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401 INTERSECTIONS AT-GRADE

401.1 Intersection Locations

Care should be taken in locating new at-grade intersections. The alignment and grade on the mainline roadway should, as a minimum, provide stopping sight distance as discussed in Section 201.2. The criteria for intersection sight distance (see Section 201.3) should also be met wherever possible.

It is best to avoid locating an intersection on a curve. Since this is often impossible, it is recommended that intersection sites be selected where the curve superelevation is 0.04 or less. It is also recommended that intersections be located where the grade on the mainline roadway is 6 percent or less, with 3 percent being the desirable maximum.

401.2 Intersection Traffic Control and Operational Analysis

The type of traffic control at intersections directly affects the geometric design. An early determination of the type of intersection control must be made (i.e. stop signs, signal, or roundabout). Whenever there is doubt as to the adequacy of stop control during the design life of the project, traffic signal warrants, as outlined in the Ohio Manual of Uniform Traffic Control Devices (OMUTCD) should be investigated.

Intersection capacity analysis procedures of the current edition of the Highway Capacity Manual shall be used to determine the number and type of lanes at intersections. Intersections shall be analyzed and designed to accommodate traffic volumes as per Section 102.2. Analyses shall be performed using the current version of Highway Capacity Software (HCS). Other software may be used to supplement the HCS analysis, depending upon intersection type. Refer to Figures 401-14a thru 401-14c for software guidance.

401.2.1 Signals

In general, when performing capacity analysis of signalized intersections, the critical (worst) delay of the north/south approach should approximately equal the worst delay of the east/west approach. Approach delays are considered balanced when they are within 3 seconds. Additionally, the highest control delays should be balanced, preferably within 5 seconds. When intersections are severely over capacity, balancing the approach and control delays may not be feasible; however, the critical delays should be as close as practical. This methodology provides a common basis for comparison between the no-build and build alternatives and is not meant to provide a signal timing plan for daily operations. This methodology defines the intersection size in consideration of the 20-year design.

Determination of the necessary number and type of lanes for the build condition is based upon a signal design where all individual lane v/c ratios are less than 1.0, and preferably less than 0.93.

401.2.2 Stop Control

For stop controlled intersections, where signal warrants are not anticipated to be met by the design year or would not be installed due to access management controls, Figures 401-5a thru 401-6d are provided to determine the need for turn lanes. The stopped approaches may be evaluated using HCS to determine the necessary number and type of lanes to improve the Levels of Service.
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401.2.3 Roundabouts

Use HCS for the analysis of a roundabout. Use SIDRA when HCS is incapable of analyzing a roundabout configuration. Configurations that HCS cannot analyze include: when more than two lanes enter a roundabout on an approach (not including a right-turn bypass lane), or when there are more than two lanes within the circulatory roadway. Turn lane lengths for the approach lanes of the roundabout shall be determined by accommodating the 95th percentile queue lengths as identified by HCS or SIDRA. Refer to Figures 401-14a thru 401-14c for software guidance.

While it is important to plan for future traffic volumes and capacity needs, the immediate effects on users should also be considered including costs. A roundabout constructed with a wide cross section (multilane) can negatively impact user (pedestrian, bicycle, unfamiliar drivers) movements. Therefore, a phased implementation on multilane roundabouts is required if the single lane construction of the roundabout can meet acceptable levels of service based on an interim design year. The phased implementation should be based on the available and future funding resources and location (rural or urban, drivers familiar or unfamiliar). The current users’ needs will be accommodated while still providing an opportunity for the roundabout to be expected for future traffic volume growth.

When using a phased approach, it is important to design the full build layout footprint to ensure right-of-way is secured for future planned improvements. It is also beneficial to plan the construction of the roundabout to potentially allow for easier expansion in the future.

401.3 Crossroad Alignment

Intersection angles of 70 degrees to 90 degrees are to be provided on all new or relocated highways. An angle of 60 degrees may be satisfactory if: (1) the intersection is signalized; or (2) the intersection is skewed such that a driver stopped on the side road has the acute angle (at center of intersection) on his left side (vision not blocked by his own vehicle).

Relocation of the crossroad is often required to meet the desired intersection location, to avoid steep crossroad profile grades and to adjust intersection angles. Horizontal curves on crossroads should be designed to meet the design speed of the crossroad. The crossroad alignment should be as straight as possible. Figure 401-1 shows an example of a crossroad relocation. Both curve 1 and curve 3 may be reduced per the figure.

401.4 Crossroad Profile

401.4.1 Intersection Area

The portion of the intersection located within 60 ft. of the mainline edge of traveled way, measured along the crossroad centerline, is considered to be the “intersection area”. The pavement surface within this “intersection area” should be visible to drivers within the limits of the minimum stopping sight distance shown on Figure 201-1. By being able to see the pavement surface (height of object of 0), drivers (height of eye of 3.5 ft.) will be able to observe the radius returns, pavement markings, and recognize that they are approaching an intersection. Figure 401-2 shows the “intersection area”. Combinations of pavement cross slopes and profile grades may produce unacceptable edge of traveled way profiles in the “intersection area”. For this reason, edge of traveled way profiles should be plotted and graphically graded to provide a smooth profile.
400 Intersection Design

401.4.2 Drainage

Within the intersection area, the profile of the crossroad should be sloped wherever possible so the drainage from the crossroad will not flow across the through road pavement. For a stop condition, the 10 ft. of crossroad profile adjacent to the through pavement is normally sloped away from the through pavement, using at least a 1.6 percent grade, as shown on Figure 401-2.

401.4.3 Profile at Stop Intersections

Profile grades within the “intersection area” for stop conditions are shown in Figures 401-2 and 401-3. The grade outside the “intersection area” is controlled by the design speed of the crossroad. Normal design practices can be used outside the “intersection area” with the only restriction on the profile being the sight distance required in Section 401.4.1.

Grade breaks are permitted at the mainline edge of traveled way for a stop condition as discussed in Note 3 of Figure 401-2. If these grade breaks are exceeded, they should be treated according to Note 3 on Figure 401-3. Several examples are shown on Figure 401-3 of the use of grade breaks or short vertical curves adjacent to the mainline edge of traveled way.

401.4.4 Profile at Signalized Intersections

Signalized intersections require a more sophisticated crossroad profile. Whenever possible, profiles through the intersection area of a signalized intersection should be designed to meet the design speed of the crossroad. Figure 401-4 shows three examples of crossroad profiles at intersections. On Examples A and B (Figure 401-4), the mainline cross slopes will need to be adjusted to match the crossroad profile within the intersection area. Grade breaks shown on Examples A and C should be in accordance with Section 203.3.2. Since the grade break across a normal crowned pavement is 3.2 percent, it should be noted that the crown must be flattened (See Example C). This will allow vehicles on the crossroad to pass through the intersection on a green signal safely without significantly adjusting their speed. The sight distance requirements of Section 401.4.1 within the “intersection area” are also applicable for signalized intersections.

401.5 Approach Radii

401.5.1 Rural

Approach radii in rural areas shall normally be 50 ft., except that radii less than 50 ft. (minimum 35 ft.) may be used at minor intersecting roads if judged appropriate for the volume and character of turning vehicles.

Radii larger than 50 ft., a radius with a taper, or a three center curve, should be used at any intersection where the design must routinely accommodate semi-trailer truck turning movements. Truck turning templates should be used to determine proper radii and stop bar location. When truck turning templates are used, a 2 foot clearance should be provided between the edge of traveled way and the closest tire path.

Normally the approach width at the ends of the radius returns should be 24 ft. The pavement width shall be tapered back to the normal pavement width at a rate of 10:1 if the taper is adjacent to the radius returns.

401.5.2 Urban

Corner radii at street intersections should consider the right of way available, the intersection angle, pedestrian traffic, approach width and number of lanes. The following should be used as a guide:
1. 15 to 25 ft. radii are adequate for passenger vehicles and may be provided at minor cross streets where there are few trucks or at major intersections where there are parking lanes.

2. 25 ft. or more radii should be provided at minor intersections on new or reconstruction projects where space permits.

3. 30 ft. radii or more should be used where feasible at major cross street intersections.

4. Radii of 40 ft. or more, three-centered compound curves or simple curves with tapers to fit truck paths should be provided at intersections used frequently by buses or large trucks.

401.5.3 Curbed to Uncurbed Transitions

*Figures 401-4a* and *401-4b* show acceptable methods to transition from curbed to uncurbed roadways at intersections. *Figure 401-4a* shows two options to transition from an uncurbed mainline roadway to a curbed approach roadway. *Figure 401-4b* shows the transition from a curbed mainline roadway to an uncurbed approach roadway. See Section 305.4 for additional information.

401.6 Approach Lanes

401.6.1 Left Turn Lanes

Probably the single item having the most influence on intersection operation is the treatment of left turn vehicles. Left turn lanes are generally desirable at most intersections. However, cost and space requirements do not permit their inclusion in all situations. Intersection capacity analysis procedures of the current edition of the Highway Capacity Manual should be used to determine the number and use of left turn lanes. For unsignalized intersections, left turn lanes may also be needed if they meet warrants as provided in *Figures 401-5a, 401-5b,* and *401-5c.* The warrants apply only to the free-flow approach of the unsignalized intersection. Refer to Section 401.2 and *Figures 401-14a* thru *401-14c* for analysis criteria and software guidance.

Left turn lanes should be placed opposite each other on opposing approaches to enhance sight distance. They are developed in several ways depending on the available width. The first example on *Figure 401-7* shows the development required when additional width must be generated. The additional width is normally accomplished by widening on both sides. However, it could be done all on one side or the other. In the second example on *Figure 401-7,* the median width is sufficient to permit the development of the left turn lane. *Figure 401-8* shows the condition where an offset left turn lane is required to obtain adequate sight distance in wide medians.

In developing turn lanes, several types of tapers may be involved as shown in *Figure 401-7.*

1. Approach Taper - An approach taper directs through traffic to the right. Approach taper lengths are calculated using the following:

   Design Speed of 50 mph or more:  \( L = WS \)

   Design speed less than 50 mph:  \( L = WS^2/60 \)

   Where:  \( L = \) Approach taper length in feet  
   \( W = \) Offset width in feet
2. Departure Taper - The departure taper directs through traffic to the left. Its length should not be less than that calculated using the approach taper equations. Normally, however, the departure taper begins opposite the beginning of the full width turn lane and continues to a point opposite the beginning of the approach taper.

3. Diverging Taper - The diverging taper is the taper used at the beginning of the turn lane. The recommended length of a diverging taper is 50 ft.

*Figures 401-9 and 401-10* have been included to aid in determining the required lengths of left turn lanes at intersections. An example problem that illustrates the use of these figures is included along with the figures.

After determining the length of a left turn lane, the designer should also check the length of storage available in the adjacent through lane(s) to assure that access to the turn lane is not blocked by a backup in the through lane(s). To do this, *Figure 401-10* may be entered using the average number of through vehicles per cycle, and the required length read directly from the table. If two or more lanes are provided for the through movement, the length obtained should be divided by the number of through lanes to determine the required storage length.

It is recommended that left turn lanes be at least 100 ft. long, and the maximum storage length be no more than 600 ft.

The width of a left turn lane should desirably be the same as the normal lane widths for the facility. A minimum width of 11 ft. may be used in moderate and high speed areas, while 10 ft. may be provided in low speed areas. Additional width should be provided whenever the lane is adjacent to a curbed median as discussed in *Section 305.3*.

