central island do not necessarily need to be round. There are examples of oval shaped central islands and odd shaped aprons that have been used to accommodate specific vehicles. Truck aprons utilizing "cut-out" central island sections have also been employed to optimize truck movements at some locations. Figure 500-42 illustrates modifying the truck apron and central island to accommodate truck movements.

Figure 500-42: Modified Truck Apron



Modifying the central island and truck apron can be beneficial in small diameter roundabouts by keeping the footprint small and still accommodating large vehicles. This can also work well at normal sized roundabouts that accommodate oversize vehicles. However, care must be taken in not creating an apron wider than necessary. Widening the truck apron will decrease the remaining raised center area.

One important reason for the raised center area is to provide a visual screen using vegetation to restrict visibility from one side of the roundabout to the other. The term used in roundabout design for blocking the view across a roundabout with earth mounding or vegetation is “Terminal Vista”. The center area needs to be visible to approaching drivers to indicate to them the existence of the roundabout. If an approaching driver can see across the roundabout, there may be a tendency to think the road continues straight through the intersection and the driver may be unaware of the necessity to deviate and maneuver around the circulatory roadway. Long range approach visibility of the central island is important at all roundabouts, but it is paramount at rural locations where approaching vehicles are traveling at a greater speed differential between normal roadway speed and roundabout entrance speed. A driver needs time to understand and slow down on approach to the entrance. The roundabout needs to be conspicuous to drivers.

In a positive sense, wider aprons can increase sight distance to the left for a driver judging a gap when entering a roundabout. Balance needs to be maintained between a truck apron wide enough to accommodate vehicles and aid in entering sight distance, but not create visibility or recognition problems for approaching traffic. If a roundabout’s inscribed diameter needs to be in the smaller end of the suggested NCHRP Report 1043 range for design, a wider apron may be necessary to accommodate large vehicles. Designing for these situations needs careful consideration to ensure compromises do not negatively affect overall roundabout performance.

509.9 Entry/Exit Geometry and Layout

Entrance and exit geometry and layout are critical to effective roundabout design. There are four key considerations when designing roundabout entrances and exits. They include:

1. Approach alignment;
2. Angle between approaches;
3. Entry/exit width, and
4. Entry/exit curve radii.

509.9.1 Approach Alignment

There are three general types of approach alignment. They include:

1. Alignment offset left of center;
2. Alignment with center, and;
3. Alignment offset right of center.

Figure 500-43 illustrates the three alignment types.

1. Alignment Offset Left of Roundabout Center

a. Advantages

i. Increased deflection for better entry speed control

ii. Potential for larger entry radii to better accommodate large vehicles with smaller inscribed diameters

iii. May reduce impacts to right side of approach roadway

b. Disadvantages

i. Potential for tangential exit or increased exit radii creating less speed control on exit

ii. May create greater impacts to left side of approach roadway

2. Alignment With Center of Roundabout

a. Advantages

i. Reduces alignment changes along approach roadway to keep impacts centered

ii. May provide for more consistent entry and exit radii and more consistent speed

iii. Centers approach on roundabout center and may make roundabout more visible to approaching drivers.

b. Disadvantages

i. May require a slightly larger inscribed diameter to maintain speed control compared to left offset style

ii. May be more difficult to control approach speeds

3. Alignment Offset Right of Center

a. Advantages

i. May improve view angles in some locations

ii. May help in large inscribed diameters, if speed can be controlled

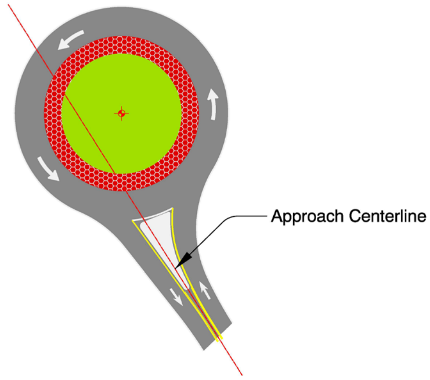
b. Disadvantages

i. Less potential for appropriate deflection to control entry speed

ii. Decreases exit radii creating greater speed differential through roundabout

iii. Creates potential for uncomfortable forces acting on vehicle occupants

Figure 500-43: Approach Alignment



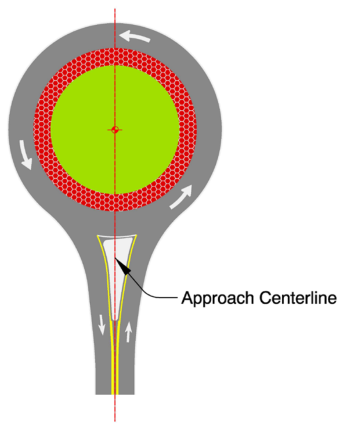
ADVANTAGES:
1. Increased Entrance Deflection Speed Control
2. May Better Accommodate Large Vehicles With Smaller Inscribed Diameter

CONCERNS:
1. Increased Exit Radius
2. Possibly Less Exit Deflection
3. Possibly Less Speed Control

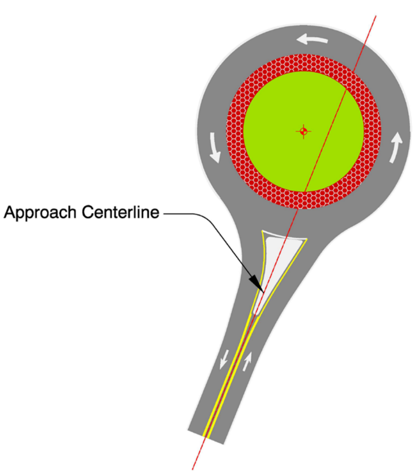
APPROACH ALIGNMENT OFFSET LEFT OF CENTER

ADVANTAGES:
1. Reduces Amount of Alignment Changes Keeps Impacts Localized to Intersection Balanced Aesthetics
2. Maintains Smaller Exit Radius
3. More Exit Speed Control

CONCERNS:
1. Minimizes Available Entrance Deflection
2. Potentially Less Overall Entrance Speed Control May Require Slightly Larger Diameter Than Offset Left



APPROACH ALIGNMENT THROUGH CENTER OF ROUNDABOUT



ADVANTAGES:
1. In Some Locations Offset Right Alignment May Prove Benefical To Minimize Impacts or Improve View Angles. However, Entrance Speed Control Must be Maintained.
2. Offset Right Alignments are Rarely Used The Tradeoffs May be Too Difficult to Overcome

CONCERNS:
1. More Difficult to Control Entrance Speed, Radius and Deflection
2. Increased Exit Curvature and Deflection May Cause Too Great a Differential in Speed Between Entering and Circulating Vehicles
3. Can Reduce Overall Roundabout Capacity

APPROACH ALIGNMENT RIGHT OF CENTER

Of the three types of approach alignments discussed, alignments offset left or alignments with the center are preferred for roundabout design on state highways. ***Approach alignments offset right are discouraged and generally should not be used.*** The major concern with offset right alignments is speed control on entry. However, there may be a rare location where an offset right alignment might be appropriate. **Offset right alignments will require design concurrence through the ODOT Technical Services, Roadway Engineering Section and the State Roadway Engineer.**

Roundabout approach alignment focuses on the centerline horizontal alignment approaching the roundabout. Consideration must also be given to the alignment the approaching vehicle actually traverses. This often begins with an offset alignment from centerline and deviates from the centerline alignment through successive curvature to control speed as the vehicle approaches the yield line at the entrance. For layout purposes, this alignment may follow the middle of the travel lane, the splitter island curb line, or in the case of a multi-lane roundabout, the center stripe between the approaching lanes. Whatever location is determined as most appropriate for the vehicle approach alignment, it is of primary importance that the alignment meet ODOT horizontal design criteria.

ODOT horizontal alignments utilize spiral transitions for curves equal to or greater than 1 degree and angle points are not permitted. ***All project design alignments must be tied to the existing alignment at beginning and end and not "float" independently.*** For approach vehicle alignments at roundabouts, the offset alignment starts parallel to the centerline alignment.

- If the approach alignment is on tangent, the offset alignment begins with the same bearing as the centerline alignment.
- If the approach alignment starts at a point on a curve of the centerline alignment, the offset alignment follows the parallel offset curvature of the centerline alignment for a minimum of 50 feet before alignment changes.
- For tangent offset approach alignments utilizing successive reversing curvature with posted approach speed of 35 mph or greater, the first curve, if 1 degree or greater, shall use an appropriate entrance spiral transition. A spiral transition is not required on the exit of the curve nor is a spiral transition required on any successive curves up to the yield line.
- For alignments beginning on a parallel offset curve, maintain a minimum of 50 feet of starting curvature prior to any alignment changes. For parallel offset curve alignments with posted approach speed of 35 mph or greater, maintain the minimum 50 feet of curvature and use an appropriate spiral transition segment to the first successive element. No spiral transitions are required on any curves following the first successive element.
- Exit horizontal geometry will follow the same layout as entrance geometry only in reverse order ending with a spiral transition back to the existing alignment at the tie in

point if the final curve is greater than 1 degree. The exit alignment will tie into the existing alignment parallel offset smoothly with no angle point.

509.9.2 Angle Between Approaches

As with design of stop controlled or signalized intersections, the angle between approaches is important to the overall design of a roundabout. ***All approaches should be designed as perpendicular to each other as possible.*** This approach design will help ensure sufficient separation between two adjacent legs. Approaches built too close together, can lead to potential traffic conflicts due to the entering driver being unaware of an entering vehicle on the upstream approach leg. In addition, if two successive approaches meet at an angle significantly greater than 90 degrees, it will often result in excessive speed of right turning vehicles. Alternatively, if two successive approaches form an angle significantly less than 90 degrees, then the difficulty for larger vehicles to successfully move through the turn is increased. Figure 500-44 demonstrates difficulties with approach angles too great or too small.

As with designing any intersection improvement, conventional or roundabout, it may be difficult if not impossible to provide perpendicular approach connections. Right-of-way, topography and existing structures are only a few of the potential restrictions and conflicts designers face when trying to improve skewed intersection alignments.

When it is not possible to re-align approaches to 90 degrees, it may be possible to increase the inscribed diameter or to change the overall geometry from a circle to an oval to achieve a balance between entry design, exit design and speed control. However, care must be taken to not compromise the overall roundabout design or project parameters. Increasing the inscribed diameter or developing an oval roundabout can improve adjacent approach geometry, but these designs can also increase roundabout speeds to the point of negatively impacting the overall design.

An oval geometry may have greater right-of-way impacts as well as being too unfamiliar to drivers, thereby creating the potential for confusion. However, oval roundabouts can provide benefits in the appropriate location. Figure 500-45 illustrates a skewed alignment and the three options to make approach alignment improvements and the potential trade-offs when using them.

A fourth option could be a combination of these design adjustments. Improving the skew with a minor alignment change and a small increase in inscribed diameter may be sufficient to provide acceptable approach geometry, while minimizing impacts to adjacent properties. For simplicity in presenting the concepts, illustrations in the figures all have the individual approach alignments meeting at the center of the roundabout. Using approach alignments other than center alignments as shown in Figure 500-43 could also help to create acceptable overall approach spacing at skewed locations. Even though a roundabout contains skewed approaches, it may still provide improved safety and operations over the existing skewed intersection it is replacing. *Given the previous discussion, skewed intersections should not be dismissed as roundabout candidates before full analysis is performed. Many skewed approach roundabouts have been constructed and are working well.*

By their nature, roundabouts with 3 or 5 (or more) approaches can be difficult to provide appropriate deflection, speed control and right turning radii. Roundabouts with only three approaches may have large angles between approaches allowing for less deflection and higher entrance and exit speeds. Roundabouts with five or more approaches present challenges not so much in achieving deflection, but in providing sufficient turning radii at some or all right turn movements, as well as challenges providing preferred entry design. *For roundabouts with three approaches, it is preferred, as much as possible, to align two of the approaches at 180 degrees with each other and the third approach at 90 degrees with the other two rather than aligning all three at 120 degrees with each other to achieve appropriate deflection and speed control.* Figure 500-46 depicts three legged roundabout approach alignment.