### 401.6.2 Double Left Turn Lanes

Double left turn lanes should be considered at any signalized intersection with left turn demands of 300 vehicles per hour or more. The actual need shall be determined by performing a signalized intersection capacity analysis. Refer to *Section 401.2* and *Figures 401-14a thru 401-14c* for analysis criteria and software guidance. Fully protected signal phasing is required for double left turns.

When the signal phasing permits simultaneous left turns from opposing approaches, it may be necessary to laterally offset the double left turn lanes on one approach from the left turn lane(s) on the opposing approach to avoid conflicts in turning paths. All turning paths of double left turn lanes should be checked with truck turning templates allowing 2 ft. between the tire path and edge of each lane. Expanded throat widths are necessary for double left turn lanes. For details on double left turn lanes, see *Figures 401-11 and 401-12*.

### 401.6.3 Right Turn Lanes

Exclusive right turn lanes are less critical in terms of safety than left turn lanes. Right turn lanes can significantly improve the level of service of signalized intersections. They also provide a means of safe deceleration for right turning traffic on high-speed facilities and separate right-turning traffic at stop-controlled intersections.
To determine the need for right turn lanes, intersection capacity analysis procedures of the current edition of the Highway Capacity Manual should be used. For unsignalized intersections, right turn lanes may also be needed if they meet warrants as provided in Figures 401-6a, 401-6b, 401-6c and 401-6d. The warrants apply only to the free-flow approach of the unsignalized intersection. Refer to Section 401.2 and Figures 401-14a thru 401-14c for analysis criteria and software guidance.

Figure 401-7 shows the design of right turn lanes. Figure 401-10 may be used in preliminary design to estimate the storage required at signalized intersections. The recommended maximum length of right turn lanes at signalized intersections is 800 ft., with 100 ft. being the minimum length.

The blockage of the right turn lane by the through vehicles should also be checked using Figure 401-10. With right-turn-on-red operation, it is imperative that access to the right turn lane be provided to achieve full utilization of the benefits of this type of operation.

The width of right turn lanes should desirably be equal to the normal through lane width for the facility. In low speed areas, a minimum width of 10 ft. may be provided. Additional lane width should be provided when the right turn lane is adjacent to a curb.

401.6.4 Double Right Turn Lanes

When they are justified, it is generally at an intersection involving either an off-ramp or a one-way street. Double right turn lanes require a larger intersection radius (usually 75 ft. or more) and a throat width comparable to a double left turn (See Section 401.6.2 and Figure 401-11).

401.6.5 Additional Through Lanes

Normally the number of through lanes at an intersection is consistent with the number of lanes on the basic facility. Occasionally, through lanes are added on the approach to enhance signal design. As a general suggestion, enough main roadway lanes should be provided so that the total through plus turn volumes does not exceed 450 vehicles per hour per lane. See Figure 402-1.

401.6.6 Recovery Area at Curbed Intersections

When a through lane becomes a right turn lane at a curbed intersection, an opposite-side tapered recovery area should be considered. The taper should be long enough to allow a trapped vehicle to escape, but not so long as to appear like a merging lane. See Figure 402-1.

401.7 Islands

401.7.1 Characteristics

An island is a defined area between traffic lanes used for control of vehicle movement. Islands also provide an area for pedestrian refuge and traffic control devices. Islands serve three primary functions: (1) to control and direct traffic movement, usually turning; (2) to divide opposing or same direction traffic streams usually through movements; and (3) to provide refuge for pedestrians. Most islands combine functions.

Although certain situations require the use of islands, they should be used sparingly and avoided wherever possible.
400 Intersection Design

401.7.2 Channelizing Islands

Channelizing islands control and direct traffic into the proper paths for the intended use and are an important part of intersection design. They may be of many shapes and sizes, depending on the conditions and dimensions of the intersection. A common form is the corner triangular shape that separates right turning traffic from through traffic. Figures 401-13a, 401-13b, 401-13c and 401-13d detail Channelizing Island designs for various vehicle combinations.

1. Channelizing Islands are used at intersections for the following reasons:

2. Separation of conflicts.

3. Control of angle of conflict.

4. Reduction in excessive pavement areas.

5. Indication of proper use of intersection.

6. Favor a predominant turning movement.

7. Pedestrian protection.

8. Protection and storage of vehicles.

9. Location of traffic control devices.

These islands should be placed so that the proper course of travel is immediately obvious and easy for the driver to follow. Care should be given to the design when the island is on or beyond a crest of a vertical curve, or where there is a substantial horizontal curvature on the approach to or through the channelized area.

Properly placed islands are advantageous where through and turning movements are heavy.

401.7.3 Island Treatments

401.7.3.1 Curbed Islands

Curbed islands are most often used in urban areas where traffic is moving at relatively low speeds (less than 50 mph). The smallest curbed island that should normally be considered is 50 sq. ft. in an urban area and 75 sq. ft. if used in a rural area. A 100 sq. ft. island is preferred in either case. Curb Islands are sometimes difficult to see at night, so the intersection should have fixed source lighting.

401.7.3.2 Painted Islands

Islands delineated by pavement markings are often preferred in rural or lightly developed areas, when approach speeds are relatively high, where there is little pedestrian traffic, where fixed-source lighting is not provided, or where traffic control devices are not located within the island.

401.7.3.3 Nonpaved Islands
Nonpaved islands are normally used in rural areas. They are generally turf and are depressed for drainage purposes.

### 401.8 Designing Roadways to Accommodate Pedestrians

Designing a roadway that successfully meets the needs of both vehicular traffic and pedestrians can be a challenging task. Basic roadway design parameters such as roadway widths, corner turning radii and sight distances affect the ability of that roadway to accommodate pedestrians.

For example, the wider the roadway, the more difficult it is for pedestrians to cross, and the greater the barrier effect of this roadway on the communities through which it passes. Undivided six-lane arterials, with or without parking, are not usually pedestrian friendly, while eight and ten-lane arterials create an even more formidable barrier.

The size of a corner radius can also have a significant effect on the overall operation and safety of an intersection. Large corner turning radii promote higher turning speeds, as well as increasing the pedestrian crossing distance and exposure time. Large curb radii also reduce the space for pedestrians waiting to cross, move pedestrians out of the turning motorists line of sight, and make it harder for the pedestrian to see turning cars. However, in some cases, corners with small turning radii can impact the overall operating efficiency of an arterial intersection, as well as cause the curb to be hit by a turning vehicle.

The designer must keep in mind that, as important as it is for the motorist to see everything adjacent to the roadway, it is of equal importance for the pedestrian, particularly children and wheelchair users, to be able to view and react to potential conflicts. At no area is this issue more critical than at crosswalk locations. Vehicles parked near crosswalks can create a sight distance problem.

#### 401.8.1 Curb Radii

The radius used at urban and suburban locations at both signalized and unsignalized intersections, where there may be pedestrian conflicts, must consider the safety and convenience aspects of both the motorist and pedestrian. The radius should be the smallest possible for the circumstances rather than design for the largest possible design vehicle, which often accounts for less than 2 percent of the total users. A large radius can increase the speed of turning motorists and the crossing distance for pedestrians, creating increased exposure risks.

Two distinct radii need to be considered when designing street corners. The first is the radius of the street corner itself, and the second is the effective turning radius of the selected design vehicle. The effective turning radius is the radius needed for a turning vehicle to clear any adjacent parking lanes and/or to align itself with its new travel lane. Using an effective turning radius allows a smaller curb radius than would be required for the motorist to turn from curb lane to curb lane. Parking lanes should end at least 20 ft. in advance of the intersection.

#### 401.8.2 Crossing Distance Considerations

Short crosswalks help pedestrians cross streets. Excessive crossing distances increase the pedestrian exposure time, increase the potential of vehicle-pedestrian conflict, and add to vehicle delay.

Curb extensions reduce the crossing distance and improve the sight distances for both the vehicle and the pedestrian. In general, curb extensions should extend the width of the parking lane, approximately 6 ft. from the curb for a minimum length of 20 ft.
400 Intersection Design

401.8.3 Crossing Islands and Medians

Where a wide intersection cannot be designed or timed to accommodate all the pedestrian crossing needs across one leg of the intersection at one time, a median or crossing island (often referred to as a refuge island) should be considered. Medians are raised or painted longitudinal spaces. Triangular channelization islands adjacent to right turning lanes can also act as crossing islands.

Desirably, crossing islands should be at least 5 ft. wide. A width of 8 ft. is needed to accommodate bicycles, wheelchairs, scooters and groups of pedestrians. Crossing island width should be a minimum of 8 ft. on roadways with speeds of 50 mph or greater.

401.8.4 Turning Movements

At both signalized and unsignalized intersections, steps should be taken to ensure that turning speeds are kept low and that sight distance is not compromised for either the motorist or pedestrian.

402 TWO WAY LEFT TURN LANES (TWLTL)

402.1 General

Midblock left turns are often a serious problem in urban and suburban areas. They can be a safety problem due to angle accidents with opposing traffic as well as rear end accidents with traffic in the same direction. Midblock left turns also restrict capacity. Two way left turn lanes (TWLTL) have proven to be a safe and cost-effective solution to this problem.

402.2 TWLTL Justification

TWLTL should be considered whenever actual or potential midblock conflicts occur. This is particularly true when accident data indicates a history of midblock left turn related accidents. Closely spaced driveways, strip commercial development or multiple-unit residential land use along the corridor are other indicators of the possible need for a TWLTL.

Some guidelines which may be used to justify the use of TWLTL are listed below:

1. 10,000 to 20,000 vehicles per day for four lane highways.
2. 5,000 to 12,000 vehicles per day for two lane highways.
3. 70 midblock turns per 1000 ft. during peak hour.
4. Left turn peak hour volume 20 percent or more of total volume.
5. Minimum reasonable length of 1000 ft. or two blocks.
400 Intersection Design

402.3 TWLTL Design

Widths for TWLTL are preferably the same as through lane widths (See Section 301.1.2). A 10 ft. lane may be used in restricted areas. Care should be taken not to make a TWLTL wider than 14 ft. since this may encourage shared side-by-side use of the lane. TWLTL markings shall be in accordance with the OMUTCD. See Section 301.1.5 for location of the crown point.

402.4 Reversible Lanes

A reversible lane is a lane on which the direction of traffic flow can be changed to utilize maximum roadway capacity during peak demand periods. Reverse-flow operation on undivided streets generally is justified where 65 percent or more of the traffic moves in one direction during peak periods, where the remaining lanes are adequate for the lighter flow period when there is continuity in the route and width of the street, where there is no median and where left turn and parking can be restricted. Reverse flow operations require special signing and additional control devices. Refer to the federal MUTCD for further guidance. Reverse flow on a divided facility is termed “contra-flow operation.” While the principle of reverse-flow operation is applicable to divided arterials, the arrangement is more difficult than on an undivided roadway.

403 ROUNDABOUTS

403.1 General

A roundabout is a form of circular intersection in which circulating traffic travels counterclockwise around a central island in which entering traffic must yield to the circulating traffic. The term “modern roundabout” is used in the United States to differentiate modern roundabouts from traffic calming circles and rotaries that have been in use for many years. The term modern roundabout and roundabout are used interchangeably throughout this document.