Figure 500-44: Angle Between Approaches

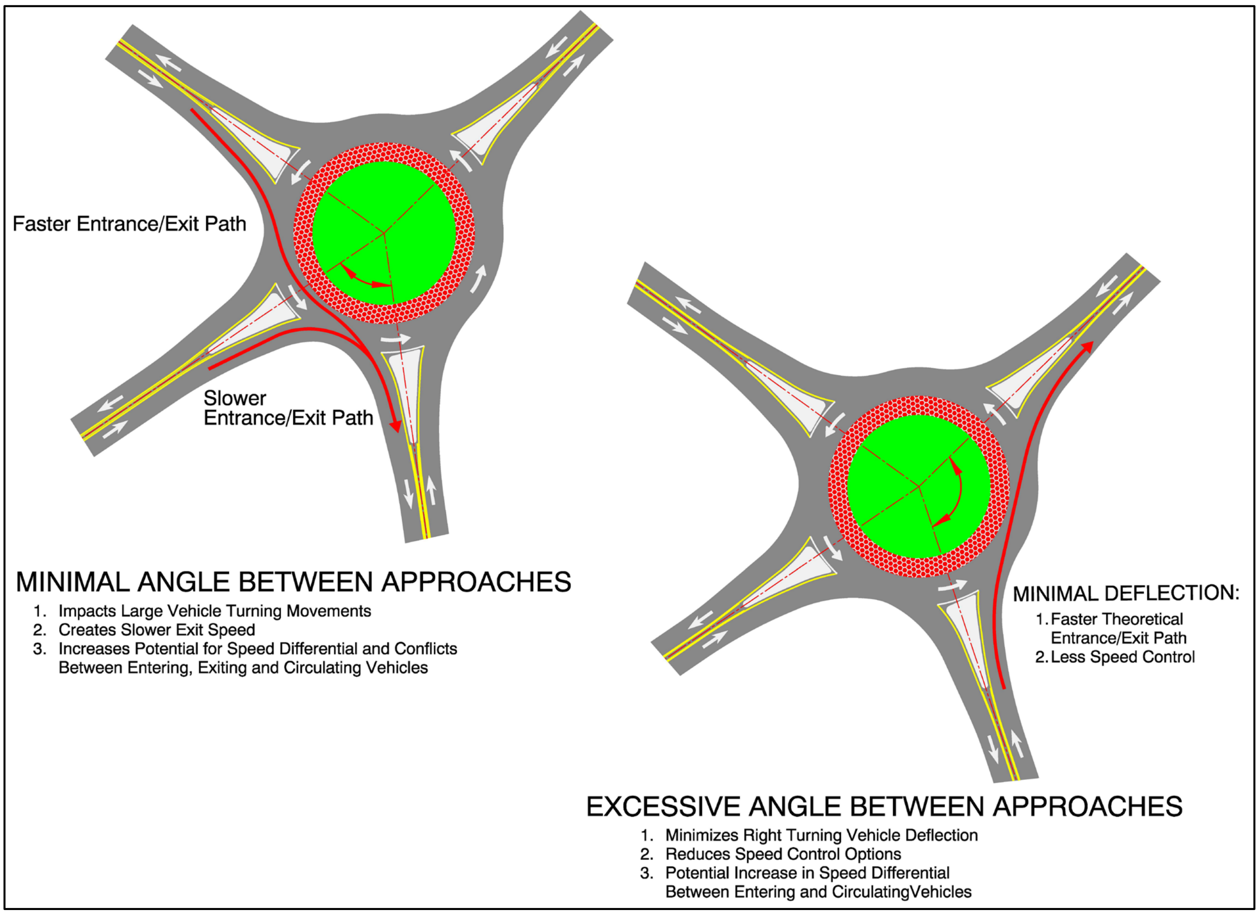


Figure 500-45: Skewed Alignments

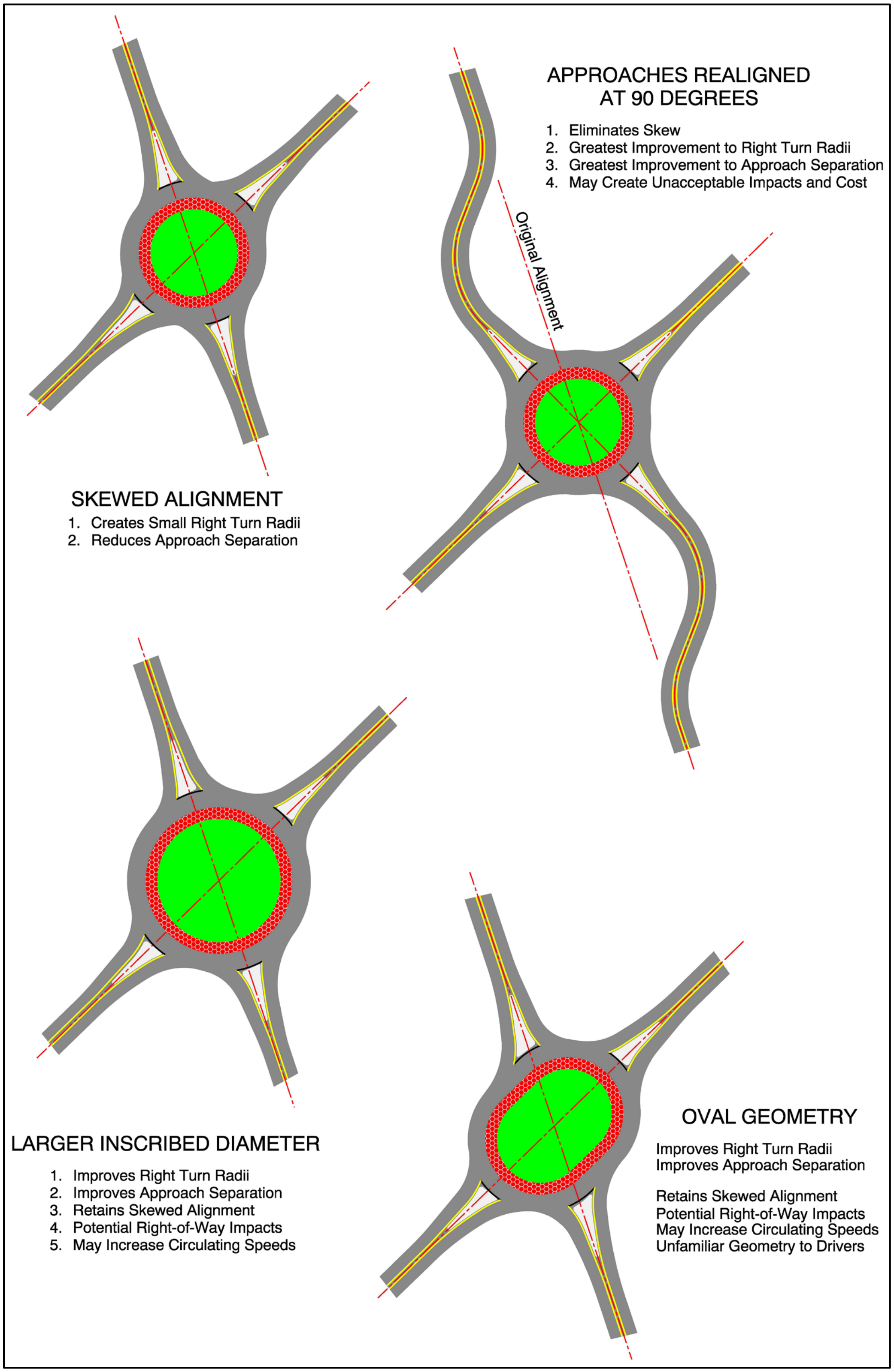


Figure 500-46: Roundabout with Three Approaches

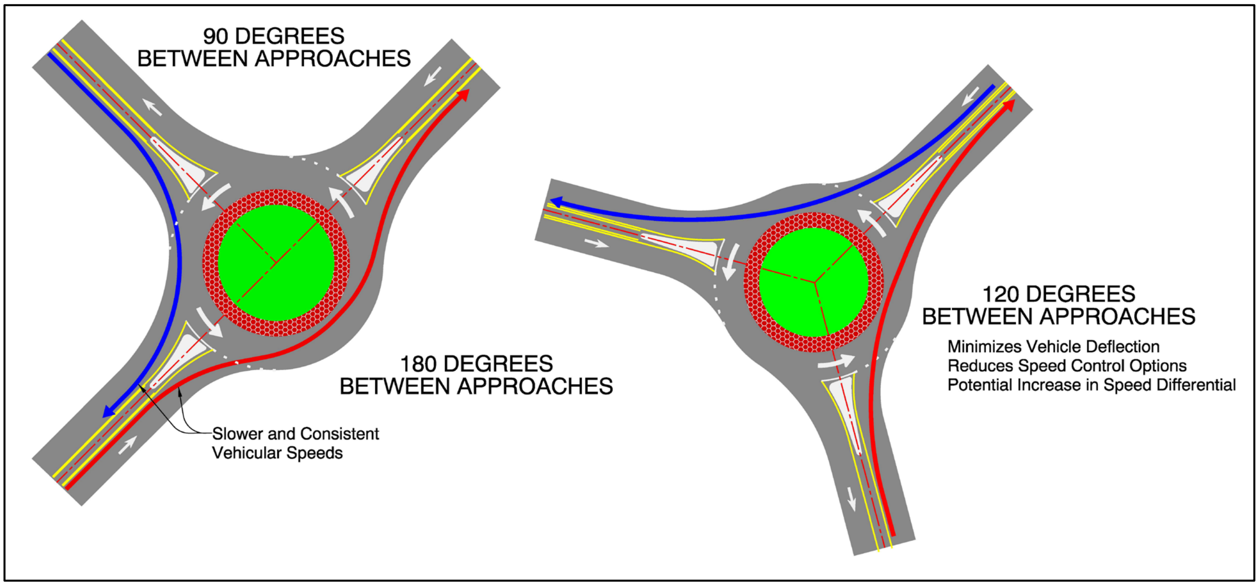
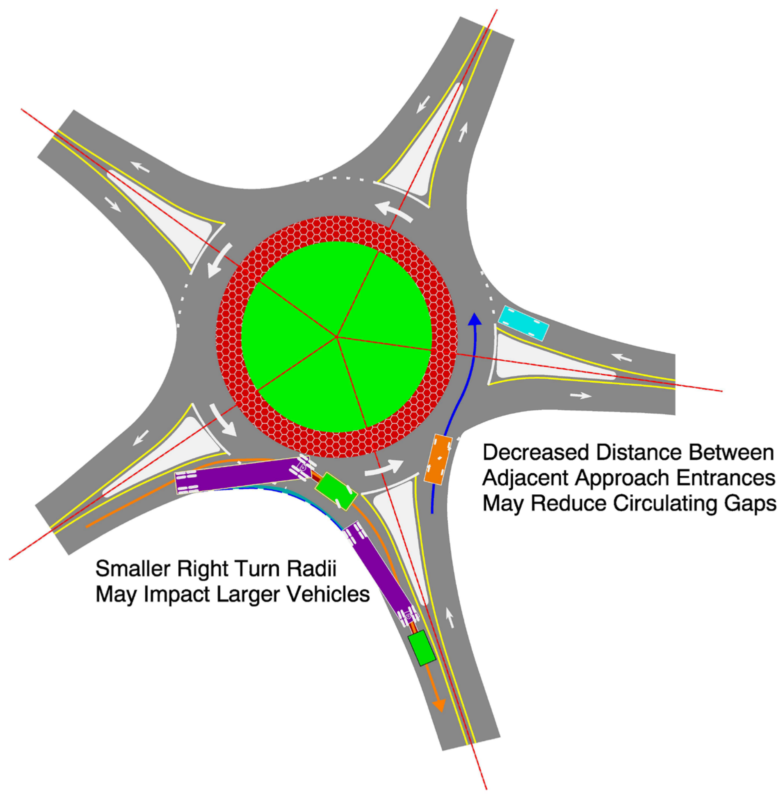


Figure 500-47 portrays a roundabout with five approaches and some of the inherent problems with roundabouts comprised of more than four legs. Roundabouts with more than four approaches present challenges with approach angles and with entry and exit parameters. In general, the more approaches there are, the smaller the angle between the approaches. These roundabouts will need special design considerations to achieve an effective design. Contact the Technical Services Roadway Engineering Unit to discuss options when laying out a roundabout with more than four approach legs.

Figure 500-47: Roundabout with Five Approaches



509.10 Entry and Exit Width

Entry width and exit width are also important factors in creating effective roundabout design. These widths are dictated by the needs of the traffic stream based principally on the design vehicle. ***Vehicle needs must be balanced against necessary speed management and pedestrian crossing needs.*** Single lane roundabouts generally employ widths between 14 ft. for smaller diameter or mini-roundabouts and 18 ft. for more standard size roundabouts. Although, in some locations, these widths may be increased if deemed appropriate and flaring the entrance can aid in truck off-tracking. For multi-lane roundabouts, required entry and exit widths depend on the number of lanes entering or exiting. Typical widths for a two-lane roundabout range from 24 ft. to 30 ft. As with single lane roundabouts, these widths may be increased for specific vehicle accommodation when necessary, keeping in mind the balance with other roundabout design needs and parameters. Widths should only be as wide as necessary. Increasing width can affect fastest path speeds and may compromise overall safety goals.

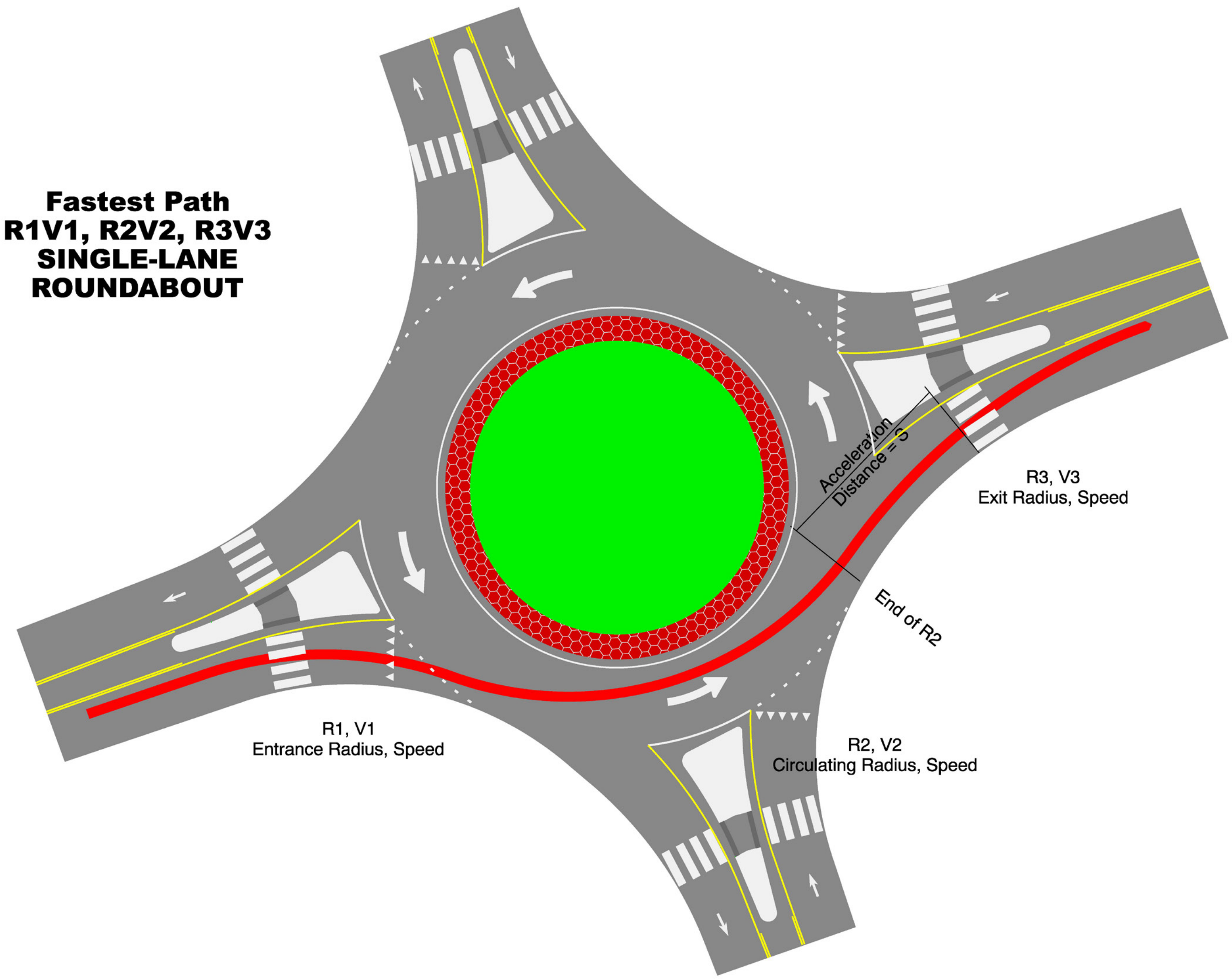
509.11 Entry and Exit Geometry

Along with entry width and exit width, entrance and exit geometry helps control speed in roundabout design. *Entrance and exit geometry can influence capacity and safety. Entrance radii designed too small may potentially create single vehicle crashes due to abrupt changes in vehicle path alignment. Entrance curve radii set too large may increase entry speeds and a fastest path greater than desired.* Entrance radii are generally in a range from 50 ft. to 100 ft. However, there is no single appropriate radius for all designs. Entrance radius should be appropriate to control entrance speed, but still provide the necessary room for large vehicles to enter the circle without hitting the curb. For some locations, compound radii may be the best solution.

Exit radii are generally larger than entrance radii to allow for consistent or slightly increased flow at the exit. Exit radii should not be designed smaller than entrance radii. When exit radii are smaller than entrance radii, the potential exists for congestion and crashes at the exit. However, if exit radii are too large, speeds may be too great at the downstream pedestrian crossing. Exit pathways must balance exit speed in relation to predicted fastest path speeds from entrance and circulating geometries along with pedestrian crossing needs. Research has demonstrated correlation between observed exit speed and a vehicle's ability to accelerate on the circulating roadway as it approaches the exit to the roundabout. ***Approach alignments left of center are beneficial for entrance geometry deflection and entrance speed control, but they can also tend to create flatter horizontal exit geometry that may have potential for greater acceleration and higher than acceptable speed upon exiting the roundabout.*** Roundabout designers must provide a consistent and controlled path for vehicles to enter, traverse and exit a roundabout at an appropriate speed. It may take several design iterations to achieve acceptable entrance and exit geometry for a roundabout location.

The generally accepted method to predict entrance and exit speed for design is to use the speed, radius relationship as previously discussed in Section 509.6. However, research projects from 2004 and 2007 have developed an alternate method of predicting vehicle speeds for entrances and exits of roundabouts. These research projects observed vehicle operation at roundabouts throughout the country and determined that in some locations, the actual vehicle speeds observed did not match predicted speeds. The intent of the two research projects was different, but they both developed an alternate method to match observed speeds with predicted design speeds at roundabout exits. The method is based on the standard Newtonian equation for uniform acceleration. Although equations were developed for both entrance speed and exit speed, it is recommended by NCHRP Report 1043, Guide for Roundabouts that the standard method using the speed, radius relationship should be used for prediction of entrance speed, while the alternate method may be used for exit speed.

Figure 500-48: Exit Geometry – Alternate Speed Prediction Method



Equation 500-4: Newtonian Equation for Uniform Acceleration to Predict Roundabout Exit Speed

$$V_f^2 = V_i^2 + 2as \qquad \text{(Figure 500-48)}$$

Where:

V_f = Final R3 Speed, ft/s (V3 – exit speed)

V_i = Initial R2 Speed, ft/s (V2 – circulating speed)

a = Acceleration, ft/s2

S = Distance, ft. (End of R2 to Crosswalk)

Generally larger exit radii will increase the overall roundabout capacity by allowing exiting vehicles to exit faster than entering vehicles. Some roundabout designs incorporate a large exit radius that creates an almost tangential alignment for exiting vehicles. *Large offset left entrance geometry to enhance entering speed control flattens the exit geometry on that leg of the roundabout.* This also maximizes flow at the exit and, thereby, potentially creates greater gaps for entering vehicles on other approaches. It can also increase exit speeds. These designs are based on the alternate method of exit speed prediction using uniform acceleration calculations.

This may work well to increase capacity and designers who prefer this type of design feel that opening up the exit geometry may provide drivers with a better line of sight to pedestrians and the crosswalk area as well. *However, the potential for loss of consistent speed control at the downstream crosswalk is a major disadvantage.* Limiting the acceleration distance and determining appropriate acceleration rates are critical to predicting potential exit speed with these types of designs. See Section 510, Analysis for Roundabout Entrance and Exit Geometry, for additional information and discussion about larger radius or tangential roundabout exits and the proposed alternate calculation method.

There is significant discussion between roundabout designers about the best method to determine exit geometry and to control exit speed within design parameters. As a result, currently there is no definitive answer to what the best method is to predict entrance and exit speed when designing a roundabout. Research has shown that in some cases where exit radii are not excessively large and/or acceleration distances are short limiting a vehicle's ability to accelerate prior to the exit crosswalk, opening up exit geometry may not have a great effect on exit speed. *Relaxed exit geometry that increases acceleration distances and acceleration rates can potentially have significant effects on a vehicle's speed at the exit crosswalk thereby impacting pedestrian movements and, potentially, pedestrian safety.*

This is particularly true for multi-lane roundabouts in off-peak times when a vehicle's fastest path may cross adjacent lanes. In any roundabout layout, it is the designer's responsibility to provide vehicle alignments that consistently control vehicle speeds from entrance to exit in an effective manner for all modes of transportation utilizing the roundabout. ODOT's preferred method of design is to use smaller, more radial alignments for entrance and exit layout when predicting vehicle speed into, through and out of a roundabout. There may be some rural locations where pedestrian activity is expected to be low or locations where pedestrian activity is restricted or prohibited that a large radius or tangential exit design might be acceptable.

For roundabouts designed on the state highway system, appropriate radius values that effectively provide design entrance, circulating and exiting speeds shall be determined using the speed, radius relationship discussed in Section 509.6 of the ODOT Highway Design Manual using Equation 500-1, Equation 500-2, or Equation 500-3 on page 500-88, Figure 500-34, or Table 500-4 to determine appropriate fastest paths for roundabout design.

Like approach alignment, exit alignment is important for overall roundabout operation and safety. As discussed previously, exit speed can impact the downstream pedestrian crossing as vehicles leave a roundabout. The R1 and R2 values help control entering and circulating speeds. While research shows that R2 can affect and control exit speed, this is only true if the distance a vehicle has to accelerate is also controlled. Exit alignment can have a key role in controlling the available acceleration distance. Figure 500-48 illustrates entrance and exit geometry and depicts exit acceleration distance to the downstream crosswalk. Flatter exit alignment increases available acceleration distance and potentially increases vehicle speed at the downstream crosswalk.