Modern roundabouts are defined by three basic characteristics shown and described below:

Exhibit 403.1-1 Characteristics of a Roundabout

1. Circular Shape: Roundabouts are generally circular in shape with traffic circulating in a counterclockwise fashion.

2. Yield-at-Entry to Circulating Traffic: Yield-at-entry requires all entering vehicles on the approaches to yield to the circulatory roadway traffic in the roundabout. The circulating traffic have the right-of-way and all entering vehicles on the approaches must wait for a gap in the circulating flow before
entering the circulatory roadway. Yield signs are used as the traffic control on each approach. Modern roundabouts are not designed for high speed or weaving maneuvers, and therefore have smaller diameters (less than 300 ft.) than large traffic circles/rotaries.

3. Slow Speeds for all Vehicles: Modern roundabouts have geometric features that slow all vehicles down, regardless of the posted speed limits on the approaching roadways. Entering traffic is slowed down and deflected to the right by the approach splitter island into an appropriate curved path along the circulating roadway and around the central island of the roundabout.

Generally, roundabouts can process high left turn volumes more efficiently than all-way stop control or traffic signals; as well as, accommodate a wide range of side road volumes.

Roundabouts can improve safety over that of a conventional intersection through the reduction of vehicular speeds through the roundabout (average 15-25 mph), the reduction of crossing conflicts where the paths of opposing vehicles intersect and a lower angle of impact in the event of a crash. Roundabouts are recognized by FHWA as a Proven Safety Countermeasure.

For additional information not detailed in this section, see NCHRP and FHWA’s Roundabouts: An Informational Guide (NCHRP Report 672).

Based on NCHRP/FHWA’s Roundabouts: An Informational Guide (NCHRP Report 672) roundabouts are separated into three basic categories:

1. Mini-Roundabouts
2. Single-Lane Roundabouts
3. Multi-Lane Roundabouts

### 403.2 Designing Roundabouts for Future Conditions

Once a roundabout has been selected the design and analysis should consider the potential to phase improvements to reduce excessive capacity in the early years and improve safety and driver/public acceptance. Designers should evaluate whether it is best to construct a roundabout based on an interim year traffic that can easily be converted when future traffic volumes dictate the need for expansion and additional capacity. Reducing the number of entry and circulating lanes reduces the number of potential conflicts with multi-lane roundabouts. When considering an interim roundabout condition that may be converted in the future, the designer should evaluate the right-of-way and geometric needs for both the interim and multilane configurations. When projected traffic volumes indicate a multilane roundabout is required in the design year, designers should evaluate how long an interim configuration (such as a single-lane roundabout) will operate acceptably using the appropriate capacity methodologies before requiring additional lanes. Designers should consider constructing and operating a roundabout in a single-lane configuration if the single-lane roundabout will provide sufficient capacity for a portion of the project design life until traffic volumes dictate an expansion to a multilane roundabout is warranted.

Expansion from the single-lane to the multilane roundabout can be accomplished in two ways:

Expansion to the Outside - The additional entering, circulating and exiting lanes are constructed to the outside of the single-lane roundabout. This option allows for easier future expansion to the multilane configuration since construction can occur while traffic is maintained on the existing single-lane pavement. Care needs to be exercised to ensure the proper geometric design of the entry and splitter islands allow for good speed reduction and the proper path alignment for the ultimate build-out of the roundabout. It is advisable to initially design the ultimate multilane configuration and remove the outside lanes from the
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design to form the initial single-lane roundabout. Acquire enough right-of-way to accommodate the future condition. It is preferred that pedestrian and off-street bicycle facilities; as well as, utilities be placed in their permanent location from the start rather than relocated at the time of the full build.

Expansion to the Inside - The additional entering, circulating and exiting lanes are constructed to the inside of the single-lane roundabout. The initial single-lane configuration occupies the same inscribed circle as the ultimate multilane roundabout allowing the designer to set the outer limits of the roundabout during the initial construction. Impacts to surrounding properties is minimized under this scenario. The single-lane design will provide wider splitter islands and an enlarged central island that occupies the space of the future inside lanes. Future expansion to the multilane roundabout is accomplished by reducing the width of the splitter islands and contracting the diameter of the central island.

403.3 Operational Analysis

Figure 403-1 is intended to provide rules of thumb for sizing a roundabout. All roundabout designs should be supported with analyses using capacity analysis software. See Section 401.2.3 and Figures 401-14a - 401-14c.

403.4 Design Principles and Objectives

The geometric design of a roundabout is generally an iterative process looking to balance competing considerations such as safety, operations and costs. Several general design principles should be applied to provide a safe and efficient roundabout design:

1. The entry curvature should provide enough deflection to provide slow entry speeds; as well as, consistent speeds through the roundabout.

2. The appropriate number of lanes and the proper lane assignments should be provided to ensure adequate capacity, volume balance and lane continuity to achieve acceptable operations.

3. Provide smooth channelization that is intuitive and will naturally guide drivers into the intended lanes.

4. Roundabout elements should be adequately designed to allow a WB-62 or larger vehicle (on state maintained roadways) that will be using intersection to enter, circulate and depart the roundabout efficiently.

5. Design for non-motorized users such as pedestrians and bicyclists.

6. Provide appropriate sight distance and visibility for driver recognition of the roundabout and conflicting users.

403.4.1 Speed Management

The most critical objective is to maintain low and consistent speeds through the roundabout. Roundabouts are safest and most effective when the geometry allows the traffic to enter, circulate and exit at slow consistent speeds. Speed management is a combination of managing speeds at the roundabout itself and managing speeds on the approaching roadways.
403.7.1 Fastest Path Speeds.

The roundabout approach design speed range is determined by engineering judgment based on several conditions:

1. The roadway classification for each leg of the roundabout and their respective design speeds (high speed or low speed).
2. The intersection users (pedestrians, bicycles, pedestrian generators, large vehicle generators, etc).
3. The location of the roundabout:
   - Rural or urban.
   - Users familiar or unfamiliar with roundabouts.
4. The type of roundabout: Mini-Roundabout, Single-Lane Roundabout or Multilane Roundabout.
5. Desirable maximum entry design speed:
   - Mini-Roundabout (15 to 20 mph)
   - Single-lane roundabout (20 to 25 mph)
   - Multilane roundabout (25 to 30 mph)
6. Design speed consistency:
   - The relative speeds between consecutive geometric elements should be minimized.
   - The relative speeds between conflicting traffic streams should be minimized.
   - Maximum speed differential between movements should be no more than approximately 10 to 15 mph.
7. It is recommended that approach speeds approximately 100 ft. prior to the entrance line (yield line) of the roundabout be limited to approximately 35 mph or less to minimize high-speed rear-end and entering-circulating vehicle crashes. On high-speed rural approaches, it is recommended to use any or some combination of the following techniques to slow down drivers approaching the roundabout:
   - Maximize the Visibility of the Central Island
   - Curbing
   - Splitter Islands
   - Reverse Curves as shown in Exhibit 6-70 of the **Roundabouts: An Informational Guide (NCHRP Report 672)**
   - Superelevation of curves on approaches to roundabouts should be based on the low speed urban street criteria L&D **Figure 202-9**. The design speed for these approach curves is based on its distance from the yield line and the deceleration length determined from AASTHO GDHS (Greenbook), 7th edition, Figure 2-34. If superelevation is not required, tangents should still be provided between reverse curves. The length of the tangent should be a minimum of 65' between the broad radius and moderate radius, and 50' between the moderate radius and entry radius (See NCHRP 672 - Exhibit 6-70).

403.4.2 Lane Arrangements

The operational analysis (See **Section 401.2.3**) will determine the required number of entry lanes to serve each approach into the roundabout. In the case of multilane roundabouts care must be taken to ensure the design provides the appropriate number of circulating and exit lanes to ensure lane continuity is preserved.
403.4.3 Appropriate Path Alignment

The geometry of the roundabout at the entry will affect the path that vehicles take circulating through and exiting the roundabout. Guided by the lane markings vehicles will continue along their natural trajectory into the circulating roadway based on their speed and orientation. At multilane roundabouts if the entry radius is small there may be a tendency for the vehicle in the outside lane to overlap paths and come into conflict with the vehicle in the inside lane of the circulatory roadway. Overlapping paths presents the potential for inefficient operations due to driver reluctance to use one or more of the entry lanes or sideswipe crashes. Likewise, overly small radii at the exit may result in vehicle path overlap.

At multilane roundabouts the entries and exits should be aligned to position vehicles into their appropriate lanes within the circulatory roadway.

403.4.4 Design Vehicle

Another important factor determining a roundabout’s layout is the need to accommodate the largest vehicle reasonably anticipated to use the intersection with some frequency. The turning path of this design vehicle controls many of the roundabout’s dimensions.

Because roundabouts are intentionally designed to slow traffic, narrow curb-to-curb widths and tight turning radii are typically used. However, if the widths and turning radii are designed too tight, difficulties for large vehicles may be created. Large trucks and buses often dictate many of the roundabout’s dimensions, particularly for single-lane roundabouts. Therefore, it is very important to determine the design vehicle at the start of the design and investigative process.

The choice of a design vehicle will vary depending upon the approaching roadway types and the surrounding land use characteristics. A WB-62 design vehicle should be used on roundabouts at interchanges with interstates, freeways, expressways and at intersections on arterial streets and highways. Smaller design vehicles may be chosen at local street intersections. At a minimum, fire engines, transit vehicles, and single-unit delivery vehicles should be considered in urban areas. In rural environments, school buses or farming equipment may govern design vehicle needs.

Design vehicles shall traverse the roundabout without off-tracking over the outside curbing or onto the splitter island curbing. All vertical and sloped curbing shall be placed to avoid trailer off-tracking (rear axles passing over curbing). The central island curbing, the curbing along the outside of the roundabout and the splitter island curbing should be vertical unless mountable slope curbing is needed for specific reason.

403.4.4.1 Design Vehicle Swept Path

Since roundabouts are designed to slow traffic, narrow curb-to-curb and tight turning radii are typically used. If these curb-to-curb widths and turning radii are too tight difficulties may occur for larger vehicles. It is very important to select the proper design vehicle, usually a WB-62 or larger vehicle (on state maintained roadways) and check the vehicle sweep or tracking using CAD-based vehicle turning software. A minimum clearance of 2 ft. should be provided between the outside edge of the vehicle’s swept path and the curb line.
403.4.5 Sight Distance and Visibility

The visibility of the roundabout as vehicles approach the intersection and the sight distance for viewing vehicles already operating within the roundabout are key components for providing safe roundabout operations. Roundabouts require both the stopping sight distance and the intersection sight distance to be met.

The design should check to verify that stopping sight distance can be provided at every point within the roundabout; as well as, each entering and exiting approach so that a driver can react to objects or conflicting users within the roadway.

Intersection sight distance must be verified for any roundabout design to ensure there is sufficient distance available for drivers to perceive and react to conflicting vehicles or pedestrians.

See Section 403.7.2 for more information on Sight Distance.

403.4.5.1 Intersection Sight Distance

Intersection Sight Distance is the distance required for a driver without the right-of-way to perceive and react to the presence of conflicting vehicles. The intersection sight distance is measured by sight triangles defining the space a driver should be able to identify gaps in circulating traffic and presence of pedestrians at crosswalks.

403.4.6 Approach Design

The primary safety concern with a high-speed roundabout is to make drivers aware of the approaching roundabout with ample distance to decelerate comfortably to the appropriate speed. To achieve the appropriate speed designs should follow these principles:

- Provide the desirable stopping sight distance at the entry point based on approach operating speeds.
- Align approach roadways and set vertical profiles to make the central island conspicuous.
- Splitter islands should extend upstream of the yield line to the point at which entering drivers are expected to begin decelerating from the approach speed to the entry design speed.
- Approach curves should be gentle, become successively smaller and should be sized based on the design speed and expected speed change.
- Tangents should be used between reverse curves to prevent truck rollovers.
- Use landscaping if sight lines are not impacted to create a tunnel effect.
- Provide illumination in transition to the roundabout.
- Use signs and pavement markings to effectively advice drivers of the change in speed and path.

403.5 Size, Position and Alignment of Approaches

Three decisions are needed in the design of roundabouts to balance the geometric design principles and objectives described in Section 403.4. The design decisions are:

- Size
- Position

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• Alignment of the Approach Legs

403.5.1 Size of the Roundabout (Inscribed Diameter)

The best parameter determining the size of the roundabout is the inscribed circular diameter which is the distance across the circle inscribed by the outer edge of the curb. In all cases, the design vehicle shall have the capability of traversing the roundabout within the circulatory roadway using the truck apron when needed. Exhibit 403.6-1 Design Elements of a Roundabout shows the Inscribed Diameter measurement.

Typical Inscribed Circle Diameters:

• Mini-Roundabout: 45 to 90 ft.
• Single-Lane Roundabout: 90 to 180 ft.
• Multilane (2-lane) Roundabout: 150 to 215 ft.
• Multilane (3-lane) Roundabout: 215 to 300 ft.

403.5.2 Position of Approaches

The position is determined by the alignment of the approach leg in relationship to the center of the inscribed circle. The position of the approach alignment for each of the legs has a primary effect on the deflection and speed control. The three positions are:

• Offset Alignment to the Left of Center
• Alignment through the Center of the Roundabout
• Offset Alignment to the Right of Center

Position 1: Offset Alignment to the Left of Center

Advantages:
• Allows for increased deflection
• Beneficial for accommodating large trucks with small inscribed circle diameter, allows for larger entry radius while maintaining deflection and speed control
• May reduce impacts to the right-side of the roadway

Trade-offs:
• Increased exit radius or tangential exit reduces control of exit speeds and acceleration through crosswalk area
• May create greater impacts to the left side of the roadway
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Position 2: Alignment through Center of Roundabout

Advantages:
- Reduces amount of alignment changes along the approach roadway to keep impacts more localized to intersection
- Allows for some exit curvature to encourage drivers to maintain slower speeds through the exit

Trade-offs:
- Increased exit radius reduces control of exit speeds/acceleration through crosswalk area
- May require a slightly larger inscribed circle diameter (compared to offset-left design) to provide the same level of speed control

Position 3: Offset Alignment to the Right of Center

Advantages:
- Could be used for large inscribed circle diameter roundabouts where speed control objectives can still be met
- Although not commonly used, this strategy may be appropriate in some instances (provided that speed objectives are met) to minimize impacts, improve view angles, etc.

Trade-offs:
- Often more difficult to achieve speed control objectives, particularly at small diameter roundabouts
- Increases the amount of exit curvature that must be negotiated

403.5.3 Alignment Approach Legs

Generally, it is preferable to have the approaches intersect at or near perpendicular. Approach legs intersecting at an angle greater than 105 degrees can result a lack of deflection may result in fast vehicle speeds. Approach legs intersecting at an angle less than 75 degrees can result in difficulty for the design vehicle to navigate the entry into the roundabout.

403.6 Design Elements of a Roundabout

This section describes the individual geometric elements comprising a roundabout.
403.6.1 Inscribed Diameter (Outside Limits of Circulatory Roadway)

See Section 403.5.1 and Exhibit 403.6-1.

403.6.2 Circulatory Roadway Width

The required width of the circulatory roadway width is determined from the number of the entering lanes and turning requirements of the design vehicle.

Circulatory Roadway Widths:

- Single Lane: 16 to 20 feet
- Two Lane: 28 to 32 feet

403.6.3 Central Island

The central island is the area surrounded by the circulatory roadway. The central island should be raised or mounded to ensure approaching drivers are aware of the approaching roundabout. The central island is mainly non-traversable, but it does include the truck apron which is traversable. Teardrop shaped islands may be used where certain movements do not exist such as an interchange or where certain turning movements cannot be accommodated.

Central Island Treatment

- Mini-Roundabout: Fully Traversable
- Single-Lane Roundabout: Raised (with traversable truck apron).
- Multilane Roundabout: Raised (with traversable truck apron).

403.6.4 Truck Apron

A truck apron is typically used to provide additional traversable area around the central island to accommodate large vehicles without compromising the deflection for the smaller vehicles. Truck apron widths should be checked with truck turning templates allowing for 2 ft. between the tire path and inside edge of the truck apron. See NCHRP/FHWA’s Roundabouts: An Informational Guide (NCHRP Report 672) for additional truck apron details.

Truck Apron Widths: 3 to 15 feet. For ODOT maintained facilities on the State Highway System (SHS) provide 12 ft. min. Truck apron reveal to circulatory roadway: 2-3 inch maximum.
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403.6.5 Entry and Exit Widths

The entry and exit widths should accommodate the desired design vehicle and avoid off-tracking over curbing and beyond pavement limits.

Preferred Entry and Exit Widths:
- Single Lane: 14 to 18 feet
- Two Lane: 28 to 30 feet

403.6.5.1 Development of Entry Widths for Multilane Roundabouts

Locations where additional entry capacity is required, Figures 402-2 and 402-3 show acceptable methods of widening the roadway prior to the roundabout.

403.6.5.2 Exit Width Reduction of Multilane Roundabouts

Locations where additional capacity is required within the roundabout but immediately reduced on the exit leg of the roundabout, the Roundabout Taper Option on Figure 402-2 shows the acceptable method of reducing lanes along the roadway of the exit leg. Lane reductions at the exit could affect lane utilization at entries.

403.6.6 Gore Striping

An allowable technique to accommodate the design vehicle is to provide gore striping. Gore striping involves placing a striped vane island between the entry lanes to help center the vehicles within the lane and allow a cushion for off-tracking by the design vehicle.

403.6.7 Right-Turn Bypass Lanes

At locations with a high volume of right-turning traffic, a right-turn bypass lane may allow a single-lane roundabout to continue to function acceptably and avoid the need to upgrade to a multilane roundabout. For additional information, see NCHRP/FHWA’s Roundabouts: An Informational Guide (NCHRP Report 672).

403.6.8 Cross Slopes

Generally, the circulating roadway and truck apron should be designed to slope away from the central island. This will promote safety by improving the visibility of the central island, lowering the vehicle speeds in the circulating roadway due to the reverse superelevation and minimizing the breaks in the cross slopes of the entry and exit lanes.

Preferred Cross Slopes:
- Circulatory Roadway: 2% away from the central island.
- Truck Apron: 2% towards the outside.
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403.6.9 Splitter Islands

Splitter islands should be provided at all roundabout approaches. Their purpose is to provide refuge for pedestrians, assist in controlling speeds, guide traffic into the roundabout, physically separate entering and exiting traffic and deter wrong-way movements. The total length of the raised island should be at least 50 ft. although 100 ft. is preferable. On higher speed roadways, the island length should be 150 ft. to 200 ft. The minimum island width at a crosswalk should be 6 ft. to provide a refuge for pedestrians.

403.6.10 Curbing

Curbing should be provided on the outside edge of the circulating roadway of the roundabout; as well as, the approach and exit legs. The outside curbs should be 6 inches in height. Refer to Section 305.2. Outside curbing provided positive guidance, slows entry speeds, and prevents parking within the roundabout. The curbing around the truck apron should have a 2-3 inch curb reveal to prevent a truck from overturning.

403.6.11 Lighting

Lighting must be provided per Traffic Engineering Manual (TEM) Section 1140-4.6.10 Roundabouts.

403.6.12 Spirals

Spirals are introduced within the circulatory roadway of the roundabout as a series of lane gains and lane drops to lead drivers into the appropriate lane for their desired exit. Spirals guide drivers entering the roundabout on the inside lane to shift into the outside lane within the circulatory roadway enabling the driver to exit from the outside lane. The spiral is designed to prevent vehicles from becoming trapped on the inside lane or requiring drivers to make a quick lane change within the circulatory roadway to exit. Spirals can be installed to accommodate heavy left turning movements. Spirals should only be considered where the circulatory roadway has enough width to provide two or more lanes of traffic and where the geometry and traffic volumes are determined to warrant the use of spirals. Circulatory roadway spirals require considerable engineering judgment to design and locate properly. Although they are intended to guide drivers, they may be confusing to properly understand and not always intuitive to the driver.

A spiral should be developed from the central island by curb and gutter until a full lane width is available. A spiral can be developed with the use of pavement markings, but experience shows drivers may ignore those markings which may lead to crashes within the circulatory roadway.

An example of a roundabout spiral is shown in Exhibit 403.6-2. This spiral is used to shift the westbound left turn to the outside lane. The spiral is used because the southbound exit is only a single lane exit and the southbound entrance allows dual left turns. To exit without conflict, the westbound left turn needs to be spiraled to the outside lane. Without the spiral, the left turn would be trapped on the inside lane and would do a U-turn or have to crossover lanes.
403.7 Performance Checks

This section describes the individual performance checks vital to good roundabout design. The following performance checks will help the designer and reviewer determine whether the design meets the design principles and objectives described in Section 403.4.

A roundabout design checklist shall be submitted with the Stage 1 plan submission to aid the reviewer of the roundabout. See Figure 403-2 for the Roundabout Critical Design Parameters Checklist.

403.7.1 Fastest Path Speeds

The fastest path determines the potential driver speed based on the geometry for a vehicle traversing into, through and exiting the roundabout. It is the smoothest, flattest path possible for a single vehicle in the absence of traffic and any regard for the lane markings. The fastest path must be drawn for all approaches and all movements. The fastest path doesn’t necessarily reflect the vehicle speeds expected through the roundabout, but rather the speeds a vehicle could theoretically attain.
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There are five critical path radii to be checked for each approach. The five critical path radii are defined as follows:

- **Entry Path Radius (R1)** is the minimum radius prior to the entrance line.
- **Circulating Path Radius (R2)** is minimum radius around the central island.
- **Exit Path Radius (R3)** is the minimum radius into the exit.
- **Left-Turn Path Radius (R4)** is the minimum radius on the path of the left-turn movement.
- **Right-Turn Path Radius (R5)** is the minimum radius on the path of the right-turn movement.

See Exhibit 403.7-1 for a visual representation of the fastest path.

The performance of the roundabout is chiefly influenced by the Entry Path Radius (R1) due to its ability to control the speed of vehicles entering the roundabout. The recommended maximum theoretical design speeds for the Entry Path Radius (R1) are as follows:

- **Mini-Roundabout:** 20 mph
- **Single Lane:** 25 mph
- **Multilane:** 25 to 30 mph

The design speeds for the movements within the roundabout (R2, R4, R5) should be designed using the following parameters:

- **Thru Movements (R2):** Provide path deflection of the approach vehicle such that the vehicle is required to slow to 15-20 mph within the circulatory roadway. R2, circulatory radius is critical for controlling thru traffic speed.
- **Left Turn Movement (R4):** Travel speed is controlled by truck apron diameter (typically 10-15 mph).
- **Right Turn Movement (R5):** Travel speed is a function of the curb radius and splitter islands between adjacent approaches.