Depending on overall roundabout geometry, it is difficult to specify exact exit alignment criteria that will work for all roundabouts. Exit geometry needs to be established on a case-by-case basis. *For ODOT exit alignments, best practice is to limit the R3 radius from getting too large or tangential while limiting the available acceleration distance to a maximum of 75 feet to 100 feet and limit potential vehicle speed at the downstream pedestrian crossing to 30 mph. In some rural locations, where pedestrian activity is anticipated to be low over the design life of a project or where pedestrian activity is prohibited, faster exit geometry and longer acceleration distances could be acceptable.*

As with approach vehicle alignments, all ODOT roundabout exiting vehicle alignments shall end parallel with the centerline alignment, either offset tangent at the centerline bearing or with offset curvature parallel to the centerline.

For additional guidance on roundabout entrance and exit geometry design, contact the ODOT Technical Services Roadway Engineering Unit.

509.12 Entrance and Exit Aprons

Depending on overall geometry, large vehicles can have difficulties negotiating entrances and exits to roundabouts. Like aprons added to central islands to aid vehicle off-tracking, truck aprons positioned on the entrance and/or exit curves have been utilized at some roundabout locations to accommodate potential off-tracking needs. While these aprons, sometimes called “blisters”, are advantageous for the movement of large vehicles through the roundabout, they can be counter-productive for the roundabout by providing an alternate fastest path that allows too great a speed for smaller vehicles, thereby, diminishing the overall effectiveness of the roundabout.

These types of entrance and exit aprons should not be a general design element included in all roundabout designs. Rather, their design should be approached with caution and should be reserved for when they are needed as a necessity to accommodate specific vehicles. Effective entrance and exit geometry to control speeds of smaller vehicles must be maintained along with the design of truck entrance aprons.

Utilizing entrance and exit aprons can keep the overall size of a roundabout small and still provide space for large vehicles to maneuver through the roundabout. Keeping the overall size of a roundabout small also helps maintain speed control. Entrance and exit geometry is a balance of many factors. Entrance and exit aprons can be effective and should not be summarily eliminated as a design option. However, they are not needed at every roundabout and should not be automatically included. Their use should be coordinated with overall design needs. Figure 500-49 demonstrates an oversize vehicle off-tracking onto an entrance apron.

When entrance or exit aprons are used, they need to be designed to allow access by large vehicles but designed to discourage their use by smaller vehicles to maintain the overall roundabout design parameters and speed control. Entrance and exit apron design is similar to central island truck apron design (See Figure 500-39). Using entrance and/or exit aprons may create potential design compromises that need to be understood and analyzed as appropriate for the overall roundabout design at any specific location. Entrance and exit aprons should only be used when all other design options have been evaluated and they are the only reasonable alternative to provide accommodation for large vehicles through the roundabout. Figure 500-50 demonstrates an oversize vehicle swept path through a single lane roundabout utilizing an entrance apron.

Figure 500-49: Oversize Vehicle and Entrance Apron

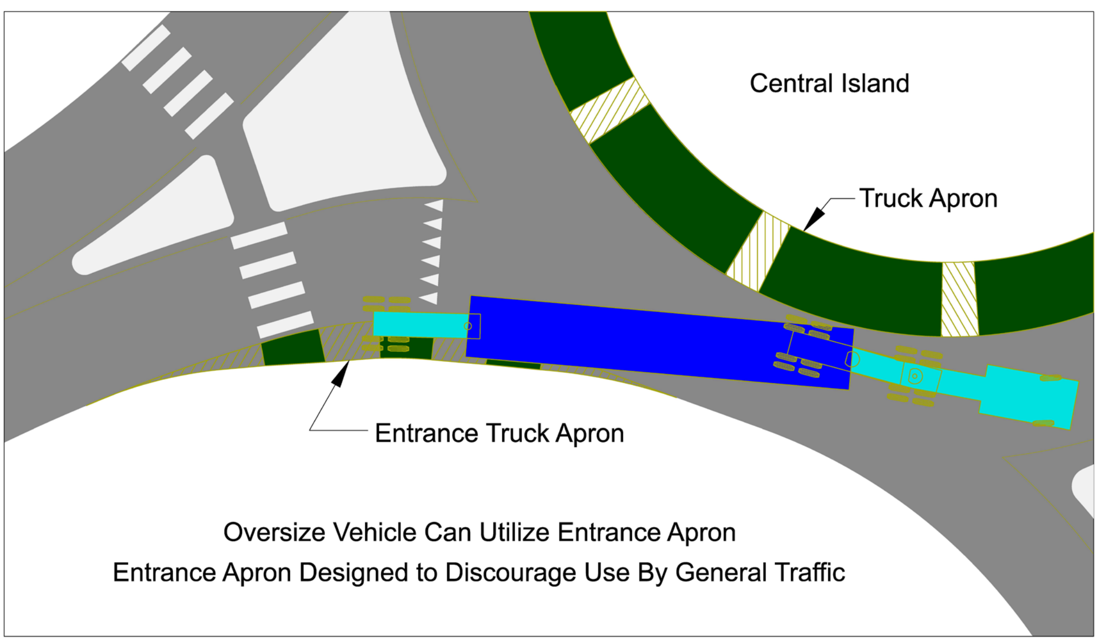
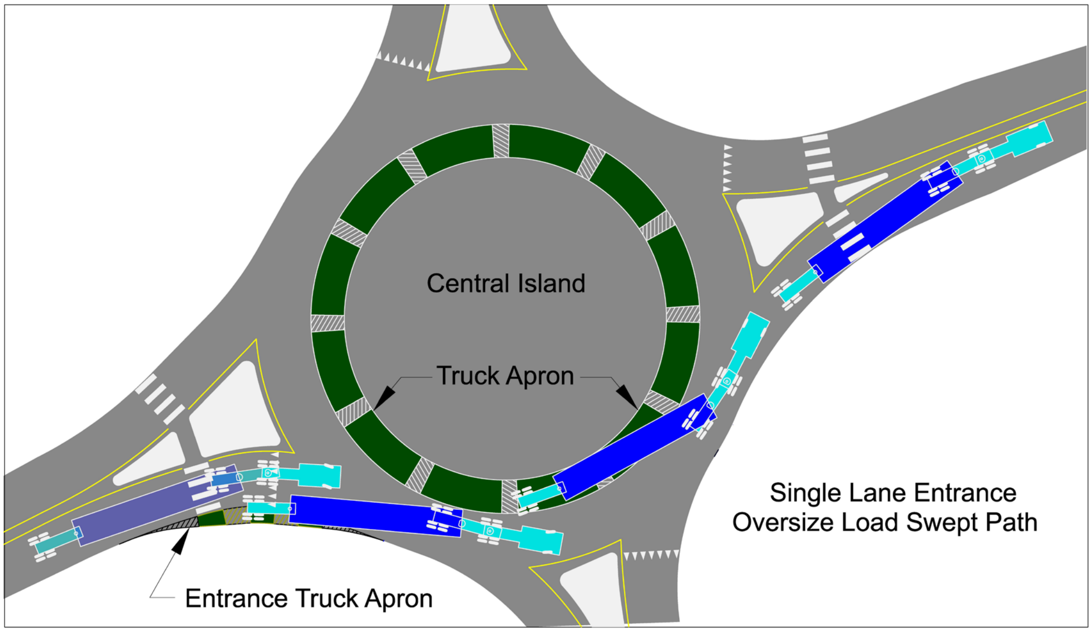


Figure 500-50: Swept Path of Oversize Vehicle Using an Entrance Apron



509.13 Splitter Island

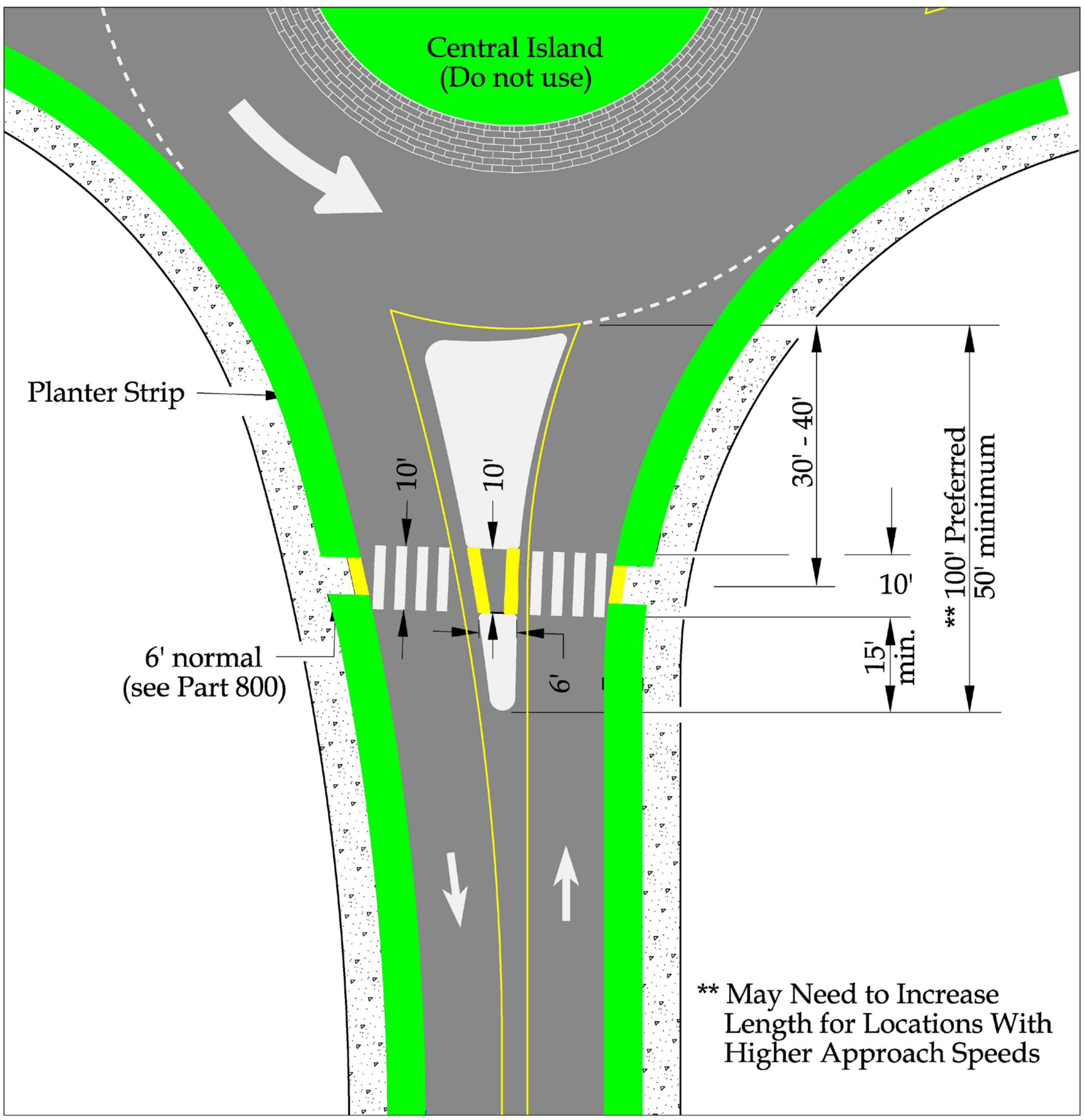
The purposes of splitter islands are to:

1. Help alert drivers of the upcoming roundabout and regulate entry and exit speed;
2. Physically separate entering and exiting traffic, minimize potential for wrong-way movement;
3. Introduce deflection into vehicle paths to control movement at the entrance/exit; and
4. Provide a refuge for pedestrians, and a place to mount traffic signs.

A length of 100 ft. is desirable in urban locations, the minimum length of the island in these locations measured along the approach should be 50 feet long to provide sufficient protection for pedestrians. Longer islands or extended raised medians are used in areas with higher approach speeds. Excessive splitter island length adds unnecessary cost to a project. For higher speed locations, median and splitter island combined length is the distance needed to comfortably decelerate from roadway speed to the desired entrance speed of the roundabout. *Using the AASHTO comfortable deceleration value of 11.2 ft/sec^2 and assuming a distance based on braking distance, splitter island length of 250 ft. to 300 ft. for higher speed locations generally is adequate to reduce vehicle speeds from highway speed to entrance speed.*

A separation between the entrance yield line on the circulatory roadway and the pedestrian crossing is crucial to safety and operation. This separation distance helps split up the decision points of yielding to a pedestrian and picking a gap in the vehicular flow of the roundabout. *It is recommended that the pedestrian crossing be located at least 30 – 40 feet from the yield line to the center of the crosswalk. The recommended crosswalk width is 10 feet. The opening through the splitter island should be a minimum of 6 feet in length at the center of the crosswalk.* Typically, the splitter island will have a cut through design to accommodate pedestrians. Figure 500-51 shows an example of a splitter island at a single lane roundabout.

Figure 500-51: Minimum Splitter Island Dimensions, Single Lane Roundabout



For multi-lane roundabouts, entry geometry is typically established first to identify a design that adequately controls fastest-path speeds, avoids path overlap and accommodates large vehicles. The splitter islands are then developed in conjunction with the entrance and exit designs to provide adequate median width for pedestrian refuge and sign placement requirements. For more information specific to overall design of multi-lane roundabouts, refer to the following 509.14 for specific multi-lane roundabout design.

509.14 Design for Pedestrians

The accommodation and safety of pedestrians at roundabouts is dependent on the following design features:

1. Slow speeds, achieved through sufficient deflection;
2. Separation of conflicts, achieved by placing the crosswalk away from the yield line of the circulatory roadway by 30–40 feet (approx. one car length); and
3. Breaking up the pedestrian crossing movements, achieved by placing a splitter island at each leg. Pedestrians only need to cross one direction of traffic at a time.

Sidewalks provide pedestrian accessibility at roundabouts. **Where bike ramps will provide bicyclists access to use the sidewalk and crosswalk with pedestrians, minimum sidewalk width is 8 feet.** Greater sidewalk widths are encouraged and should be used. ***10 feet or more is preferred for the width of the walkway as it functions as a shared use path.*** When pedestrians and bicyclists share a sidewalk, appropriate shared use path requirements are employed for the design.

It is preferred sidewalks are set back from the edge of the circulatory roadway whenever possible using landscaped buffer zones. ***Recommended set back widths (buffer zone) should be at least 5 feet.*** **For ODOT design, the minimum width of the set back (buffer zone) is 3 feet.** Landscape strips and buffer zones provide more benefits than just aesthetic value. Buffer zones:

- Increase comfort for pedestrians
- Provide an area for snow storage
- Allow for the overhang of large vehicles, if necessary, as they traverse the roundabout
- Help direct pedestrians to appropriate crosswalks, rather than crossing to the center island or cutting across the circulatory roadway

Vegetated buffers are the preferred option, however, other softscape and hardscape options are available. **Hardscape options must include tactile relief adequate for low vision and blind individuals to discern and detect the buffer zone and provide guidance to the crosswalk.** For additional information on buffer zone requirements, see Part 800 or contact the Technical Services Roadway Engineering Unit. Grass or low shrub type vegetation should be the choice for plantings. They provide the visual and tactile delineation, but also allow drivers to see pedestrians on the sidewalk and at crosswalks.

Taller plantings may block driver sight distance and mask the presence of pedestrians. Roundabout signing and vegetation placement must be coordinated to ensure signs are not obscured as vegetation grows over time. Legible signs, easily understood by drivers are an important feature of roundabouts.

Where no buffer zone is provided and the sidewalk is curb tight, then continuous vertical delineation or edge treatment that is discernable and detectable is required to provide direction to crosswalk locations. Examples of detectable edge treatments include chains, fencing or railings. **Do not use a Detectable Warning Surface for edge delineation.** For additional information, see Part 800.

Research has shown multi-lane roundabouts to be safer for pedestrians than signal controlled, multi-lane intersections. Low vision and blind pedestrians may find crossing multi-lane roundabout connections to be difficult, due to limited or masked audible cues to traffic movements. However, this would not be dissimilar to multi-lane, mid-block crossings or multi-lane, uncontrolled intersection crossings as well. When appropriate, multi-lane roundabouts benefit from the installation of special traffic control devices (Signals or Rectangular Rapid Flash Beacons) at crosswalk locations to accommodate pedestrians with vision disabilities. NCHRP Report 834, Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities: A Guidebook, provides information for potential design of pedestrian crossings. **Install appropriate "signal" equipment with all multi-lane roundabout projects to ensure accessibility**.

It is beneficial and prudent for potential future signalization requirements to be incorporated with project design criteria to the greatest extent possible with all designs. ODOT's preference is that the designer should consider what would be required to retrofit a signal into the proposed multi-lane roundabout layout particularly underground infrastructure. *Consideration should be given to signal pole placement, signal head visibility, and controller cabinet location as well as conduit, wiring and operational needs.* At the very least, the roundabout design should be as easily adaptable and possible in the future to include these requirements for accessibility. ***Check with the Region Traffic Unit and the Traffic and Roadway Engineering Sections of Technical Services for current direction on accessibility requirements.*** For more information on pedestrian design at roundabouts, see Part 800.