Avoid designing strictly for R1/R2/R3 relationship as described in *Roundabouts: An Informational Guide (NCHRP Report 672)* since this can result in a very tight design for trucks to negotiate.

See Section 403.7.1.1 for guidance on constructing the fastest path.

403.7.1.1 Construction of Vehicle Fastest Path

The fastest path radii should not be mistaken for the curb radii. The vehicle width is assumed to be 6 ft. and maintain a minimum clearance of 2 ft. offset from a roadway centerline or concrete curb and flush with a painted edge line. The path of the fastest path is drawn with the follow distances:
The construction of the fastest path should begin at least 165 ft. in advance of the entrance line using the appropriate offsets identified above and the Entry Path Radius (R1) should be measured as the best-fit curve over a distance of at least 65 to 80 ft. near the entrance line.

See Exhibits 403.7-2 and 403.7-3 for Fastest Path movements.
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See NCHRP/FHWA’s Roundabouts: An Informational Guide (NCHRP Report 672) for additional information

403.7.2 Sight Distance

The two aspects of sight distance are the stopping sight distance and the intersection sight distance.

403.7.2.1 Stopping Sight Distance

The stopping sight distance is the distance along a roadway required for a driver to perceive and react to an object in the roadway and brake to a complete stop before reaching the object. The stopping sight distance should be provided at every point within the roundabout and on each entering and exiting approach. For more information regarding stopping sight distance see Section 201.2 and Figure 201-1.

At roundabouts, three stopping sight distance checks should be performed:
- Sight Distance on the Approach
- Sight Distance in the Circulating Roadway
- Sight Distance to the Crosswalk on Exit

See Exhibits 403.7-4 - 403.7-6 below:

Exhibit 403.7-4 Sight Distance on the Approach

Exhibit 403.7-5 Sight Distance in the Circulating Roadway
403.7.2.2 Intersection Sight Distance

The intersection sight distance is the distance required for a driver without the right-of-way to perceive and react to the presence of conflicting vehicles. The intersection sight distance is determined with the use of sight triangles that allow a driver to see and safely react to conflicting vehicles. For more information regarding intersection sight distance see Section 201.3 and Figures 201-4 and 201-5. For roundabouts the only location requiring intersection sight distance checks are the entries.

The intersection sight distance is traditionally measured by the determination of a sight triangle. The triangle is bounded by a length of roadway defining a limit away from the intersection on each of the two conflicting approaches and by a line connecting those two limits. These legs are assumed to follow the curvature of the roadway. These distances should not be measured as straight lines, but rather as the distance along the vehicular path. The length of the approach leg should be limited to 50 ft. from the entrance line. See Exhibit 403.7-7.

Exhibit 403.7-7
Intersection Sight Distance Checks
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403.7.3 Entry Angle, Phi

The phi angle is a gauge of the sight to the left and ease of entry to the right. This affects both the capacity and safety at the roundabout. The typical range for the phi angle is between 20 and 30 degrees with 25 degrees being the optimal although designs may operate safely and efficiently with a phi angle as low as 16 degrees. Even if phi angles are not in the desirable range provided the fastest path speeds are relatively low, the phi angle is not a controlling criterion.

There are three situations or design conditions in which Phi can be measured. They are:

- **Condition 1**: \( \phi = 2 \times (\phi/2) \) where the distance between the left sides of an entry and the next exit are not more than approximately 100 feet. In Condition 1, the acute angle is denoted as 2 \( \phi \) in which the actual value must be divided by two to obtain \( \phi \) (see Method 1 below).

- **Condition 2**: \( \phi = \phi \) if the distance between the left sides of an entry and the next exit are more than approximately 100 feet (see Method 2 below).

- **Condition 3**: Applicable when an adjacent exit does not exist, or an exit located at such a distance or obtuse angle to render the circulatory roadway a dominating factor of an entry (such as in a “3-leg” intersection). Used at “T” intersections or where the adjacent entrance and exit lane(s) are far apart (see Method 2 below).

The two methods of measuring phi are described below:

- **Method 1**: \( \phi \) is measured by dividing the entry and exit radii into three segments. The midpoint of the lane for each segment is best fit with a curve that extends to the face of curb of the splitter island extended. Begin line \( (a-b) \) and \( (c-d) \) at the intersection of the best fit arc and face of curb of the splitter island extended. Line \( (a-b) \) and \( (c-d) \) are then projected tangent from the best fit arc towards the circulating roadway, the angle formed by the intersection of the two lines is twice the value of \( \phi \). See Exhibits 403.7-8 and 403.7-9.
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- Method 2 phi is measured by dividing the entry radii into three segments. The midpoint of the lane for each segment is best fit with a curve that extends to the face of curb of the splitter island extended. Begin line (a-b) at the intersection of the best fit arc and face of curb of the splitter island extended. Line (a-b) is then projected tangent from the best fit arc towards the circulating roadway. Begin line (c-d) at the intersection of line (a-b) and the arc located at the center of the circulating roadway. Line (c-d) is then projected tangent from the arc located in the center of the circulating roadway. The angle formed by the intersection of (a-b) and (c-d) is phi.

Exhibit 403.7-9 Entry Angle, Phi

404 RESTRICTED CROSSING U-TURNS (RCUTS)

404.1 General

A Restricted Crossing U-turn (RCUT) also referred to as a J-turn intersection, a superstreet intersection or a synchronized street intersection is a reduced conflict intersection that displaces left turn and through movements from the minor intersecting roadway. The minor roadway left turns and through movements are accommodated by providing one-way median openings located at least 600 feet on each side of the main intersection and requiring a driver from the minor road to turn right onto the main road (multi-lane divided facility) and make a U-turn maneuver downstream at a one-way median opening. When the left-turn volumes are low the left turn movements from the main road can also be prohibited at the main intersection and accommodated at the one-way median opening. There are three main types of RCUT intersections:

- Merge or Yield-Controlled: Merge or Yield-Controlled RCUT intersections allow for a high-speed divided four-lane facility in a rural area to function like a freeway corridor. These are a good
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alternative when funding for interchanges and overpasses may not be readily available. Longer
distances between the intersection and the U-turn crossovers will be needed for the weaving
movement.

• **Stop-Controlled**: Stop-Controlled RCUT intersections are a good safety treatment for an isolated
intersection on a four-lane divided arterial in a rural area. The stop-controlled RCUT intersection
can be upgraded to a signal-controlled intersection as traffic volumes increase.

• **Signal-Controlled**: Signal-Controlled RCUT intersections provide good progression along an urban or
suburban corridor. Efficiency is provided due the signals requiring only two phases. Speed and
signal spacing do not adversely impact the performance of the RCUT intersection. A signalized RCUT
intersection can accommodate pedestrians and adjacent driveways. Capacity limits for the minor
street may limit the effectiveness of the RCUT intersection so this option may not be appropriate
at the intersection of two high volume arterials.

Hybrids of these three types are possible.

The RCUT is a very adaptable intersection which can be used in both a rural and urban setting. The RCUT
intersection can be a corridor treatment for arterials and some freeway look-alikes, but they are typically
not suitable at the intersection of two arterials.

404.2 RCUT Advantages and Disadvantages

RCUT intersections have unique features and characteristics regarding multimodal considerations, safety
performance, operations geometric design, spatial requirements, constructability and maintenance. This
section will provide the advantages and disadvantages of RCUT intersections.

**Pedestrians/Bicycles**

**Advantages:**
- Reduces conflicts between vehicles and pedestrians for most crossing movements.
- Creates shorter pedestrian crossing distance for some movements.
- Creates opportunities to install mid-block signalized crossings along an arterial.

**Disadvantages:**
- Increases conflicts between vehicles and pedestrians for some crossing movements.
- Creates longer pedestrian crossing distances for some movements which could add delay and reduce
  convenience.
- Requires pedestrians to cross in two stages in some cases which could add delay and reduce
  convenience.
- Pedestrian wayfinding may require additional signage and/or other features to create appropriate
  crossings for pedestrians of all abilities.
- Provisions for bicycle facilities may be different from conventional intersections and may result in
  reduced convenience.

**Safety**

**Advantages:**
- Reduces the number of vehicle-vehicle conflict points at the intersection which should reduce the
  potential for crashes.
- At rural four-lane sites, reduces crashes, injuries and fatalities.
- Potentially reduces high severity turning and angle crashes.
- Less severe crash types compared to a conventional intersection.
- Reduces vehicle-pedestrian conflict points.
Disadvantages:
- Increases sideswipe crashes.
- Introduces weaving movements on the high speed mainline roadway.
- Increases travel distances which could lead to more crashes related to distance traveled.

Operations
Advantages:
- Creates the possibility for the largest possible progression bands in both directions of the arterial at any speed with any signal spacing.
- Provides potential to reduce overall travel time at signalized sites.
- Provides potential to reduce delay and travel time for arterial through traffic at signalized sites.
- Provides potential for shorter signal cycle lengths.
- Allows larger portion of signal cycle to be allocated to the arterial through movement.
- Reduces delay for the major street movements by using a two phase rather than a four phase traffic signal control.
- Reduces the need for signalization of intersections along rural, high-speed, divided highways.
- Improves minor street travel times if traffic gap times are insufficient at conventional intersections.

Disadvantages:
- Increases travel distance (and potentially travel time) for minor street left turn and through movements.
- Experiences a firm capacity.
- Creates potential for spillback out of the crossover storage lane.
- Minor-street left turn and through traffic must make unusual maneuvers and may require additional guidance.

Access Management
Advantages:
- Allows multiple driveway or side street locations along the RCUT corridor.
- Signals for driveways or side streets may be installed without introducing significant delay for arterial through movement.
- Allows flexibility for crossover locations to accommodate adjacent driveways and side streets.
- Does not require frontage roads.

Disadvantages:
- Does not allow for a driveway or a side street near entrance to U-turn crossover.
- Landowners will not have driveways with direct left turns out of their properties.

Traffic Calming
Advantages:
- Two-way progression provides the opportunity to set any progression speed (even low speed).
- Provides an additional barrier to fast moving minor-street through traffic.

Disadvantage:
- The additional barrier to direct minor-street through traffic may cause separation to a community.

Footprint
Advantages:
- The greater arterial throughput creates the possibility to reduce the basic number of through lanes on the arterial and still achieve similar service levels.

Disadvantages:
- May require additional right-of-way for loons or wider medians.
400 Intersection Design

Maintenance
Advantages:
• Less queuing on the arterial may reduce pavement rutting and wear.
Disadvantages:
• When signalized, there are more signal controllers and cabinets than a comparable conventional intersection.
• There are more signs than a comparable conventional intersection.
• If designed with a larger median, there is more pavement to maintain than a comparable conventional intersection.
• More pavement to maintain in U-turn crossovers and loons.

Aesthetics
Advantages:
• Median and islands provide opportunity for landscaping.

Costs
Advantages:
• A more cost-effective design as compared to a grade separated facility.

Construction
Advantages:
• Fewer construction impacts.
• Project can be implemented quickly reducing inconvenience to the motorist.

Education
Disadvantages:
• Lack of driver familiarity may require investments in public education and outreach.

404.3 Applications

RCUT intersections can be a great alternative to a conventional intersection under certain conditions. RCUT intersections are most effective at intersections with at least one of the following attributes:

• Intersections where side-street left turn and through volumes are relatively low and the left turn volumes from the major road are high; the ratio of minor road total volume to total intersection volume should be less than or equal to 0.20.

• Areas where median widths are greater than 40 feet; for narrower medians, loons or bulb-outs on the shoulders need to be constructed to allow all vehicles to perform the U-turn movement.

• Intersections with a high number of far-side right-angle crashes.

A table has been provided below for guidance on the feasible demand conditions for an RCUT intersection.
400 Intersection Design

<table>
<thead>
<tr>
<th>Minor Street Demand ((D_{\text{Minor}}))</th>
<th>Type of RCUT Intersections</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D_{\text{Minor}} &lt; 5,000 \text{ vpd})</td>
<td>Consider unsignalized RCUT intersections</td>
</tr>
<tr>
<td>(5,000 \text{ vpd} &lt; D_{\text{Minor}} &lt; 25,000 \text{ vpd})</td>
<td>Consider signalized RCUT intersections</td>
</tr>
<tr>
<td>(D_{\text{Minor}} &gt; 25,000 \text{ vpd})</td>
<td>There are most likely other alternative intersections such as a MUT or DLT intersection that would generally serve the minor street more efficiently.</td>
</tr>
</tbody>
</table>

404.3.1 Signalized RCUT

On a major road where the progression of the through route needs to be maintained with more green time than a conventional signalized intersection can provide the table below summarizes rules-of-thumb for various percentage of green time allocated to the major/minor road. Note an RCUT intersection may be an appropriate solution based on the analyses of traffic operations and geometric requirements.

<table>
<thead>
<tr>
<th>Green %</th>
<th>Major Street</th>
<th>Minor Street</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 60%</td>
<td>≥ 40%</td>
<td>Other intersection designs will likely serve the relatively heavy minor street demand more efficiently</td>
<td></td>
</tr>
<tr>
<td>&lt; 67%</td>
<td>≥ 33%</td>
<td>Minor street demands may be relatively too heavy for an RCUT</td>
<td></td>
</tr>
<tr>
<td>67%</td>
<td>33%</td>
<td>Signalized RCUT is probably appropriate</td>
<td></td>
</tr>
<tr>
<td>75%</td>
<td>25%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;75%</td>
<td>≤ 25%</td>
<td>Minor street demands may be too light for signals to be warranted</td>
<td></td>
</tr>
</tbody>
</table>

404.4 Geometric Design

RCUT intersection geometrics create some design principles not present at conventional intersections. These principles include:

- A wide median can make accommodating U-turn movements easier or more straightforward. Bumpouts or loons can be used at narrower medians.
- Positive guidance through design elements and traffic control reduce driver error and promote efficient movements that might otherwise be unexpected.
- U-turn crossovers are large enough to accommodate the design vehicle and allow for more efficient movements through the U-turn by passenger vehicles.
- Corridor-wide access management strategies promote safe and efficient access to properties.
- Stopping sight distance at all points through the intersection and intersection sight distance for all movements is provide at each RCUT intersection junction.

Designing the geometric layout of an RCUT intersection requires considering the relationship between safety, operations and design.

For signal-controlled RCUTs, the main intersection operates as a two-phase signal which may require a shorter cycle length than a conventional signal-controlled intersection. The shorter cycle length may result
400 Intersection Design

in shorter traffic queues, less storage lengths and shorter travel distances from the main intersection to the U-turn crossovers.

RCUT intersections are very versatile and offer a wide range of possibilities. A list of design possibilities is provided below:

- Major streets can range from four lanes to eight lanes.
- Minor streets can be up to four through lanes wide.
- U-turn crossovers can be one or two lanes wide.
- Left-turn crossovers can range from one to three lanes wide.
- The distance from the main intersection to the U-turn crossover can vary from 600 feet for a stop or signal controlled RCUT intersection to one-half mile for a merge-controlled RCUT intersection.

The orientation of an RCUT intersection angle may influence the ability to convert a conventional intersection into an RCUT intersection. An RCUT intersection at an acute angle (< 90 degrees) between the major street and the minor street can serve the left turns on the major street more efficiently than one at an obtuse angle (> 90 degrees). See the illustration below.

**Better Candidate for RCUT Conversion**

**Less Ideal for RCUT Conversion**

404.4.1 Main Intersection

404.4.1.1 Left Turns

At a four-legged RCUT, the left-turns are served only on the major street. The number of left-turn lanes shall be based on operational analyses using HCS. The length of the left-turn lanes shall be calculated per Figures 401-9 and 401-10. Typically, any channelization for the left turn radii should be designed using a 10 to 15 mph design speed.

Main road left-turn movements can be prohibited when volumes are low and they can be accommodated at the downstream one-way median opening. This treatment is referred to as a Thru-Turn and does not preclude constructing a main road left turn in the future.

404.4.1.2 Minor Street Right Turn Lanes

Since the minor street left turn and through movements are being converted into right turning movements, the design of the right turn lanes must be sufficient to accommodate all traffic from the minor street. Based on the right turning movement volumes an operational analysis shall be performed to determine the number and length of the right turn lanes required.

January 2020
The minor street approaches need to be designed to prevent wrong-way maneuvers. If the minor street is not a boulevard or a multi-lane divided facility, right-turn channels should be used to minimize wrong way maneuvers. The distance to the U-turn may need to be increased if the right turn is channelized. If multiple right turn lanes are provided, channelization of the lanes may help direct vehicles into the appropriate receiving lanes reducing initial driver confusion and downstream lane changes. A down-side to channelizing the right turn lanes may be the creation of imbalanced lane utilization.

Three options exist for handling the channelizing of the minor street traffic:

- No channelizing island
- A channelizing island (median) separating the traffic turning right from the minor street onto the major street and the traffic turning right from the major street onto the minor street.
- A channelizing island separating minor street right turns that will remain on the major street from the minor street right turns that subsequently makes a U-turn movement on the major street.

The advantages and disadvantages of right turn channelization on the minor street of an RCUT intersection are as follows:

Advantages:
- Drivers are more firmly guided, likely reducing sideswipe conflicts during the turn.
- Shortens pedestrian crossing distances to a pedestrian refuge.
- Reduces paved surface areas.
- Provides the opportunity for a lane addition and a free right turn (merge), reducing delay.

Disadvantages:
- Requires pedestrians to cross more vehicle pathways, with the right turns moving faster and/or more freely.
- Creates the potential for uneven lane utilization on the minor street.
- Drivers on the minor street must select a lane (preposition) earlier.
- Increases right-of-way to accommodate the channelization.

404.4.1.3 Right Turn (Minor Street to Major Street) without Acceleration Lanes

RCUT intersections with stop signs or signals controlling the minor streets can eliminate weaving movements and thus the need for acceleration lanes by extending the U-turn lane back to the main intersection. By providing pavement markings guiding drivers directly into the U-turn lane drivers can wait for an acceptable gap or a green signal. Extending the U-turn lanes to the main intersection is the preferred design and can shorten the distance between the minor street right turn and the median U-turn crossover.

404.4.1.4 Right Turn (Minor Street to Major Street) with Acceleration Lanes

RCUT intersections with acceleration lanes join the major road as an add-lane, then merge upstream of the U-turn crossover creating weaving movements. Field observations of RCUTs with acceleration lanes determined vehicles destined for the downstream U-turn tend to use the acceleration lane as little as possible. Vehicles tend to make the lane shifts as soon as an appropriate gap is available. Based on these tendencies the use of acceleration lanes upstream of the U-turn crossover should be discouraged especially at signalized RCUT intersections. If acceleration lanes are constructed the downstream U-turn is typically placed further away from the main intersection as compared to when acceleration lanes are not constructed.
400 Intersection Design

404.4.2 Median U-turn Crossover

404.4.2.1 Crossover Spacing

The distance between the main intersection and the U-turn crossover must be designed for both directions of travel on the major street. The distance from the main intersection to the U-turn intersections should be kept as short as operational (queuing) and geometrical (location of nearby intersections, drives, bridges, right-of-way constraints and uphill grades etc.) conditions will allow. The U-turn lane can be extended back to the main intersection so the minor road left/thru vehicles destined for the U-turn can enter the U-turn lane as early as possible.

At a signalized RCUT intersection where the main intersection and the two U-turn crossovers are controlled by traffic signals the recommended spacing between the main intersection and the U-turn crossings ranges from a minimum of 600 ft. to a maximum of 1,000 ft. Several factors should be considered when selecting the appropriate spacing from the main intersection to the U-turn crossover. A longer spacing provides more time and space for driver maneuvers into the proper lane; as well as, read and respond to traffic control markings and highway signs. A shorter spacing translates into shorter driving distances and travel times for the minor street left turn and through movements.

In cases where the major road has higher speeds and volumes, the distance to the U-turn may need to be moved further away from the main intersection. The following steps are required to determine the distance from the main intersection to U-turn intersection:

1. Determine distance from minor road right turn to beginning of U-turn taper by determining the distance required to go from 0 mph to 10 mph below the main road design speed using the chart below.

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
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<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
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<tr>
<td>Feet to reach speed</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>225</td>
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<td>450</td>
<td>600</td>
<td>800</td>
<td>1000</td>
<td>1300</td>
</tr>
</tbody>
</table>

2. Determine the U-turn lane length based on Figure 401-9 and Figure 401-10, or HCS/Sim Traffic 95th percentile queue, whichever controls.

404.4.2.2 Crossover Design

Proper design of U-turns is essential to ensure safe traffic operations. A properly designed U-turn crossover should provide adequate pavement to accommodate a WB-62 without creating conflicts with other vehicles. For crossovers with inadequate median width for the WB-62 to maneuver loons or bulb-outs should be installed to provide adequate turning radii for the tracking of both the front and rear ends of a WB-62.

Four possible U-turn lane destinations exist to account for the truck tracking through the U-turn crossover.

- Inside Lane to Inside Lane
- Inside Lane to Outside Lane
- Inside Lane to Outside Shoulder
- Inside Lane to Loon

Typically, the U-turn crossovers should be designed using a design speed of 15 mph.
400 Intersection Design

404.4.2.3 U-turn Lane Design

U-turn deceleration/storage lengths should be designed to accommodate the 95th percentile queue of U-turning vehicles. See Figures 401-9 and Figure 401-10 for determining the length of the U-turn deceleration/storage length at the approach to the crossover.

Larger vehicles have a larger swept path and may require an additional paved area. For dual U-turn, the U-turn crossover should accommodate one WB-62 and one single unit truck vehicle. Signage should be provided for the WB-62 to use the rightmost or outermost U-turn lane. The crossover must be designed so the path of the WB-62 in the rightmost lane and the path of the single unit truck in the leftmost lane provides at least a minimum of 2 ft. between the tire paths of the respective vehicles.

404.5 Multimodal Considerations

RCUT intersection design should consider all the different transportation modes that will be using the intersection.

Due to their unique geometrics and traffic control features, RCUT intersections can provide both benefits and challenges to non-automobile modes of transportation and these factors need to be considered early in the project development process rather than incorporating them in the later stages of design.

404.5.1 Pedestrians

Factors such as non-signalized movements, a greater percentage of vehicles making right turning movements and the RCUT intersections wide geometric footprint create challenges to accommodating pedestrians. Pedestrian crossing lengths may be longer than those at conventional intersections, but the shorter traffic signal cycle lengths can help make crossing times comparable to those at conventional intersections. RCUT intersections reduce the number of vehicle-pedestrian conflict points compared to conventional intersections, but they also require pedestrian crossings that differ from conventional intersections. The most common means of serving pedestrians is a “Z” crossing treatment. Other options include a Signalized Mid-Block Crossing and a Median Crossing. Examples of each pedestrian crossing treatment are shown below.