509.15 Design for Bicyclists

Greater emphasis is being placed on separated bicycle facilities at roundabouts. *The preferred method is to accommodate cyclists on separated facilities.* Not all locations will have the ability to include fully separated designs. When fully separated designs are not possible, bicyclists are given a choice to enter a roundabout as a vehicle and occupy a lane until exiting the roundabout, or to use the sidewalks and crosswalks with pedestrians. Occupying a lane through the roundabout will, in most cases, be the most expedient method of traversing a roundabout for a bicyclist. Riding with traffic in a roundabout may not be comfortable for many bicyclists. For these bicyclists, a bike ramp is provided for them to exit the bike lane on approach to the roundabout and use the sidewalk and crosswalks in the manner of a pedestrian.

In single lane roundabouts, occupying a lane through the roundabout is less complicated than occupying a lane in a multi-lane roundabout. With a single lane roundabout, bicyclists will generally be traveling at relative speed to other vehicles on the roadway. Since it is easier to command the lane in a single lane roundabout, there is less chance of a bicyclist being cut off at an exit by a motorist. Also, bicyclists are more visible to motorists in a single lane roundabout, as there is less room and less distraction for vehicle drivers.

Multi-lane roundabouts pose greater challenges to bicyclists when occupying a lane to navigate through them. The greater complexity of multi-lane roundabouts may cause bicyclists to be less visible to motorists. Bicyclists will have a greater challenge in controlling the lanes in a multi-lane roundabout and there is greater potential to be cut off at an exit. Depending on roundabout configuration and bicyclist destination, a bicyclist may need to enter the roundabout in the left lane of a multi-lane roundabout. This may not be familiar or expected by other roundabout users. When considering bicycle access and movement through a multi-lane roundabout, it is important to remember that ORS 811.292 and ORS 811.370 have provision for “commercial motor vehicles” to operate outside a single lane in a multi-lane roundabout when necessary. Like other vehicle drivers traversing a roundabout, bicyclists must not pass or ride beside a commercial vehicle. In Oregon, by statute (ORS811.292), it is a Class C Traffic Violation to drive beside or pass a commercial vehicle in a roundabout.

If bicyclists choose to ride with traffic through any roundabout, single lane or multi-lane, they are expected to be a vehicle and should not be given individual direction to maneuver in a manner unexpected or different than a motor vehicle. They should be provided with efficient, safe and effective means of traversing the roundabout, as are other roundabout users. Bicyclists choosing to use the travel lane through a roundabout are given ample space and distance to merge into the travel lane prior to the roundabout entry to allow motorists time to recognize them.

Do not provide a bike lane within the circulatory roadway of a roundabout. Providing a bike lane to the actual circulatory roadway entrance will compound the merge maneuver for the bicyclist and create a conflict point between the bicyclist and motorist who are both concentrating on entering a gap in roundabout traffic. Providing a bike lane within the circulatory roadway of a roundabout would create a condition with greater potential for conflicts between vehicles and bikes than if bicyclists use the travel lane. Figure 500-52 provides the recommended design options for roundabout approach legs that have a shoulder or bike lane.

The shoulder/bike lane should terminate at a distance sufficient to allow bicyclists to merge into traffic before drivers’ attention is on roundabout traffic coming from the left. Bicycle ramps are placed where the shoulder/bike lane terminates, allowing bicyclists to access the sidewalk should they choose to utilize it and the crosswalks to traverse the roundabout. **End the bike**

lane 165 feet in advance of the yield line and provide a bicycle ramp 100 feet in advance of the yield line.

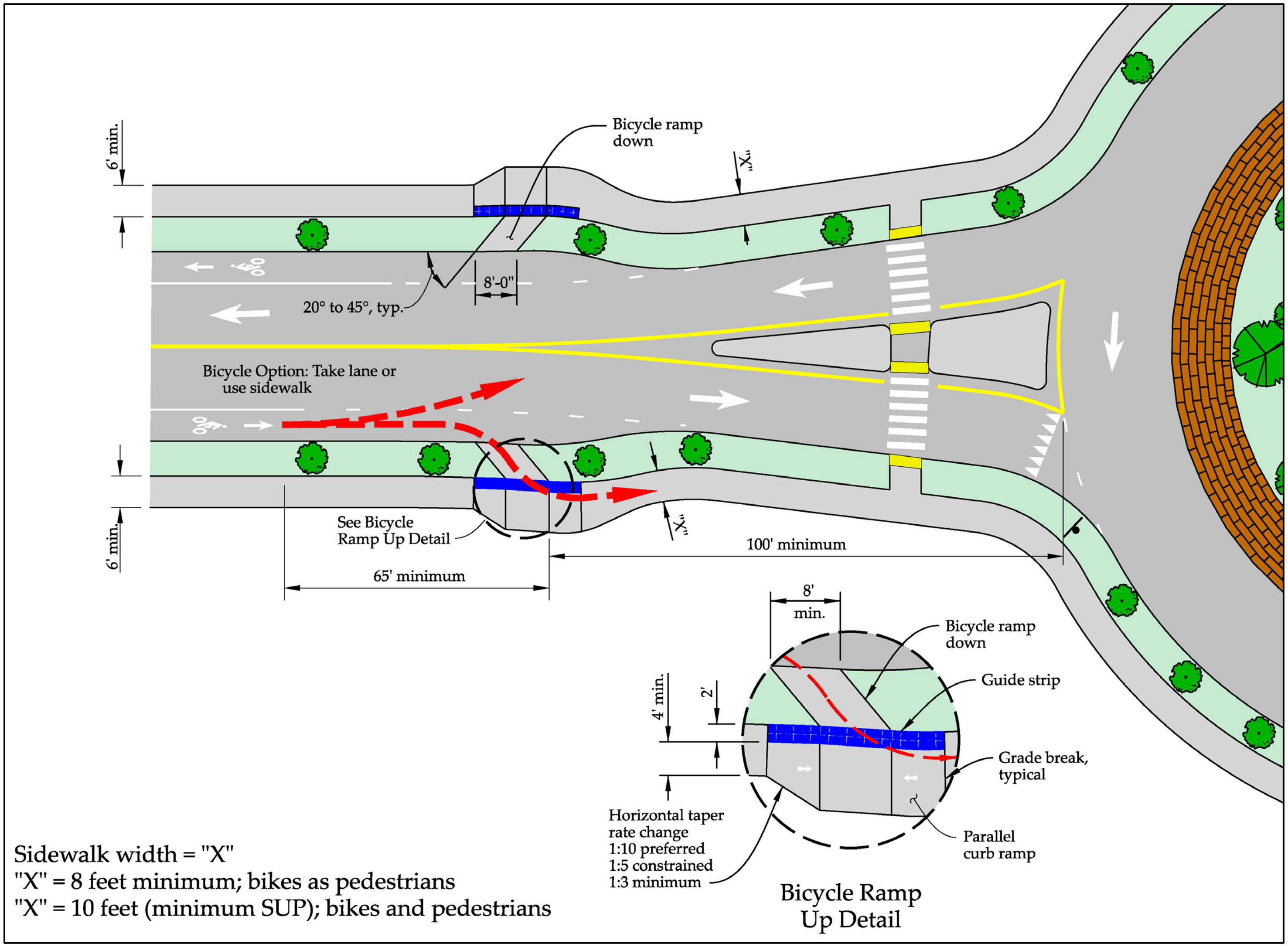
Bicycle ramps are not intended to serve pedestrian traffic. If there is no sidewalk on the approach to a roundabout, the ramp to a path serving the roundabout functions for both bicyclists and pedestrians. Use a pedestrian curb ramp rather than a bicycle ramp in that case.

The width of the bicycle ramp depends on the layout. Where a bicycle ramp is in line with the approaching bicycle lane, the bicycle ramp may be equal in width to the approaching bicycle lane. Where the bicycle ramp requires bicycles to move parallel to the bicycle lane, **provide a bicycle ramp with minimum of 8 feet width.** General design practice attempts to keep roundabout entrances relatively flat with a suggested maximum grade of 4 percent. However, this is not always possible due to existing topographic conditions. Even a maximum grade of 4 percent sustained over a long enough distance can slow a cyclist. *Approach grade and expected cyclist speed in relation to vehicle speed at the lane merge point is an important design consideration when designing for bicyclists to use the travel lane through a roundabout.*

Bicycle ramps can be confused with curb ramps by low vision and blind pedestrians. **Include a Detectable Guide Strip adjacent to bicycle ramps.** See part 800 for additional guidance on detectable guide strips and refer to Oregon Standard Drawing RD909 for placement of detectable guide strips. Gaining popularity is the use of Tactile Wayfinding Tiles also called Tactile Walking Surface Indicators across the top of the bicycle ramp and sidewalk. This option is relatively new and is ODOT's preferred method (See Part 900 for bicycle ramp design). More direction will be available when the next addition of the AASHTO Bicycle Design Guide is published. Contact the Bicycle and Pedestrian Design Engineer or the Senior ADA Standards Engineer in the Technical Services Roadway Engineering Unit for more information on installing Tactile Walking Surface Indicators at roundabouts. *It is preferred to locate bicycle ramps in a buffer zone. In these locations, the bike ramp is considered as part of the traveled way that needs to be detectable to pedestrians.*

The least desirable location for the bicycle ramp is within the sidewalk itself. Use this design option only if necessary and no other option will work. Review Oregon Standard Drawing RD909 for detectable guide strip placement.

Figure 500-52: Bike Accommodation



Where bike ramps will provide bicyclists access to use the sidewalks and crosswalks, minimum sidewalk width is 8 feet. ***10 feet or more is preferred for the width to allow for bicycles and pedestrians to function as a shared use path.*** If there is a separated bicycle facility, apart from the sidewalk, the sidewalk width may be 6 feet, although wider sidewalks are preferred. In locations where bicycle riding on the sidewalk is prohibited by statute, appropriate signage is necessary to inform bicyclists.

Bicycle ramps up from the roadway to the sidewalk should be placed at a 35 degree to 45 degree angle with the roadway allowing bicyclists to use the bike ramp, while discouraging them from entering the sidewalk area at too great a speed. Since the bicycle ramp is not a pedestrian curb ramp, its slope is not limited to a maximum of 1 in 12 (8.33%), however wheelchairs and power assisted mobility devices are permitted to use the shoulder and may use the bike ramp to enter the sidewalk.

If necessary, the slope may be greater than 1 in 12. Ramps steeper than 1 in 12 can be a clue for low vision and blind pedestrians to differentiate between the bicycle ramp and the pedestrian curb ramp. Steeper ramps can also slow bicycle traffic as it enters the sidewalk zone. In general, bike ramps should only be as steep as necessary to fit the location with a potential maximum of 1 in 5 (20%) in extreme circumstances. Bicycle ramps from the sidewalk down to the roadway at roundabout exits can be placed with an angle as small as 20 degrees with the roadway since it is not necessary for a bicyclist to slow upon entry to the roadway. A flatter angle can be beneficial in allowing a bicyclist to enter the bike lane or travel lane at a relative speed to traffic. However, some discernible angle is preferred to provide information to pedestrians with vision disabilities that the bicycle ramp is not the pedestrian curb ramp.

When roadways leading up to a roundabout location have been designed utilizing a separated or protected bicycle facility like a cycle track, side path or multi-use path, there may be several options for providing accommodation for bicyclists to navigate the roundabout. For guidance in melding the bicycle facility design with the roundabout design, contact the ODOT Bicycle and Pedestrian Design Engineer in the Technical Services, Roadway Engineering Unit. For more information on bicycle facility design at roundabouts, see Part 900.

509.16 Design for Trucks

Freight transport is a vital function of the state highway system. Improperly designed roundabouts can impede freight traffic. ***Roundabouts proposed on a Reduction Review Route will need to go through a review with the ODOT Statewide Mobility Program and affected parties to obtain a "Record of Support". Roundabouts proposed on Non-Reduction Review Routes do not need a Record of Support from interested parties. However, those projects will need to comply with ODOT Directive, DES-02. The DES-02 Directive requires collaboration with interested parties from industry to come to agreement that the proposed roundabout is properly sized for the location.***

Roundabouts on the state highway system must be designed to accommodate the necessary movement of freight. The WB-67 class, “interstate” truck will be the basic design vehicle for roundabouts on the state highway system. Larger, permit vehicles will be accommodated as needed on a case-by-case basis. At specific locations, a smaller design truck than a WB-67 might be appropriate on some sections of highway. If a vehicle smaller than a WB-67 is anticipated to be used as the roundabout design vehicle, discussions with the ODOT Statewide Mobility Program and representatives of the trucking industry will be necessary to reach a final determination of feasibility.

When oversize/overweight (OSOW) loads may need to move through a roundabout location, these loads will need to be accommodated in an acceptable manner. To create an overall roundabout design that will accommodate the anticipated OSOW vehicles at a particular roundabout, discussion between the designer, Technical Services staff, ODOT Statewide Mobility Program, and trucking industry representatives will be necessary to determine appropriate loads and vehicle configurations to consider and how best to accommodate their movement through the roundabout. Section 509.5 provides general information about roundabout design vehicles and accommodation vehicles.

There may be locations where a smaller diameter roundabout is required that may also need to allow for OSOW vehicle traffic or a location may need to allow for unique or specialized loads to pass through the proposed roundabout. For these situations, there are several alternative design concepts that provide special access and movement through the roundabout. Contact the Technical Services Roadway Engineering Section for assistance in designing these unique and special access locations. In most cases, they will require design concurrence and may need additional design approval from the State Roadway Engineer, as well as support of groups with a stake in highway configuration.

509.17 Transit Considerations

While it is possible to effectively locate roundabouts on transit corridors, placement of actual transit stops in proximity to roundabouts is problematic for smooth operation of both the transit system and the roundabout. ***The placement of bus or other transit stops near roundabouts should be consistent with the needs of the users and the desired operations of the roundabout.*** Stops should be close to passenger generators or destinations, and pedestrian crossings of the roundabout legs should be minimized. A bus or transit stop is best situated:

1. On an exit lane, in a pullout just past the crosswalk; or
2. On an approach leg 60 feet upstream from the crosswalk, in a pullout; or
3. On a single lane entrance leg, just upstream from the crosswalk, if the traffic volume is low and the stopping time is short. This location should not be used on two-lane entrances (In the interest of pedestrian crossing safety, a vehicle should not be allowed to pass a stopped bus).

Bus pullouts or transit stops shall not be located within the circulatory roadway of the roundabout on the state highway system.

Although rare, there are locations in other jurisdictions where fixed transit lines (light rail, Bus Rapid Transit) have been provided with independent alignment through roundabouts. The best practice for the state highway system is to avoid placing a fixed transit line through a roundabout; however, when it cannot be avoided, care must be taken when establishing the transit alignment to not diminish the performance of the roundabout. The design can be successful. However, care must be taken to determine the transit schedule and its impact on the traffic flows at the roundabout. The interaction between the transit vehicles and normal traffic must be considered for present volumes and patterns as well as anticipated future transit and traffic needs.

Exhibit 500-2: Example of a Light Rail Line through a Roundabout

509.18 Roundabouts Near Railroad Crossings

Locating any intersection near an at-grade railroad crossing is generally discouraged, but this is often unavoidable, and roundabouts have been successfully used to control traffic near railroad crossings in many places around the US. Where an at-grade rail crossing is provided at a roundabout, design consideration should include the provisions of traffic control such as crossing gates and flashing lights at the grade crossing consistent with treatments at other highway-rail grade crossings. The treatment of at-grade rail crossings should follow the recommendations of the MUTCD and the FHWA Railroad-Highway Grade Crossing Handbook.

Where roundabouts include or are in proximity to a highway at–grade rail crossing, a key consideration is the accommodation of vehicle queues to avoid queuing across the tracks. The

MUTCD requires an engineering study to be conducted for any roundabout near a highway-rail grade crossing to determine queuing effect at the rail crossing and to develop provisions to clear highway traffic from the crossing prior to train arrival. Contact the ODOT Rail Safety Program in the ODOT Commerce and Compliance Division for more information when considering a roundabout near an at-grade railroad crossing.

509.19 Roundabout Metering

When one approach to a roundabout may be creating operational issues for the roundabout as a whole or is impacting access to the roundabout at another approach, a metering device installed on the higher volume approach can improve overall operations of the roundabout. Metering devices have been used successfully in many locations. Metering devices should not be indiscriminately installed at roundabouts. Their use should be limited to when it is necessary for operations for them to be installed. ***Metering a high-volume entrance can provide gaps for the other entering legs improving overall operation and potentially extending the life of a single lane roundabout before additional circulating lanes are needed.*** Metering can be an effective method of providing operational improvements, but their use must be evaluated and determined to be appropriate.

509.20 Multi-Lane Roundabout Configuration

Since many design features of roundabouts are integral to both single lane and multi-lane roundabouts, the previous discussion about roundabout design elements did not specify explicit information about single lane roundabouts or multi-lane roundabouts, but rather discussed the design elements themselves in more general terms for both applications. There are a few unique design needs at a multi-lane roundabout that are not shared with single lane roundabouts. As a result, multi-lane roundabout design presents a greater challenge to the designer.

In the past, roundabouts were classified as single lane, double lane and, in extreme cases, triple lane roundabouts. The intent was to have equal lanes entering and exiting assuming balanced flow between intersecting roadways. As roundabout design has evolved and a roundabout is just another form of intersection control, general intersection control principles are being applied to roundabout design.