404.5.2 Bicycles

Bicycles on the major street navigate an RCUT intersection the same way they navigate a conventional intersection. Minor street left-turning or through bicycles do not have a direct route at an RCUT intersection if they are utilizing the vehicular lanes. There are three primary ways to facilitate minor street left-turn and through bicyclists in an RCUT intersection:

- Use a path matching the pedestrians
- Use a path matching the motor vehicle traffic
400 Intersection Design

- Direct bicycle crossings

The choice of which option will depend on the quality of interaction with motorists, the speed of the major street vehicle traffic, shoulder width or the presence of a bicycle lane, the volume of the major street traffic, the distance to the U-turn crossover and the level of bicyclist experience.
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<th>Date</th>
<th>Title</th>
</tr>
</thead>
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<td>07/2006</td>
<td>Radius Returns for Curbed Mainline Uncurbed Approach</td>
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<td>401-10</td>
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<td>Roundabout Critical Design Parameters</td>
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* Note: For the design criteria pertaining to Collectors and Local Roads with ADT’s of 400 or less, refer to the AASHTO Publication - Guidelines for Geometric Design of Very Low-Volume Local Roads ADT≤400).
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See explanation on adjacent sheet.
Explanation of Figure 401-1 Typical Crossroad Relocation

1. Curve - This portion of the crossroad can occur by itself at “T” type or three-legged intersections. If possible, the radius of this curve should be commensurate with the design speed of the crossroad. Often, the length of the required profile controls the work length. The horizontal curvature is then chosen so it can be accomplished within this work length. Regardless of the length of the profile adjustment, it is desirable to provide at least a 230 foot radius for this curve. When a 230 foot radius incurs high costs, it is permissible to reduce this radius to a minimum of 150 ft.

2. Tangent and Approach Radii - The crossroad in this area should have a tangent alignment. For the condition shown, the alignment between the radius returns is tangent from one side of the road to the other. However, at some intersections with a minor through movement (for example, crossroad intersections of standard diamond ramps) it may be desirable to provide different intersection angles on each side of the through road. For approach radii, see discussion in Section 401.5.

3. Curve - The statements in (1) above also apply to this curve. With the reverse curve condition shown, the radius will often not exceed 250 ft. because flatter curves make the relocation extraordinarily long.

4. Tangent - This tangent should be approximately 150 ft. in length for 30 or 40 mph design speeds on the existing road, and approximately 250 ft. for 50 or 60 mph design speeds. These lengths are generous enough to allow reasonable superelevation transitions between the reverse curves. In general, it is usually not desirable to make this tangent any longer than required. If a longer tangent can be used, the curvature or intersection angle can be improved and these two design items are more important.

5. Curve - This curve should be much flatter than the other two curves. It should be capable of being driven at the normal design speed of the existing crossroad.

July 2006
CROSSROAD PROFILE
-STOP CONDITION-
THROUGH ROAD NORMAL CROWN

REFERENCE SECTIONS
401.4.1 - 401.4.4

NOTES:

1. 5% maximum grades are permitted and shown for illustration but grades of 3% or less are preferred.

2. Grade to be 1.6% or steeper to provide drainage away from through road pavement.

3. Recommended crest break 5% sag break 3%. If break is greater see Figure 401-3

4. Crest Vertical Curve Length (Height of eye 3.5' - height of object 0')
   \[ S < L \quad L = \frac{AS^2}{700} \]
   \[ S > L \quad L = 2S - \frac{700}{A} \]

October 2004
CROSSROAD PROFILE
-STOP CONDITION-
THROUGH ROAD SUPERELEVATED

NOTES:
1. 5% grades are shown for illustration but grades of 3% or less are preferred.
2. Grade to be 1.6% or steeper to provide drainage.
3. Crest breaks exceeding 5% shall be rounded using vertical curves having a K of 1 or greater. Sag breaks exceeding 3% shall be rounded using vertical curves having a K of 1.5 or greater.
4. For grade treatment of this area, see Figure 401-2.

July 2006
Example A - Crossroad Profile Tangent through Intersection

1. Location of permissible grade break per Figure 203-2
2. Edge of pavement of intersecting roadway extended through the intersection
3. Width of intersecting roadway

Example B - Crossroad Profile on Vertical Curve through Intersection

Example C - Crossroad Profile Fitted to a Normal Crown on the Mainline Road

October 2004
UNCURBED MAINLINE CURBED APPROACH

Curb and Gutter

Edge of Traveled Way

Mainline

Paved Shoulder

Paved Shoulder Width or 8’ Whichever is greater

See Section 305.4 For Curb Height Transitions

July 2006
CURBED MAINLINE UNCURBED APPROACH

Width Transition Occurs Over the Curb Return

Curb and Gutter
Curbed Approach Radii

Mainline

Uncurbed Approach Radii
Paved Shoulder

OPTION 1

Paved Shoulder
Edge of Traveled Way

OPTION 2

See Section 305.4 For Curb Height Transitions

July 2006
2-LANE LEFT TURN LANE WARRANT (LOW SPEED)

REFERENCE SECTION 401.6.1

**Includes Left Turns**

**There is no minimum number of turns**

October 2004
4-Lane Highway Left Turn Lane Warrant

Opposing Volume (dhv)

0 200 400 600 800 1000 1200 1400 1600 1800 2000

Left Turn Volume (dhv)

October 2004
2-LANE RIGHT TURN LANE WARRANT (LOW SPEED)

2-Lane Highway Right Turn Lane Warrant

= < 40 mph or 70 kph Posted Speed

Right Turn Lane Required

Right Turn Lane Not Required

Advancing Traffic* (dhv)

*Includes Right Turns

Right Turning Traffic (dhv)

October 2004
2-Lane Highway Right Turn Lane Warrant

> 40 mph or 70 kph Posted Speed

Right Turn Lane
Required

Right Turn Lane
Not Required

*Includes Right Turns
4-LANE RIGHT TURN LANE WARRANT (LOW SPEED)

4 Lane Highway Right Turn Lane Warrant
(<40 mph or 70 kph Posted Speed)

Right Turn Lane Required
Right Turn Lane Not Required

Advancing Traffic Volume (d/hv)

October 2004
4-LANE RIGHT TURN LANE WARRANT (HIGH SPEED)

4 Lane Highway Right Turn Lane Warrant
(
>40 mph or 70 kph Posted Speed)

Right Turn Lane Required

Right Turn Lane Not Required

Advancing Traffic Volume (dhv)

October 2004
LEFT TURN LANE - NO MEDIAN OR MEDIAN WIDTH < $W_L$

LEFT TURN LANE - MEDIAN WIDTH $\geq W_L$

RIGHT TURN LANE

- See Figures 401-9 and 401-10 to compute length.
- May be reduced or eliminated in urban areas if intersection spacing or storage is constraining.
- Diverging taper

$W_L$ = Turn Lane Width

October 2004
Islands created by excess pavement are normally identified using pavement marking.

Use Figure 401-9 to determine length. Minimum storage length equals 8 x offset + 50'.
### BASIS FOR COMPUTING LENGTH OF TURN LANES

**401-9**

**REFERENCE SECTIONS**

401.6.1, 401.6.3

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<thead>
<tr>
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<td><strong>Turn Demand Volume</strong></td>
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<td>All</td>
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<td>Low*</td>
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<tr>
<td>High</td>
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</table>

Signalized

- Signalized
- Design Speed
- Length

Unsignalized

- Unsignalized
- Design Speed
- Length

**CONDITION A**

**STORAGE ONLY**

Length = 50' (diverging taper) + Storage Length (Figure 401-10)

**CONDITION B**

**HIGH SPEED DECELERATION ONLY**

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<th>Length (including 50' Diverging Taper)</th>
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<td>40</td>
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<tr>
<td>45</td>
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<td>60</td>
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**CONDITION C**

**MODERATE SPEED DECELERATION AND STORAGE**

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<th>Length (including 50' Diverging Taper)</th>
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</thead>
<tbody>
<tr>
<td>40</td>
<td>115 + Storage Length (Figure 401-10)</td>
</tr>
<tr>
<td>45</td>
<td>125</td>
</tr>
<tr>
<td>50</td>
<td>145</td>
</tr>
<tr>
<td>55</td>
<td>165</td>
</tr>
<tr>
<td>60</td>
<td>185</td>
</tr>
<tr>
<td>65</td>
<td>205</td>
</tr>
</tbody>
</table>

**For explanation, see Turn Lane Design Example**

July 2018
**STORAGE LENGTH AT INTERSECTIONS**

REFERENCE SECTIONS 401.6.1, 401.6.3

<table>
<thead>
<tr>
<th>*AVERAGE NO. OF VEHICLES/CYCLE</th>
<th>REQUIRED LENGTH (FT.)</th>
<th>*AVERAGE NO. OF VEHICLES/CYCLE</th>
<th>REQUIRED LENGTH (FT.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>17</td>
<td>600</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>18</td>
<td>625</td>
</tr>
<tr>
<td>3</td>
<td>150</td>
<td>19</td>
<td>650</td>
</tr>
<tr>
<td>4</td>
<td>175</td>
<td>20</td>
<td>675</td>
</tr>
<tr>
<td>5</td>
<td>200</td>
<td>21</td>
<td>725</td>
</tr>
<tr>
<td>6</td>
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<td>22</td>
<td>750</td>
</tr>
<tr>
<td>7</td>
<td>275</td>
<td>23</td>
<td>775</td>
</tr>
<tr>
<td>8</td>
<td>325</td>
<td>24</td>
<td>800</td>
</tr>
<tr>
<td>9</td>
<td>350</td>
<td>25</td>
<td>825</td>
</tr>
<tr>
<td>10</td>
<td>375</td>
<td>30</td>
<td>975</td>
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<td>11</td>
<td>400</td>
<td>35</td>
<td>1125</td>
</tr>
<tr>
<td>12</td>
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<td>500</td>
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<td>1550</td>
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<tr>
<td>15</td>
<td>525</td>
<td>55</td>
<td>1700</td>
</tr>
<tr>
<td>16</td>
<td>550</td>
<td>60</td>
<td>1850</td>
</tr>
</tbody>
</table>

* AVERAGE VEHICLES PER CYCLE = \( \frac{DHV \text{ (TURNING LANE)}}{CYCLES/HOUR} \)

**IF CYCLES ARE UNKNOWN ASSUME:**
- UNSIGNALIZED OR 2 PHASE = 60 CYCLES/HOUR
- 3 PHASE = 40 CYCLES/HOUR
- 4 PHASE = 30 CYCLES/HOUR

October 2004
**Example - Turn Lane Design Using Figures 401-9 and 401-10**

**Problem**
Calculate the length of an exclusive left turn lane.

Traffic Control: **Signalized**
Design Speed: **55 mph**
Cycle Length: **90 sec**

**Determine Storage and Turn Lane Lengths**

Turn Lane Demand (High/Low) = \[
\frac{200 \text{ veh/hr}}{200 \text{ veh/hr} + 680 \text{ veh/hr}} = 23\% = \text{High Demand}
\]

Refer to the matrix in **Figure 401-9**.

For Signalized, 55 mph, High Demand, use Method B or C, whichever is greater.