In conventional intersection design, it is not required to have an equal number of lanes at each leg. Intersection lane configuration is based on the needs of the traffic movements through the intersection. If one leg has a high volume of left turn traffic, a dedicated left turn lane may be designed for that leg as well as a through lane. This, in effect, creates a two-lane entrance, while the through lane may align with only one lane on the opposite leg exiting the intersection.

Likewise, if one leg has a high volume of right turn traffic, a dedicated right turn lane or even a "free right" slip lane might be designed to improve operation.

The same concepts are now being applied to roundabout design and the term "multi-lane roundabout" has replaced the previous "double lane" or "triple lane" nomenclature. The term multi-lane covers a wider range of various lane configuration options that a design might employ to better tailor the design to the specific intersection control required for a specific location. ***Because lane configuration on entrance and exit may be specific to a particular move at a particular exit, signing and striping of multi-lane roundabouts must convey to drivers which lane they need to be in to negotiate the roundabout successfully.*** The information contained in the signing and striping must be understood by the approaching driver far enough in advance of the roundabout to safely make the appropriate lane choice. If drivers are positioned in the correct lane for their destination when entering the roundabout, the lane striping and guidance will get them to the appropriate exit.

Some multi-lane roundabout configurations may appear complex to an approaching driver. When examining a design in plan view it may be easy to see how the lanes flow. At driver eye level that may not be the case. ***The designer must keep in mind what drivers see or don't see as they approach the roundabout. The designer must also consider what drivers need to see to understand how to get to the appropriate exit for their journey.*** Efficient, effective and well-placed signing, striping and lane markings are critical to convey that information to motorists in modern multi-lane roundabout design. Figure 500-53 and Figure 500-54 portray examples of multi-lane roundabout design with various entrance and exit lane configurations. These layouts are hypothetical and are intended to provide guidance and illustration for potential options to meet traffic control needs at a given location.

These multi-lane roundabout layouts are not all inclusive and other configurations may fit a particular location better. Individual designers will need to design for the needs of the site for which the roundabout is being designed. Some of the entrance and exit options shown in the figures would only be employed at unique or high-volume locations. ***As with any intersection design, it is important to only provide what is necessary to meet the control needs of the traffic movements. It is good design practice to keep the layout and operation of a multi-lane roundabout as simple as possible, while still providing the necessary control functions to allow smooth, efficient traffic flow.*** Additional information about roundabout lane configuration and striping can be found in the ODOT Traffic Line Manual and the 2023 Edition of the MUTCD, Chapter 3C Roundabout Markings.

Figure 500-53: Various Multi-Lane Roundabout Entrance and Exit Configurations

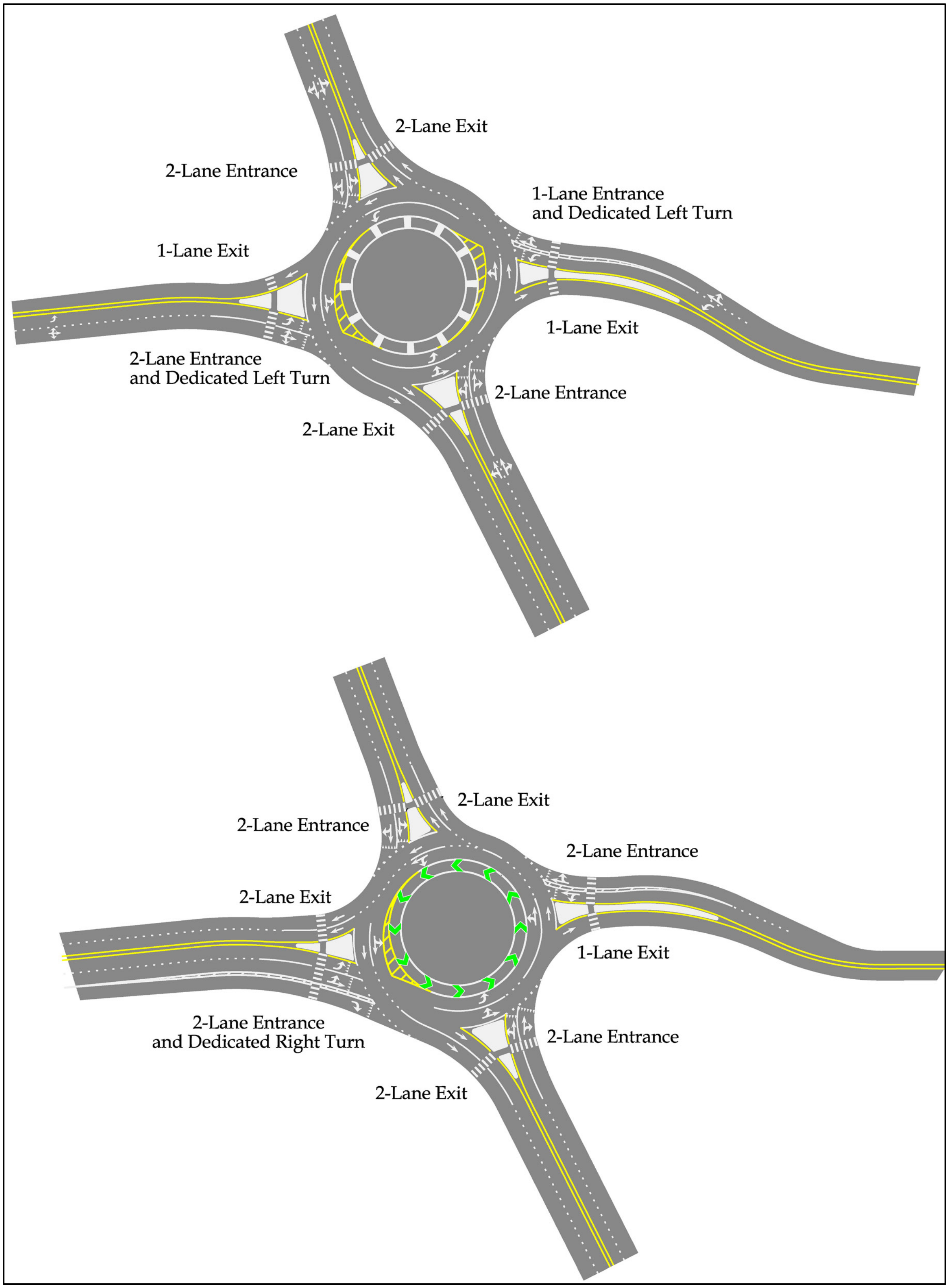
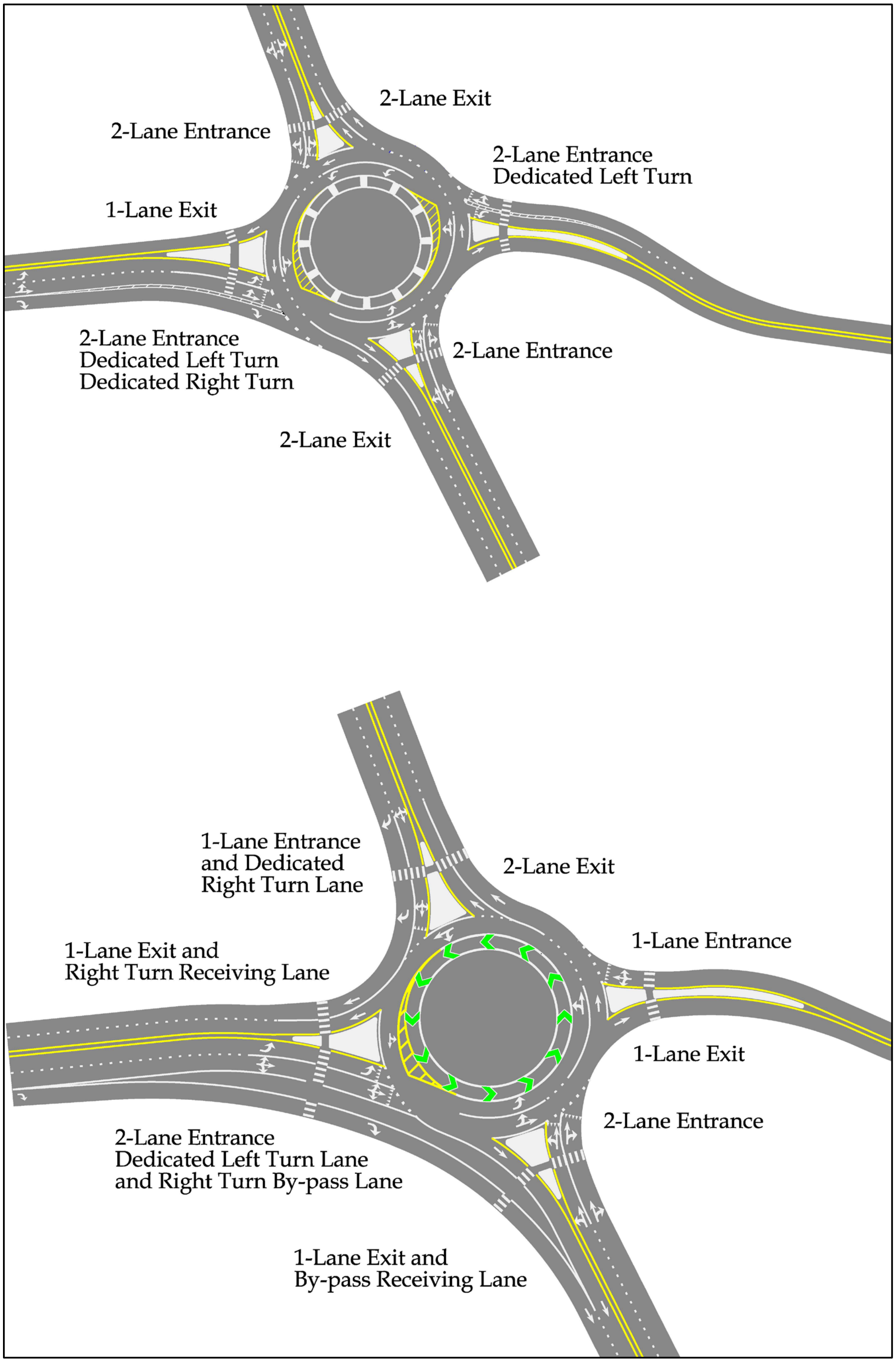
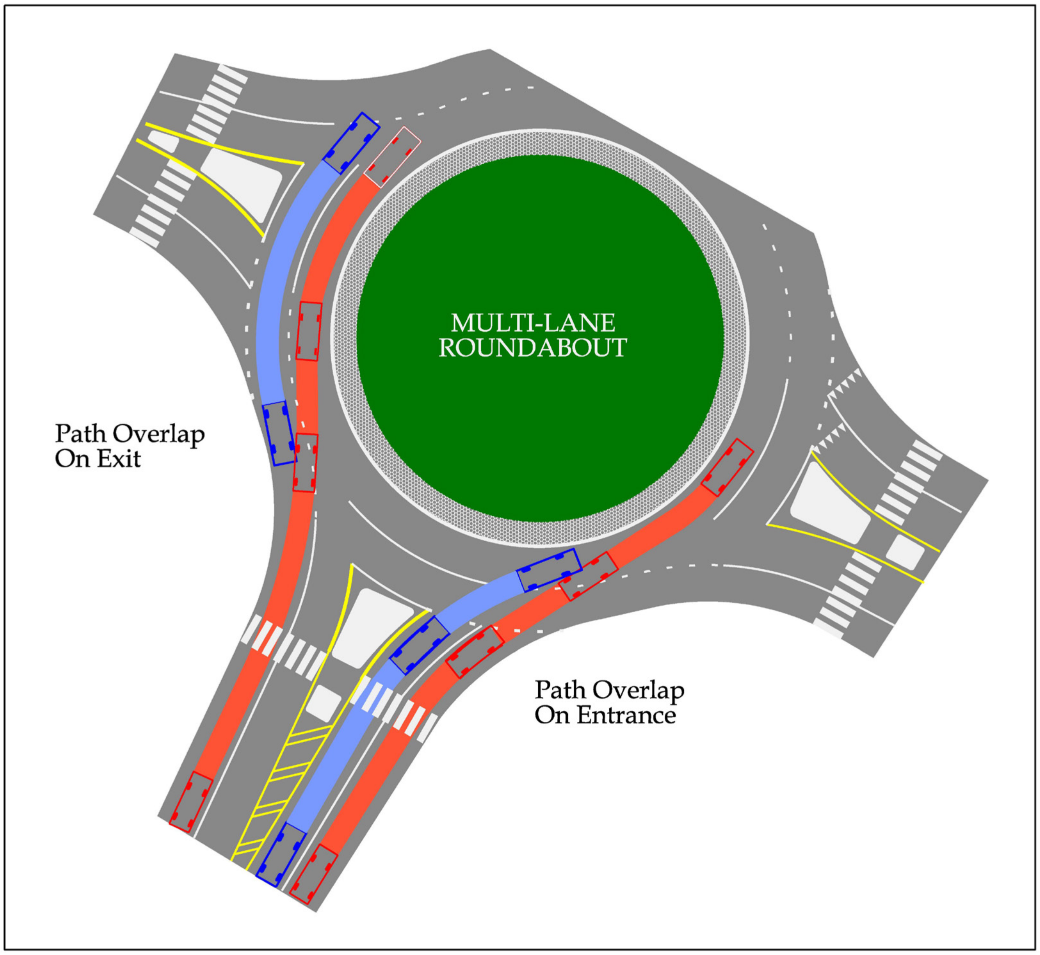


Figure 500-54: Additional Multi-Lane Roundabout Entrance and Exit Configurations



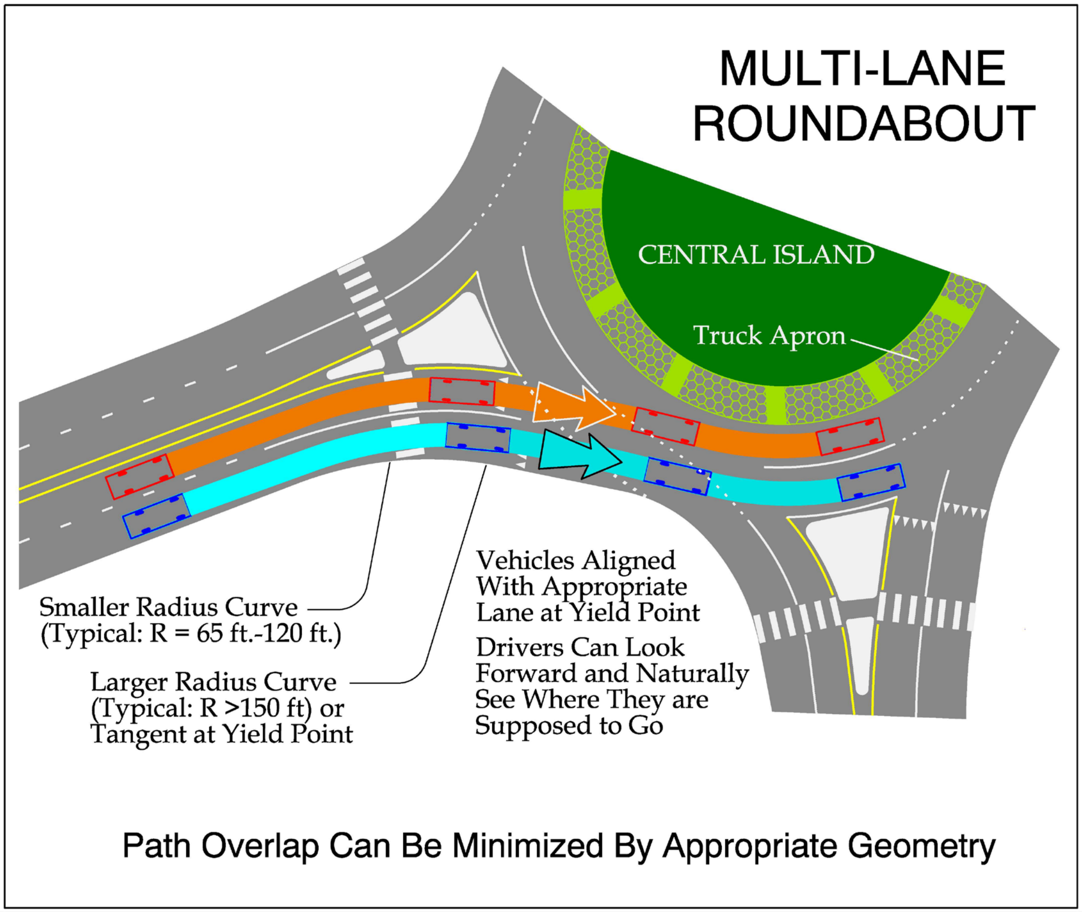
509.21 Path Overlap (Multi-Lane Roundabouts)

Figure 500-55: Path Overlap - Multi-Lane Roundabout



Path overlap is another unique design concern present with multi-lane roundabouts. Figure 500-55 demonstrates the effect of path overlap at a multi-lane roundabout. Entrance design, central island design and exit design must be balanced to provide a consistent, comfortable flow when designing both single lane and multi-lane roundabouts. Multi-lane roundabouts, however, pose a greater problem with entry and exit design. Because more than one lane enters and exits the circulating roadway at multi-lane locations, a phenomenon known as path overlap can occur. *Vehicle path overlap occurs when the natural path of a vehicle crosses into the adjacent lane.* It generally happens at entrances to roundabouts but can also occur at exits or even along the circulating roadway itself. *The natural path of a vehicle is the path a driver seeks based on comfort due to the applied forces to the vehicle from the roadway geometry.* The natural path is determined by approach geometry, entrance radii and entrance width. To avoid path overlap and potential side-swipe crashes at a multi-lane roundabout, the entry design for the approach lanes must provide a comfortable path for drivers to keep their vehicles in one lane and not encroach on the adjacent lane. While proper entry curvature is a key factor in avoiding path overlap, there is no single method for creating a desirable vehicle path alignment. It may take several iterations of design elements to finalize an appropriate vehicle path to provide a smooth transition from entrance to circulating roadway to exit that eliminates path overlap.

Figure 500-56: Minimizing Path Overlap - Multi-Lane Roundabouts

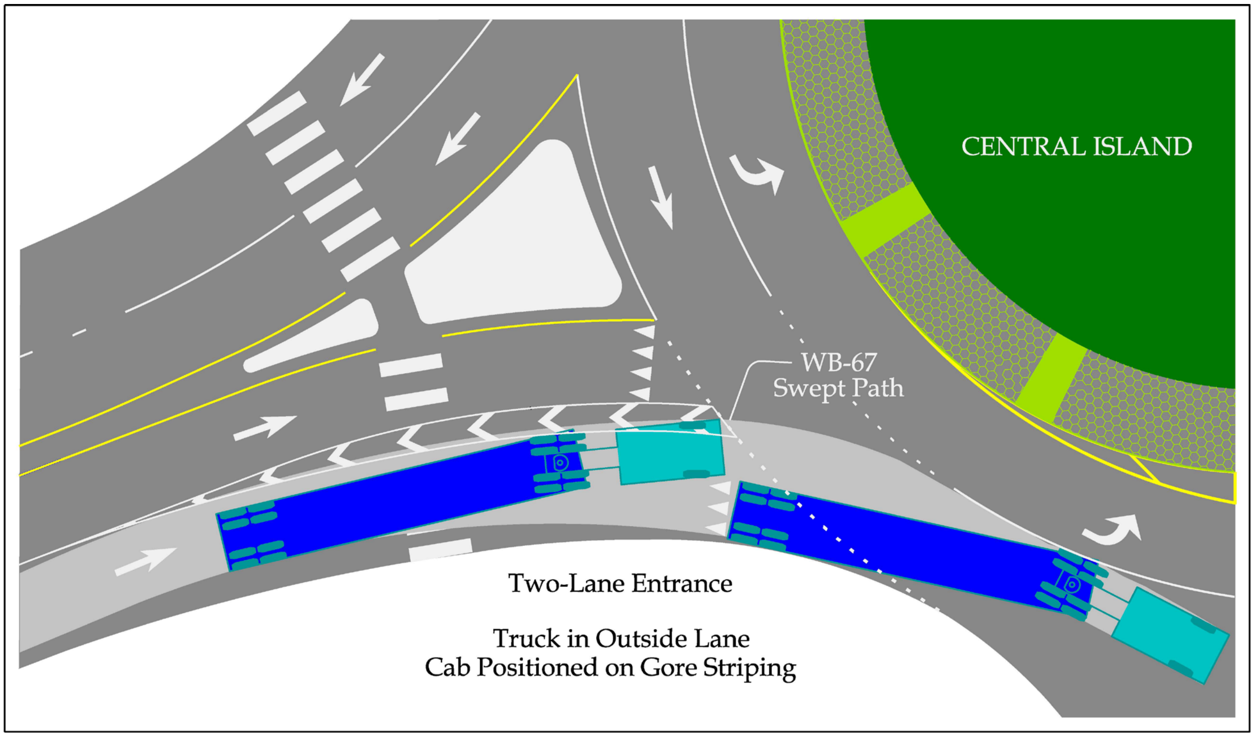


As a general starting point, entrance radii should be greater than 65 feet and less than 120 feet. Compound curve sets or a single curve in series ahead of a tangent may prove beneficial in creating a successful design that balances desired speed constraint, provides large vehicle accommodation and addresses bicycle and pedestrian needs while directing the entering driver to the appropriate lane through the multi-lane roundabout. Figure 500-56 illustrates geometry that can minimize path overlap. The general idea is to create entrance geometry that slows the entering vehicle to the desired entry speed and then comfortably leads it to the appropriate circulating lane with a smooth transition to the circulating roadway and another smooth transition from the circulating roadway to the exit radius out of the roundabout.

509.22 Large Vehicle Accommodation (Multi-Lane Roundabout)

Large vehicles must be able to negotiate a multi-lane roundabout. As with single lane roundabouts, truck aprons around the central island are used to aid large vehicle movements through multi-lane roundabouts. *ORS 811.292 and ORS 811.370 provide for "commercial motor vehicles" to operate outside a single lane in a multi-lane roundabout when necessary. It is sometimes beneficial to design multi-lane roundabouts to allow larger vehicles to traverse the roundabout without operating outside of a single lane. However, this need must be balanced with the overall effectiveness of the roundabout. It is acceptable and sometimes necessary to allow truck off-tracking into an adjacent lane for overall design of a roundabout.*

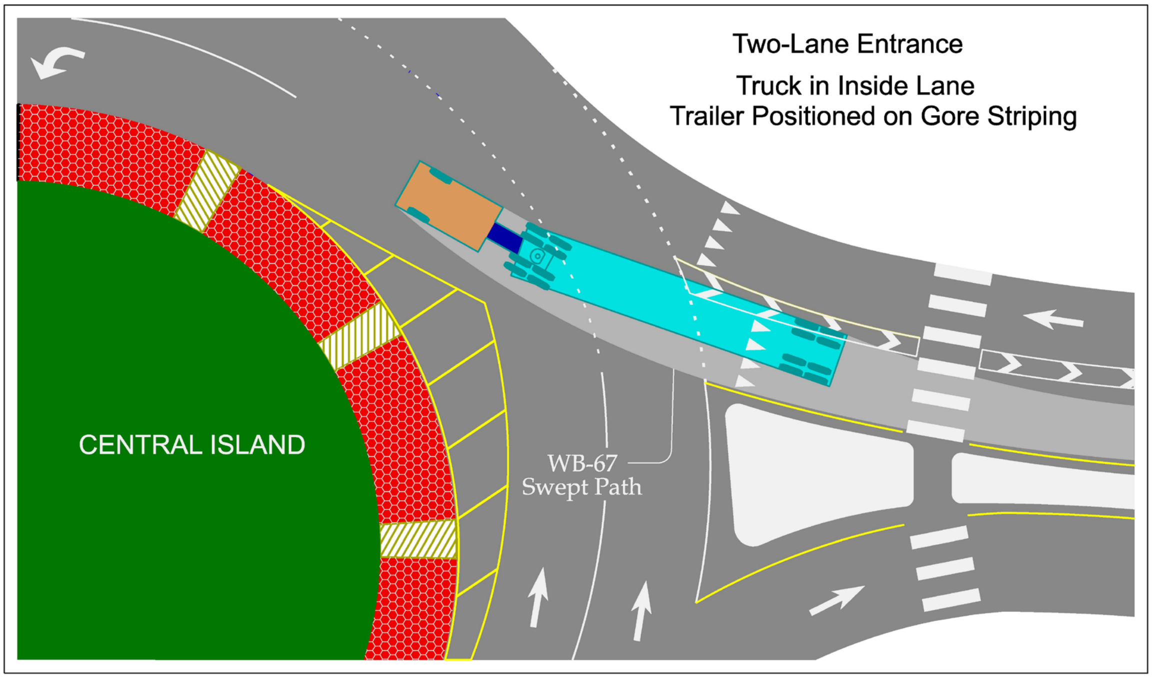
Figure 500-57: WB 67 Entering in the Outside Lane, Using Gore Striping – Two-Lane Entrance



Designing a multi-lane roundabout keeping large vehicles in one lane can lead to overly large inscribed diameters that can jeopardize desired speed control and safety goals. In Oregon, by statute (ORS 811.292), it is a Class C Traffic Violation to drive beside or pass a commercial vehicle in a roundabout. As a result, designing for large vehicle to remain in a single lane is not always necessary or beneficial. Providing too large of a multi-lane design may encourage faster path speeds for passenger vehicles when truck volumes are not present.

When accommodating larger vehicles, one way to help keep them from encroaching on the adjacent lane at the entrance to a multi-lane roundabout, while keeping entrance width to a minimum, is to provide a section of "Gore Striping" between the entrance lanes. Figure 500-57 and Figure 500-58 depicts a WB-67 swept path at a roundabout entrance that utilizes gore striping. The drawings show a truck entering from either lane utilizing the striping to minimize encroachment of the adjacent lane.

Figure 500-58: WB-67 Entering in the Inside Lane, Using Gore Striping – Two–Lane Entrance



509.23 Artwork at Roundabouts

Artwork added to the central island of a roundabout installation can provide aesthetic value, promote placemaking, and provide community recognition as a gateway treatment to a city or town. There also is recognition that artwork (coordinated effectively with landscaping) placed in the roundabout can benefit safety by making the intersection a focal point that provides greater recognition by drivers of expected roadway operation thereby promoting lower speeds which translates to potential for improved safety. There are many successful roundabout artwork installations in Oregon, across the United States and around the world. However, each roundabout location has different needs and artwork installed at roundabouts must be carefully determined on a case-by-case basis. Not all roundabouts are good candidates for artwork. This is particularly true for small diameter roundabouts where there is minimal room to provide an acceptable clear zone. When artwork is requested at a roundabout location, follow requirements and guidance in this section of the Highway Design Manual and the ODOT Highway Directive Hwy 01 for Placement of Artwork on State Highway Right of Way.

As with artwork installed anywhere within the Oregon State Highway Right of Way, artwork proposed for roundabouts must be suitable for heavy traffic conditions, comply with highway safety requirements and practices, not degrade highway safety and operations, be long-term durable, and be weather and vandal resistant. The following requirements include specific guidance for artwork at roundabouts and do not supersede ODOT's Highway Directive HWY 01, Placement of Artwork on State Highway Right of Way. Rather, they supplement directive HWY 01 and provide guidance for applying the directive in relation to specifics of artwork installed at roundabouts that Highway Directive HWY 01 may not directly address, since it is focused more on artwork placement outside the roadway. Artwork placed within the central island of a roundabout is similar to placement of an object within the median of a roadway section between travel lanes.

To better understand overall traffic operations after a roundabout is constructed at a specific location, it is recommended that a two-year waiting period be provided prior to artwork installation to determine and verify any specific design parameters including allowable clear zone needed in relation to the artwork installation. The 2-year period from day of opening provides a real-world, art free test and allows drivers to adjust to the traffic change before artwork is installed. District input and crash history over the first two years after opening can be reviewed by the Region Traffic and Roadway managers before proceeding with artwork installation.

When artwork is proposed for a roundabout location, the selection, funding, installation, and maintenance is the responsibility of the local jurisdiction where the roundabout is located. In many cases, the time frame to obtain funding, work through the RFP and artist/artwork selection process, ODOT approval process, and final installation may take much, if not all, of the two-year suggested waiting period. During this time, region traffic, roadway, and maintenance units should be reviewing traffic operations at the roundabout for indications of potential issues with artwork placement. Communication with the local jurisdiction of any problems or operational conditions that would affect final decisions on artwork placement is critical in the overall process during this interim time.

ODOT's responsibility is for the appropriateness and placement of the artwork in terms of safety and operation of the highway, not the aesthetic value of the artwork itself. While the selected artwork must fit with the roundabout design and there are specific parameters for materials, signs, symbols, and objects that can be used in artwork placed within the state highway right of way, the local jurisdiction chooses the content, context, and overall aesthetic theme of the artwork selected. In addition, an intergovernmental agreement is established between ODOT and the local jurisdiction to provide direction and define responsibilities for installation and long-term maintenance of the artwork. ODOT reserves the right to remove any artwork that is not maintained or becomes a safety or operations concern.

509.23.1 Parameters for Roundabout Artwork Installations

Artwork must not interfere with the operation, maintenance, or use of the highway. The safety of the highway system and travelers is of utmost concern for ODOT. Although a desired benefit of the Artwork is to make the central island more conspicuous (thus improving safety), it must not cause an unsafe distraction for motorists and other travelers. Artwork must:

1. Be of a size and scale that fits within the allowable area, must be coordinated to match the aesthetic design of the roundabout, and not demand a driver's attention to cause distraction from blinking or bright lights, glaring materials, or reflective surfaces.
2. Be placed in compliance with clear zone requirements as determined by ODOT policy for applicable installation areas at roundabouts. (See process outlined below in the Location of Artwork Within the Central Island section)
3. Not imitate a traffic control device.
4. Not have moving elements or water, nor simulate movement.
5. Not have elements that would cause the proposed Artwork to obscure the form of the roundabout, nor be a distraction to (e.g., not cause glare for, nor impair the safe vision of) motorists and other travelers.
6. Not attract pedestrians nor cyclists to the center island area.
7. Not contain text, interpretation of the Artwork, information on the artist, nor advertising or other form of a commercial message (business, product, or brand name, logo, phone number, web page, etc.), nor represent or pay tribute to a specific individual.
8. Utilize long lasting materials and construction techniques which will require minimal care and resist vandalism.
9. Must utilize shielded illumination to prevent light from being directed at the highway and of such low intensity or brilliance as to not cause glare or impair vision of motorists on the highway and must meet all state and local illumination codes.
10. Not have any foundation or base of the artwork installation exposed more than 4 inches above the ground.
11. Utilize breakaway features or frangible materials to the maximum extent feasible.

The artist(s) must coordinate design work closely with ODOT traffic and roadway engineers and with the state and local jurisdiction landscape architects and meet all federal, state, or local restrictions for aesthetic elements of the roundabout for compatibility and to match the aesthetic design of the roundabout, provide a site plan, and provide design plans stamped by a professional engineer registered in the State of Oregon demonstrating structural stability, the ability to withstand the necessary wind loads, and the means or method of installation (e.g., foundation and footing drawings complete with structural calculations and details of the interface and connection between the art and the foundation and/or footing). The artist(s) must provide a one-year warranty of the art structure, foundation/footing and workmanship from the date of final approval of the installation of the project.

509.23.2 Location of Artwork Within the Central Island

Once it has been established that artwork is appropriate at a roundabout location, it must be determined where within the central island it will be acceptable to install the chosen artwork piece. Artwork adds aesthetic value to a roundabout installation and can play a key role in placemaking as a gateway treatment to local communities. In addition to the aesthetic value artwork can also improve the overall safety and operations of the roundabout as well. Artwork adds increased conspicuity to the central island and the roundabout in total. Increasing the visual awareness for drivers approaching the roundabout can improve drivers understanding and recognition of operations of the roadway ahead and help prepare them to enter the roundabout.

Any object placed along the roadway like signs, signals, bridge columns, guardrail, shoulder barrier, etc., poses some risk that vehicles may collide with the object. Artwork placed within the roundabout central island also carries some risk of potential collision from an errant vehicle. As with placing any object along the roadway, minimizing the risk of collision is paramount. To determine appropriate placement of the artwork piece and minimize risk of impact, follow the process outlined below.

Determine Artwork Placement Design Speed and Design ADT - Design Speed for the artwork installation is considered to be the determined approach speed to the roundabout. Engineering judgement is needed to establish an appropriate speed. The Artwork Placement Design Speed could be the posted speed approaching the roundabout or it could be posted speed+5 mph or even posted speed+10 mph depending on location specific context.

After establishing an appropriate Artwork Placement Design Speed, use the Clear Zone Distance Table (Table 400-1) found in the ODOT Highway Design Manual to determine an initial Artwork Placement Design Clear Zone

Based on the Horizontal Curve Adjustment Table (Table 400-2) found in the ODOT Highway Design Manual use a 1.5 adjustment factor applied to the initial clear zone value determined in step 2 above to determine a calculated Artwork Placement Clear Zone value.

The Artwork Design Clear Zone is measured from the inside edge of the circulating roadway towards the center of the central island and includes the truck apron. This determines the area within the center of the central island where artwork may be located to minimize the risk of collision. It is best to keep this area as small as practicable.

After determining an appropriate area for artwork installation from the procedure described in previous steps, perform a visual check by using a computer-generated simulation on a plan view of the roundabout establishing a reasonable errant passenger vehicle pathway projected along an assumed approach alignment into the central island. Based on engineering judgement, adjustments may need to be made to the previously determined allowable installation area based on the outcome of the simulation.

Final determination and agreement of the artwork installation area is a collaborative effort of Region Traffic and Roadway Mangers and Technical Services, Traffic Engineering Section and Roadway Engineering Section staff.

Document the decision process in project files for future reference.

While artwork can be an integral part of a roundabout installation, artwork may not be appropriate at all roundabout locations. Having a process to determine an area for artwork installation does not, in itself, dictate the inclusion of artwork at a roundabout location. ODOT reserves the right to not allow artwork installations at any roundabout location based on overall safety, operational needs, or other significant impacts to the roadway section attributed to the artwork installation.

509.23.3 Roundabout Artwork Placement Evaluations

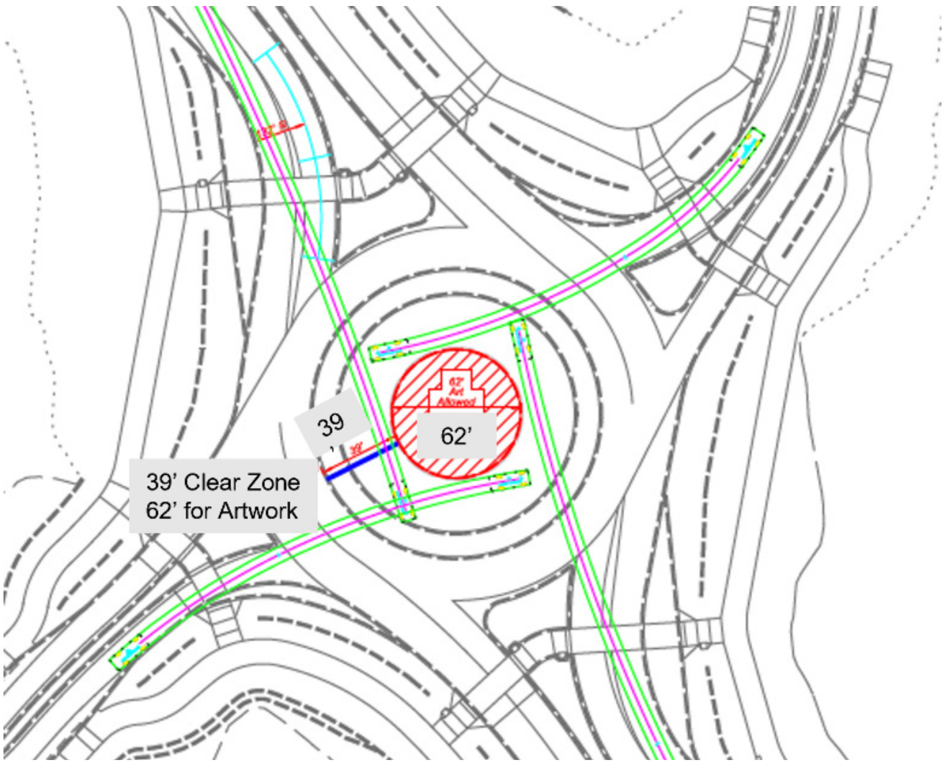
Example 1: Higher speed multi-Lane roadway – Posted Speed Approaching – 55 mph

- Multi-Lane Roundabout Design
- Fastest Path (Calculated) – 28-29 mph
- Target Speed (Circulating) – 20-25 mph

1. Determine artwork placement design speed - Since multi-lane higher speed roadway approaching the roundabout location, a posted speed + 5 mph could be used – use 60 mph.
2. From HDM Table 400-1 for 60 mph – Initial Artwork Placement Clear Zone = 26 ft.
3. Apply adjustment factor - Calculated Artwork Placement Clear Zone = 26 x 1.5 = 39 ft.
4. Define potential area where artwork could be allowed – Total width across central island including truck apron minus the artwork placement clear zone times 2. Width across central island - 140ft. – 2(39ft. clear zone) = 62ft. for potential artwork area.
5. As a visual verification, use computer generated simulation of an errant passenger vehicle alignment into the central island.

6. Evaluate final allowable artwork area – graphic representation agrees with calculated area at 62ft.
7. Obtain agreement on determined area with Region Traffic and Roadway mangers and with Technical Services Traffic and Roadway Engineering Sections staff.
8. Document decision in project files.

Figure 500-59: Roundabout Artwork - Higher Speed Multi-Lane Roadway



Example 2: Lower Speed Urban Roadway - Posted Speed Approaching – 35 mph

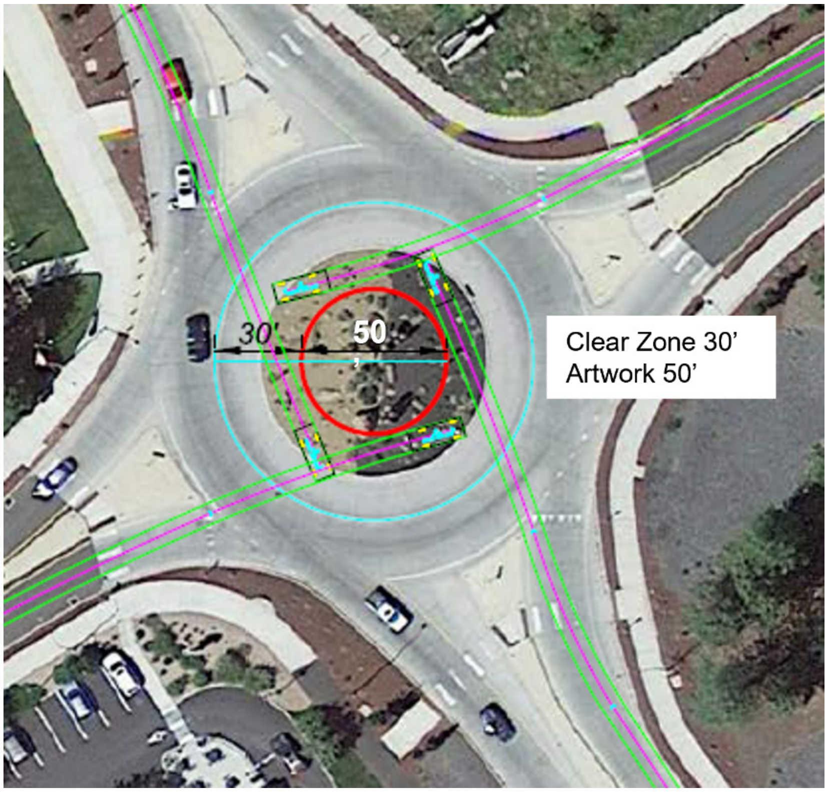
- Single Lane Roundabout Design
- Entrance Fastest Path (Calculated) – 25-26 mph
- Target Speed (Circulating) – 15-20 mph

1. Determine artwork placement design speed – Single-lane urban roadway approaching the roundabout location, a posted speed of 35 or posted speed + 5 mph could be used – both are in the same category on Table 400-1 - use 40 mph.
2. From HDM Table 400-1 for 40 mph – Initial Artwork Placement Clear Zone = 16 ft.

3. Apply adjustment factor - Calculated Artwork Placement Clear Zone = 16 x 1.5 = 24 ft.
4. Define potential area where artwork could be allowed – Total width across central island including truck apron minus the artwork placement clear zone times 2.

   Width across central island – 110 ft. – 2(24 ft. clear zone) = 62 ft. for potential artwork area.
5. As a visual verification, use computer generated simulation of an errant passenger vehicle alignment into the central island.
6. Evaluate final allowable artwork area – Based on roundabout approach geometry and splitter island placement, the visual representation of a reasonable errant vehicle path is outside the calculated artwork clear zone and inside the potential area for artwork. Increase the artwork placement clear zone to 30 ft. and reduce the final allowable area for artwork to 50 ft. (110 ft. – 2(30 ft.) = 50 ft.)
7. Obtain agreement on determined area with Region Traffic and Roadway mangers and with Technical Services Traffic and Roadway Engineering Sections staff.
8. Document decision in project files.

Figure 500-60: Roundabout Artwork - Lower Speed Urban Roadway



Section 510 Analysis; Roundabout Entrance and Exit Geometry (White Paper)

Entrance and exit geometries play an important role in controlling speed and movement of a vehicle through a roundabout. In general, providing roundabout alignments that increase flow at the exit may provide increased gaps in the circulating traffic stream and may provide greater opportunities for entering vehicles. Currently, there is significant discussion between roundabout designers about the best method to determine exit geometry and to control exit speed within design parameters. The discussion centers around the prediction of vehicle speed and how to calculate appropriate values for design. The standard method has been to utilize the speed, radius relationship as shown in Figure 500-34. The graph was derived using the basic equation for velocity and minimum radius from the AASHTO Green Book;

$V = \sqrt{15R(e+f)}$, where superelevation, e, is held to +2% and -2% with side friction factor, f, values assumed for general design.

Table 500-4 is a tabular form of the values in Figure 500-34 reported at 25 ft. radius intervals. In addition, NCHRP Report 1043, Guide for Roundabouts provides simplified equations to calculate speeds for given radii as well. Equation 1 is for +2% superelevation and Equation 2 is for -2% superelevation.

Speed (V), Radius (R) Relationship Equations:

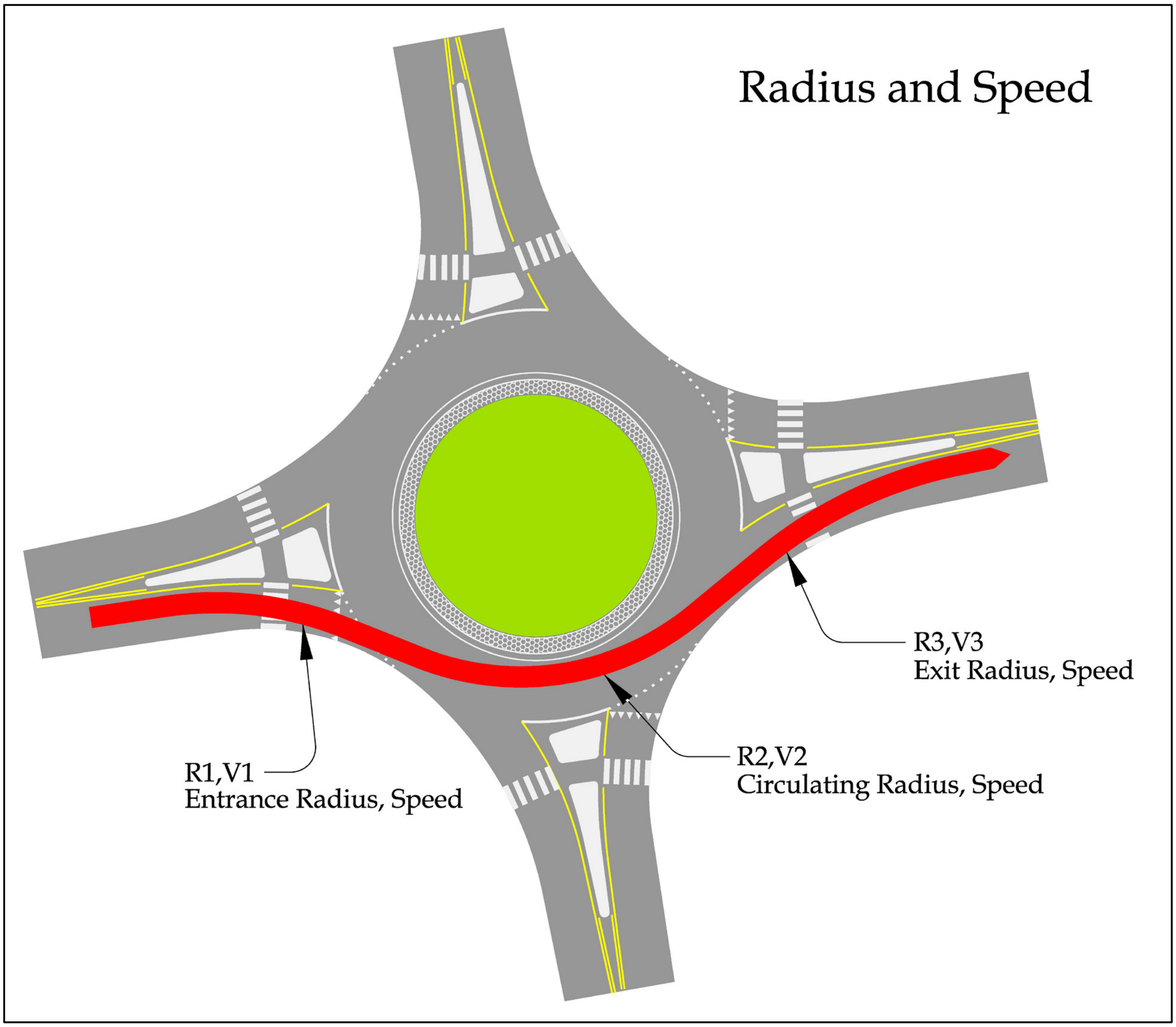
Equation 1: $\boldsymbol{V = 3.4415R^{0.3861}}$ For e= 2% (NCHRP Report 1043)

Equation 2: $\boldsymbol{V = 3.4614R^{0.3673}}$ For e= -2% (NCHRP Report 1043)

Equation 3: $\boldsymbol{V = \sqrt{15R(e+f)}}$ (AASHTO Minimum Radius)

Figure 500-61 illustrates the vehicle path through a roundabout depicting the R1,V1; R2,V2; and R3,V3 locations.

Figure 500-61: Vehicle Path through a Roundabout - Speed, Radius Locations



For superelevation other than +/- 2%, Equation 3, AASHTO Minimum Radius calculations need to be used with an appropriate side friction factor, f.

However, there is thought that exit radii designed too small to reduce predicted exit speed in an attempt to focus on pedestrian safety may unnecessarily limit overall roundabout capacity. This leads to the question, then, how to calculate appropriate exit radii to maximize capacity and still protect pedestrian movements at the downstream crosswalk?

510.1 Research for Alternate Calculation Method

510.1.1 Report: Alternate Design Methods for Pedestrian Safety at Roundabout Entries and Exits:

Crash Studies and Design Practices in Australia, France, Great Britain and the USA Bill Baranowski, Edmund Waddell (2004)

Research done in 2004 by Bill Baranowski of Roundabouts USA and Edmund Waddell of Michigan DOT investigated entrance and exit geometry in order to determine appropriate roundabout alignments to increase capacity without negatively effecting pedestrian safety. The investigation determined that R_1 and R_2 values along with vehicle acceleration from R_2 through R_3 may play more of a role in exit speed than exit radius, R_3, alone. The researchers looked at the circulation radius, speed; R_2,V_2 relationship, the distance from the end of the R_2 radius to the exit crosswalk and the potential acceleration of a vehicle over that distance. Figure 500-48 illustrates the acceleration distance from the R_2V_2 location and the downstream pedestrian crossing.

The research assumed an exiting vehicle can accelerate along a given R3 radial path with an acceleration rate of 3.5 ft/s2 and also assumed acceleration starts at the end point of R2. The standard Newtonian equation for uniform acceleration was used to compute potential vehicle speeds at the exit crosswalk.

Newtonian Equation for Speed and Acceleration

$$V_f^2 = V_i^2 + 2aS$$

Where: V_f = Final R3 Speed, ft/s (V_3, Exit Speed)

V_i = Initial R2 Speed (V_2, Circulating Speed)

a = Acceleration, (3.5 ft/s^2)

S = Distance, ft (End of R2 to Crosswalk)

After analyzing theoretical roundabout layouts and investigating several existing roundabouts, the researchers concluded that the R_2,V_2 radius, speed relationship and vehicle acceleration from R_2 to the crosswalk as a vehicle exits a roundabout has more effect on the vehicle speed at the exit crosswalk than a tighter exit radius using only the radius, speed relationship for R3 alone. The theory then is that exit geometry (radius) can be relaxed to increase overall capacity and not appreciably affect pedestrian activity or safety at the exit crosswalk by increased vehicle speed. This may prove to be true for small acceleration distance values coupled with relative radius values to predict and control maximum potential exit speed. However, effectively controlling this relationship may not always be easily accomplished.

While the theory may have validity, it is only one analysis and appropriate application is critical to its effectiveness for speed prediction and control. Two key variables in the calculation are the distance available to accelerate prior to the exit crosswalk and the acceleration rate itself. If available acceleration distance is kept short, the exit speed may not be greatly affected. However, in larger diameter roundabouts, the available distance to accelerate may have an appreciable effect on exit speed. This may be particularly true for multi-lane roundabouts. The acceleration rate chosen for design will also influence the predicted speed. The research used a rate of 3.5 ft/sec^2 for exit speed calculations. This is not a particularly fast rate of acceleration and may be acceptable for a curvilinear acceleration rate for small to moderate radii transitioning to the exit. Some roundabout designs are utilizing large exit radii that become almost tangential. In these designs, it would be expected that vehicles would be accelerating from R_2 to the exit at a rate greater than 3.5 ft/sec^2. NCHRP Report 1043, Guide for Roundabouts uses 6.9 ft/sec^2 for an acceleration rate in similar equations. This is nearly twice the rate used in the Baranouski/Waddell research and may be a better estimation when considering that the current vehicle fleet is capable of maximum performance, straight line acceleration rates of 9 ft/sec^2 for a four cylinder compact car to over 20 ft/sec^2 for a high performance eight cylinder vehicle with the average (non-weighted for vehicle types) for all vehicles about 13 ft/sec^2. (See Table 500-6 attached, Maximum Performance – Straight Line Acceleration by Vehicle.)

The Baranowski/Waddell research is significant in that it shows the role R_2 can play in controlling exit speed when alignments incorporate smaller curvilinear radii and short acceleration distances between R_2 and the exit crosswalk. However, for a larger R_3 radius or tangential exit, the acceleration rate for predicted speed calculations may need to be increased to better represent conditions as available acceleration distances increase.

510.1.2 NCHRP Report 572, Roundabouts in the United States

Rodegerdts, Blogg, Wemple, Myers, et al (2007)

NCHRP Report 572 was a research project that investigated roundabouts in the United States and analyzed their operation. Authors of NCHRP Report 572 collected data from 103 roundabouts from around the United States. One of their findings indicated that observed entry and exit speeds did not always correlate well to the predicted entry and exit speeds determined for a given roundabout using the speed, radius relationship. The predicted speeds tended to be greater than the observed speeds. This was particularly evident for roundabouts with tangential or large entrance or exit radii. However, the speed, radius relationship did well in predicting observed circulating speeds through the R_2 and the R_4 pathways around the central island.

It is unclear as to why the speed, radius relationship is effective to predict speeds for pathways around the central island radius but is not as effective when predicting speeds in relation to entry and exit radii when correlated to observed speeds at specific roundabouts. From their observations and analysis, the authors developed equations that, in some locations, may better predict entry and exit speeds based on vehicle deceleration and acceleration ability. Like the previous research work done in 2004, these equations include vehicle deceleration and acceleration parameters based on observations and analysis and use the standard equation for uniform acceleration as a basis.

These equations are also presented in NCHRP 1043, Guide for Roundabouts (2023) to calculate predicted values for V_1 and V_3 along a vehicle's fastest path as it enters and exits a roundabout. The guide suggests these equations can be used as an alternative to using values derived from the simplified speed, radius relationships. However, as a cautionary statement, since predicted V_2 values derived from the speed, radius relationship seem to correlate to observed V_2 values, there may be other factors involved like driver behavior, driver expectation, driver familiarity, etc. affecting the correlation of predicted exit speeds and observed exit speeds rather than straight forward correlations to radial path, speed or acceleration.

Equation 4 – Alternative Entrance Speed Calculation, V_1

$$\boldsymbol{V_1 = \frac{1}{1.47}\sqrt{(1.47V_2)^2 + 2a_{1,2}d_{1,2}}}$$

V_1 = entry speed, mph

V_2 = circulating speed based on path radius, mph

$a_{1,2}$ = deceleration between point of interest along V_1 path and mid-point of V_2 path, = -4.2 ft/s^2

$d_{1,2}$ = distance between point of interest along V_1 path and mid-point of V_2 path, ft.

The deceleration rate of -4.2 ft/s^2 for entry speed was developed from the observed driver/vehicle behavior at the researched sites. While this equation had better correlation predicting entry speed with observed speed, the authors also included the following statement in NCHRP 572:

> "However, given the hesitancy currently exhibited by drivers under capacity conditions, the observed entry speeds may increase over time after drivers acclimate further. Therefore, the research team believes that an analyst should be cautious when using deceleration as a limiting factor when establishing entry speeds for design.

Furthermore, the research team believes that a good design should rely more heavily on controlling the entry path radius as the primary method for controlling entry speed, particularly for the fastest combination of entry and circulating path (typically the through movement)."

NCHRP Report 672, Roundabouts: An Informational Guide, second edition also addresses this concern and states:

"Analysts should use caution in using deceleration as a limiting factor to establish entry speed for design. To promote safe design, deflection of the R_1 path radius should be the primary method for controlling entry speed. Therefore, while Equation 6-3 may provide an improved estimate of actual speed achieved at entry, for design purposes it is recommended that predicted speeds from Equation 6-1 be used."

(Note: In this White Paper, NCHRP Report 672 Equation 6-3 and Equation 6-1 are reported as Equation 4 and Equation 1 respectively)

Similar to entry speed, NCHRP Report 572 developed an equation that utilizes vehicle acceleration ability for predicting exit speed based on the standard uniform acceleration equation to better correlate predicted exit speed with observed exit speed for investigative purposes. As with the deceleration rate for entry speed, the report developed a vehicle exit acceleration value of 6.9 ft/s2 from observed information.

Equation 5 – Alternative Exit Speed Calculation, V_3

$$\boldsymbol{V_3 = \frac{1}{1.47}\sqrt{(1.47V_2)^2 + 2a_{2,3}d_{2,3}}}$$

V_3 = Exit Speed, mph

V_2 = circulating speed based on path radius, mph

$a_{2,3}$ = average acceleration between midpoint of V_2 path and the point of interest along V_3 path = 6.9 ft/s^2

$d_{2,3}$ = distance along vehicle path between midpoint of V_2 path and the point of interest along the V_3 path, ft.

The authors of NCHRP 572 did not provide a caveat for not using the alternate V_3 calculation method for design as was provided for the alternate V_1 calculation method. There is no explanation provided in the report to indicate why one calculation may be considered more valid than the other. One must remember the reason for the derivation of these equations. The intent was to provide a prediction of exit speed that better correlated to observed exit speed at roundabout locations. The use of these equations lies in the assumption that since the predicted exit speed using the speed, radius relationship is greater than the observed speed, there must be something affecting the speed, radius relationship at exits. Acceleration rates were determined to make a better correlation. However, it works fine for R_2,V_2 and R_4,V_4 predicted and observed values. There may be other driver behavior factors that also affect observed R_1,V_1 and R_3,V_3

relationships. The authors are concerned this is the case with entrance speed and the same may be true for exit speed. The derived equations use a single deceleration or acceleration rate determined from observed data. Applying these acceleration rates to large radius or tangential exits and small radius, tight curvilinear exits equally may not produce effective design results in both cases. Using the same rates for both exit types assumes acceleration in a straight line or in a large radius is the same as acceleration in a tighter curvilinear path. This may not be the case. Therefore, lowering the acceleration rate for smaller radius paths seems reasonable. The research done in 2004 used 3.5 ft/s^2 as an acceleration rate for their investigation into exit geometry. This seems a more reasonable acceleration rate for smaller radial paths. NCHRP 572 uses 6.9 ft/s^2 as an acceleration rate. This seems reasonable for larger radius or tangential exits and seems to represent where, by observation, American drivers currently feel comfortable when exiting a roundabout. However, will this rate increase as drivers become more familiar with roundabouts? This is a concern of the authors of NCHRP Report 572 for V_1 values.

510.2 Evaluation of Large Radius or Tangential Exits and Small Radius Exits

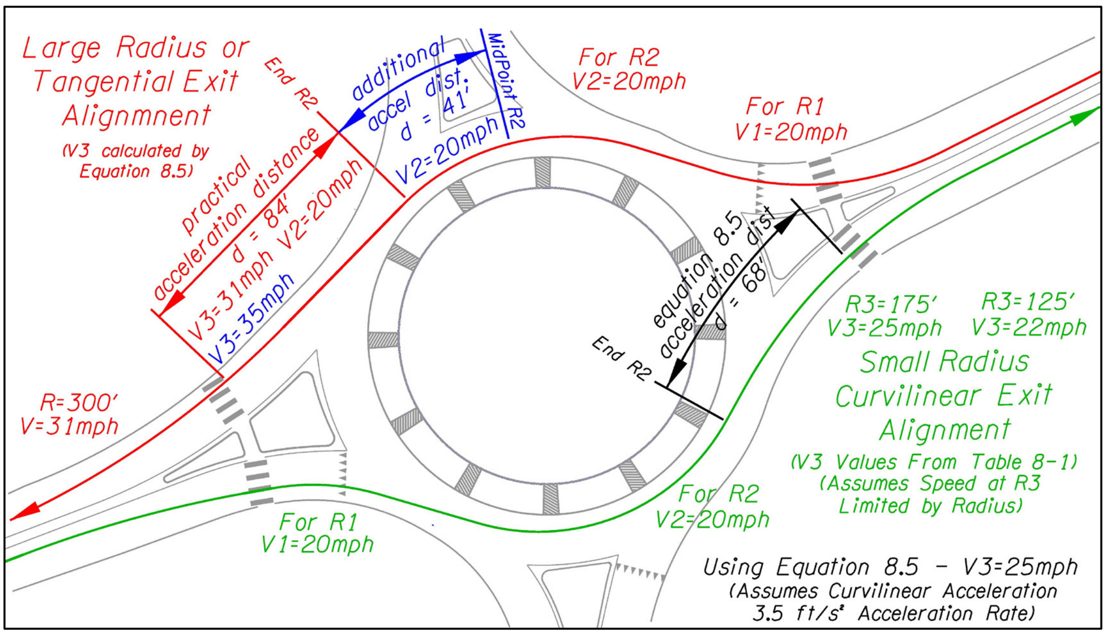
In addition to determining an acceptable acceleration rate, the other two critical variables in these equations are the V_2 speed and the distance, d, over which the deceleration or acceleration can take place. Therefore, if a large radius or tangential exit is designed for a roundabout, the R_2 value must provide the appropriate design V_2 and the acceleration distance must be effective in limiting a vehicle's potential downstream speed to design values.

Figure 500-62 is a hypothetical roundabout layout based on real roundabout dimensions that portrays potential differences in speed between a smaller curvilinear exit and a more tangential or large radius exit. The vehicle path alignment shown from lower left to upper right (green) assumes radii for R_1 and R_2 that provide a 20 mph V_1 and V_2. The curvilinear R_3 exit radius is shown as both 175 ft. and 125 ft. for illustrative purposes and correlates to a V_3 speed of 25 mph and 22 mph respectively. These V_3 values are based on the speed, radius equations discussed previously in Section 510 and is shown in Table 500-4 is a tabular form of the values in Figure 500-34 reported at 25 ft. radius intervals. In addition, NCHRP Report 1043, Guide for Roundabouts provides simplified equations to calculate speeds for given radii as well. Equation 1 is for +2% superelevation and Equation 2 is for -2% superelevation.

, Figure 500-34. For comparison, the speed, acceleration equation was used to calculate a predicted V_3 exit speed along the radial R_3 path. Since the exit radius is small, using the 3.5 ft/s^2 acceleration rate discussed previously and coupled with the relatively short acceleration distance shown, a predicted V_3 of 25 mph was determined. This is equal to the value predicted for V_3 using the speed, radius relationship for a 175 ft. exit radius. This is in line with the conclusions of the 2004 research report. However, keep in mind, this geometry has a smaller curvilinear alignment with a short acceleration distance that helps limit a vehicle's ability to accelerate. For comparison, increasing the acceleration rate for the calculation to the NCHRP Report 572 value of 6.9 ft/s^2 yields a predicted speed of 29 mph at the crosswalk. This is beginning to reach the unacceptable level for speed at the crosswalk when considering pedestrian safety.

Large radius or tangential exit geometry set for increased capacity or exit geometry opened up due to skewed approach alignments or other site specific parameters that might dictate positioning of roundabout elements may have equal or greater impact to potential vehicle speeds at the crosswalk.

Figure 500-62: Exit Geometry – Comparison Tangential and Small Radius



The vehicle path shown on the opposite side of the roundabout from upper right to lower left (red) in Figure 500-62 also assumes radii for R_1 and R_2 that provide a 20 mph V_1 and V_2. However, the V_3 value of 31 mph is based on the potential for vehicle acceleration from the end of R_2 to the crosswalk. This distance is shown as a “practical acceleration distance”, d, and for this layout is equal to 84 ft. This distance assumes a driver does not accelerate until reaching the end of the circulating path radius R_2. This is the approach the researchers in 2004 preferred. The equation parameters listed in NCHRP 672, Roundabouts: An Informational Guide, second edition define the acceleration distance as the distance from the midpoint of the V_2 path and a point of interest along the V_3 path.

The point of interest is the downstream crosswalk in this analysis. Adding the additional acceleration distance back along the path to the midpoint of R_2 and assuming a vehicle is capable of accelerating at 6.9 ft/s2 along this reversing radial to tangential path, yields a total distance of 124 ft. that a vehicle can accelerate prior to the downstream crosswalk increasing the calculated V_3 speed to 35 mph. These calculated speeds are 6 mph and 10 mph faster than the predicted V_3 speed of 25 mph at the tighter curvilinear exit on the opposite path of the roundabout. Either of these speeds would be considered excessive for design at the downstream crosswalk. This exemplifies the need to limit the acceleration distance, d, to provide acceptable exit speed if a tangential or large radius design is used.

510.3 Conclusion

The two research projects discussed both used uniform acceleration in their calculations. However, they each used different rates of acceleration. Baranowski and Waddell used 3.5 ft/s^2 for acceleration. NCHRP Report 572 used 6.9 ft/s^2, which is almost double the rate used by Baranowski and Waddell. Both these rates appear to be rates that were field observed by the authors of the reports. The difference may be attributed to the focus of the individual research. Baranowski and Waddell were studying roundabout locations where they considered exit radii to be excessively tight to restrict speeds. Therefore, the observed rates of acceleration were compatible with the geometry.

In the case of NCHRP Report 572, the authors were trying to correlate observed exit speed with predicted speed, and they noted there was a greater discrepancy when the exit radius was large – predicted speed greater than actual observed speed. In these cases, it appears the acceleration rate was determined to match the observed speed and the 6.9 ft/s^2 value they determined in 2007 may in fact be a comfortable rate for American drivers at larger radius exits. This is further borne out when looking at potential 0 – 60 mph maximum performance characteristics of the current vehicle fleet. Table 500-6 is a listing of maximum performance and straight line acceleration of various late model production vehicles ranging from 4 cylinder compact cars to high performance 10 cylinder “muscle cars”.

The data was collected from the on-line automotive sight AutoRooster at http://www.autorooster.com. The site reports 0 - 60 times for a variety of current vehicles. The corresponding accelerations were calculated and added to the table as 60 mph acceleration values in ft/s^2. The acceleration values ranged from 9.09 ft/s^2 for a 2008 Honda Civic, 4-cylinder vehicle to 24.50 ft/s^2 for a 2010 Dodge Viper, 10 cylinder vehicle. The mathematical average (non-weighted for numbers of vehicle type) for all the vehicles in the table is 12.89 ft/s^2. This indicates that the 6.9 ft/s^2 value determined from observed speeds in NCHRP Report 572 may be an acceptable overall value as a “comfortable” acceleration rate to most drivers, since the average in Table 2 of 12.89 ft/s^2 was determined from maximum, straight line performance.

Currently, there is no definitive answer to what the best method is to predict entrance and exit speed when designing a roundabout. Research has shown that in some cases where exit radii are smaller and/or acceleration distances are short limiting a vehicle’s ability to accelerate prior to the exit crosswalk, opening up exit geometry may not have a great effect on exit speed. However, relaxed exit geometry that increases acceleration distances and acceleration rates can potentially have significant effects on the exit crosswalk impacting pedestrian movements. This is particularly true for multi-lane roundabouts in off-peak times when a vehicle's fastest path may cross adjacent lanes.

In any roundabout layout, it is the designer's responsibility to provide vehicle alignments that consistently control vehicle speeds from entrance to exit in an effective manner for all modes of transportation utilizing the roundabout. For this reason, after the above discussion, it seems reasonable to use roundabout entrance and exit alignments that limit a driver's ability to accelerate prior to the exit crosswalk and it appears that a good method to do that is the standard radius, speed relationship.

Table 500-6: Maximum Straight Line Acceleration Performance by Vehicle

Vehicle Data	0-60 (sec)	1/4 Mile (sec)	60 MPH Distance (ft)	60 MPH Acceleration (ft/sec^2)
2008 Honda Civic, 4cyl	9.7	17.1	427.8	9.09
2010-12 Nissan Versa, 4 cyl.	9.4	18.3	414.5	9.38
2013 Ford Escape, 4 cyl.	9.3	17.4	410.1	9.48
2011-14 Chevy Cruze, 4 cyl.	9.0	16.5	396.9	9.80
2009-12 Toyota Corolla. 4 cyl.	8.9	16.7	392.5	9.91
2010-13 Chevy Tahoe, 8 cyl.	8.5	16.9	374.9	10.38
2013 Ford Fusion, 4 cyl.	8.5	16.9	374.9	10.38
2014 Ford Focus, 4 cyl.	8.5	16.7	374.9	10.38
2012 Toyota Camry, 4 cyl.	8.3	15.6	366.0	10.63
2011-12 Dodge Caravan, 6 cyl.	8.1	16.7	357.2	10.89
2014 Chevy Impala, 6 cyl.	8.1	16.3	357.2	10.89
2012-14 Ford Explorer, 4 cyl.	7.8	15.9	344.0	11.31
2013 Honda Accord, 4 cyl.	7.7	15.8	339.6	11.45
2013 Nissan Altima, 4 cyl.	7.1	15.5	313.1	12.42
2012 Mercedes S Class, 6 cyl. (D)	7.0	15.3	308.7	12.60
2013 Toyota Avalon, 6 cyl.	6.8	15.3	299.9	12.97
2012 Mercedes C Class, 4 cyl.	6.8	15.3	299.9	12.97
2011-13 Ford F-150, 6 cyl.	6.5	15.3	286.7	13.57
2012-13 BMW 5 Series, 4 cyl.	6.1	14.5	269.0	14.46
2012-13 Chevy Camero, 6 cyl.	6.0	14.4	264.6	14.70
2009-12 Nissan Maxima, 6 cyl.	5.8	14.4	255.8	15.21
2012-12 BMW 3 Series, 4 cyl.	5.6	14.4	247.0	15.75
2011-13 Ford Mustang, 6 cyl.	5.3	14.0	233.7	16.64
2014 Chevy Corvette, 8 cyl.	3.9	12.1	172.0	22.62
2008-10 Dodge Viper, 10 cyl.	3.6	11.9	158.8	24.50
				Average, 12.89 ft/s^2

Note: Data from AutoRooster (autorooster.com/0-60-times)

Section 511 References

511.1 AASHTO References

- A Policy on Geometric Design of Highways and Streets – 2018 (AASHTO Green Book)
- Guide for Development of New Bicycle Facilities – 2012

511.2 Other References

- Oregon Standard Drawings
- The 1999 Oregon Highway Plan
- ODOT Traffic Manual
- ODOT Traffic Line Manual
- Oregon Bicycle and Pedestrian Plan
- Oregon Bicycle and Pedestrian Design Guide
- Manual on Uniform Traffic Control Devices and Oregon Supplements
- NCHRP Report 1043, Guide for Roundabouts, 2023
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