**Method B** – For 55 mph, a **285’** turn lane length is required (235’ storage + 50’ taper).

**Method C** – For 55 mph, 165’ + calculated storage length in **Figure 401-10**.

Total Length = 165’ + 200’ = **365’** (315’ storage + 50’ taper)

Method C = **365’** > Method B = **285’**

**Use Method C**

**Check Length for Thru-Block**

Refer to **Figure 401-10** to calculate thru lane(s) queue distance.

\[
680 \text{ veh/hr} / 2 \text{ lanes} = 340 \text{ veh/hr/ln}
\]

Average Vehicles per Cycle = \[
\frac{(340 \text{ veh/hr/ln}) \times (90 \text{ sec/cyc})}{3600 \text{ sec/hr}} = 9 \text{ veh/cyc} \Rightarrow 350\’
\]

Thru Block = **350’** > Method C Storage = **315’** ➔ **Turn Lane Blocked**

Use **350’** storage + **50’** taper = **400’** Turn Lane Length
DOUBLE LEFT TURN LANES

LOCATION OF a:b TAPER

INSIDE RADIUS -R-

EXPANDED THROAT WIDTH -W-

DESIGN TRAFFIC CONDITION ▼

<table>
<thead>
<tr>
<th>INSIDE RADIUS</th>
<th>EXPANDED THROAT WIDTH -W-</th>
<th>DESIGN TRAFFIC CONDITION ▼</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>50 ft.</td>
<td>31 ft.</td>
<td>36 ft.</td>
</tr>
<tr>
<td>75 ft.</td>
<td>29 ft.</td>
<td>33 ft.</td>
</tr>
<tr>
<td>100 ft.</td>
<td>28 ft.</td>
<td>31 ft.</td>
</tr>
<tr>
<td>150 ft.</td>
<td>26 ft.</td>
<td>29 ft.</td>
</tr>
<tr>
<td>200 ft.</td>
<td>26 ft.</td>
<td>28 ft.</td>
</tr>
</tbody>
</table>

▼ A = mostly 'P' vehicles, some 'SU' trucks
B = sufficient 'SU' trucks to govern design, some semitrailers
C = sufficient bus and combination types to govern design

Generally, A is when T < 5%
B is when T = 5-10%
C is when T > 10%
T = percentage of type B and C trucks in Design ADT
Notes for Figure 401-11 Double Left Turn Lanes

1. Notice that the single left turn lane at the top of the page has been laterally offset from the through lanes in order to prevent conflicts between opposing turning paths.

2. Opposing turning paths should always be checked to verify that there is no conflict (see dimension "G"). Per AASHTO "Green Book", page 9-138, dimension "G" should be at a minimum, 10'.

3. The double right turn lane design follows the same criteria as the double left turn lane for expanded throat width.

4. The pavement width of the receiving lanes for a double left turn at an intersection needs to be checked to see if design vehicles can complete their turns within the pavement area. This is especially important where the radius returns are curbed. The use of radius templates is one method that can be used to check wheel tracking to see if additional pavement area adjacent to the far return area is needed. If the turning lanes are 12 ft. in width, the following formula is recommended to estimate a need for widening the pavement at the receiving throat:

   \[ F = \frac{(W-24)}{2} \]

   where W is the maximum expanded throat width from the table on Figure 401-11. If the turn lanes are not 12 ft., use truck turning templates.
   The use the following guidelines:

   - If \( F < 2.0 \), no widening is required.
   - If \( F = 2.0 \) through 3.9, use a 40:4 taper.
   - If \( F = 4.0 \) through 5.9, use a 45:6 taper.
   - If \( F = 6.0 \) through 9.0, use a 50:8 taper.

   See Figure 503-5 for examples of how these tapers are used at radius returns.

5. Stop bar locations may need to be adjusted to the inside radius return of the left turn movements.
**Development of Dual Left Turn Lanes**

- **L1 (Deceleration Length)**
  - 40 mph: 125'
  - 45 mph: 175'
  - 50 mph: 225'
  - 55 mph: 285'
  - 60 mph: 345'
  - 65 mph: 405'

- **L2 (Deceleration Length)**
  - 40 mph: 75'
  - 45 mph: 125'
  - 50 mph: 145'
  - 55 mph: 165'
  - 60 mph: 185'
  - 65 mph: 205'

- **S (Storage Length)**
  - Minimum: 50'

- **Taper at 8:1**

- **Islands created by excess pavement are normally identified using pavement marking**

- **Use Figure 401-10 to determine storage length. For offset left turn lanes, minimum storage length equals 8 x offset + 50'.**

- **Taper is used when dual left turn lanes are offset.**

- **△ If opposite approach has one left turn lane, these lanes should line up.**

- For intersection details see Figure 401-11.
Note: Only the approximate location of the Turn Prohibition Sign Posts are shown.

URBAN (CURBED) - RIGHT IN / RIGHT OUT

Without Right Turn Lane

URBAN (CURBED) - RIGHT IN / RIGHT OUT

With Right Turn Lane

RURAL (UNCURBED) - RIGHT IN / RIGHT OUT

Without Right Turn Lane

RURAL (UNCURBED) - RIGHT IN / RIGHT OUT

With Right Turn Lane

Note: Only the approximate location of the Lane Use Sign Posts are shown.

Note: See SCDOT 71.10 for turn lane pavement marking details.
CHANNELIZING ISLANDS
TYPICAL ISLANDS WITH PERMITTED LEFT TURNS

REFERENCE SECTION 401.7.2

URBAN (CURBED) - RIGHT IN/ ALL OUT
WITHOUT RIGHT TURN LANE
SU & P DESIGNS (MINIMUM)

RURAL (UNCURBED) - RIGHT IN/ ALL OUT
WITHOUT RIGHT TURN LANE
SU & P DESIGNS (MINIMUM)

Note: Only the approximate location of the Turn Prohibition Sign Posts are shown.
Traffic operational analysis used for design purposes (i.e. determination of number and type of lanes) must use the current version of the Highway Capacity Software (HCS) by McTrans. ODOT may allow use of other traffic analysis and modeling programs when HCS is incapable of providing analysis results or when supplemental analysis is desired. Software currently used by ODOT for traffic operations analyses includes Synchro/SimTraffic, SIDRA, and TransModeler. Synchro/SimTraffic may be used for assessing corridor progression. However, Synchro shall not be used for design. While other programs may be considered for unique situations, it is preferred that the above identified programs be used.

Default Values and Guidance

The following section provides information on required input values and default values to be used for traffic analyses and methodologies.

Highway Capacity Software (HCS) – Streets (Signalized Intersection)

Primary Input Data
• Traffic → Storage Length, ft → Enter left/right turn lane and thru lane storage, see figure to right on how values are measured.
• Traffic → RTOR, veh/h → 0 veh/h
• Phasing → Cycle,s → 60-120s, typically
• Phasing → Uncoordinated Intersection → Toggle on
• Phasing → Field-Measured Phase Times → Toggle on
• Timing → Yellow Change, s & Red Clearance, s → Minimum Y+R is 5s. Actual/calculated values may be used.
• Timing → Minimum Green, s → a) 10s for phase that includes a thru movement, b) 7s for a phase that excludes a thru movement. Note, protected lefts must have a minimum contiguous duration of 7s.

Detailed Input Data
• General → Queue Length Percentile → 95th percentile

Note: A queue storage ratio (QSR) will be calculated using the storage length input and calculated queue length. If QSR exceeds 1.0, HCS will not identify that there will be spillovers into other lanes and cause unforeseen delays because HCS does not currently account for turn lane overflow and queue spillback. If possible, any QSR above 1.0 should be alleviated prior to finalizing the analysis. If not possible, microsimulation (i.e. SimTraffic) may be required.

Highway Capacity Software (HCS) – All Modules
• PHF (peak hour factor) → Use HCS7 default (typically)
Note: A PHF less than the default value may be required to analyze sites where peaked traffic is anticipated (i.e. sports center, school, factory, etc.

Note: Default values shall not be used for readily available information such as acceleration/deceleration length(s), storage length(s), lane width(s), percent heavy vehicles, free-flow speed, etc.
Exhibit for Figure 401-14a TRAFFIC OPERATIONAL ANALYSIS DESIGN SOFTWARE
**SIDRA (Limited to roundabout analyses) – The settings below are for SIDRA 8.0**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Site Input - Tab / Section</th>
<th>Change Setting To</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roundabout Capacity Model</td>
<td>Roundabouts - Options - Roundabout Model Options</td>
<td><strong>SIDRA Standard</strong></td>
</tr>
<tr>
<td>Site Level of Service Method</td>
<td>Parameter Settings - Options - General Options</td>
<td><strong>Delay &amp; Degree of Saturation (SIDRA)</strong></td>
</tr>
<tr>
<td>Roundabout LOS Method</td>
<td>Roundabouts - Options - Roundabout Model Options</td>
<td><strong>Same as Signalized Intersections</strong></td>
</tr>
<tr>
<td>Exclude Geometric Delay</td>
<td>Roundabouts - Options - Roundabout Model Options</td>
<td><strong>Unchecked</strong></td>
</tr>
<tr>
<td>HCM Delay Formula</td>
<td>Roundabouts - Roundabout Model Options</td>
<td><strong>Unchecked</strong></td>
</tr>
<tr>
<td>Environmental Factor (Single-Lane)</td>
<td>Roundabouts - Roundabout Data - SIDRA Standard Model Calibration</td>
<td><strong>1.10 - Opening Day</strong> <strong>1.00 - Design Year</strong></td>
</tr>
<tr>
<td>Environmental Factor (Multi-Lane)</td>
<td>Roundabouts - Roundabout Data - SIDRA Standard Model Calibration</td>
<td><strong>1.20 - Opening Day</strong> <strong>1.10 - Design Year</strong></td>
</tr>
<tr>
<td>Entry/Circulating Flow Adjustment</td>
<td>Roundabouts - Roundabout Data - SIDRA Standard Model Calibration</td>
<td><strong>Medium</strong></td>
</tr>
<tr>
<td>Lane Width</td>
<td>Lane Geometry - Lane Configuration - Lane Configuration Data</td>
<td><strong>14 feet min. (each lane)</strong> <em>(use design width if known)</em></td>
</tr>
<tr>
<td>Circulating Width</td>
<td>Roundabouts - Roundabout Data - Geometry</td>
<td><strong>14 feet min. (each lane)</strong> <em>(use design width if known)</em></td>
</tr>
<tr>
<td>Entry Radius</td>
<td>Roundabouts - Roundabout Data - Geometry</td>
<td><strong>Single Lane - 90 feet</strong> <strong>Multi-Lane - 150 feet</strong> <em>(use design width if known)</em></td>
</tr>
</tbody>
</table>

January 2019
Microsimulation software (SimTraffic)

- Analysis should use a minimum of 10 simulation runs with different number seeds.
- Refer to the FHWA Traffic Analysis Tools Program for additional guidance on using simulation software: [http://ops.fhwa.dot.gov/trafficanalysistools/index.htm](http://ops.fhwa.dot.gov/trafficanalysistools/index.htm)

Synchro (SimTraffic)

Below is a screen capture of the minimum parameters, for the peak period that must be used when running SimTraffic. These are found by selecting “Options” in the menu bar, then “Intervals and Volumes”.

![SimTraffic Parameters Screen Capture](image)
ROUNDABOUT TAPER OPTION

See Figure 402-3 for Notes:

- See Note 2 for Calculation of Taper Lengths.
- See Note 6 for Relationship of Departure and Approach Taper Layouts.
- See Figures 401-9 and 401-10 for Calculation of Storage Lengths.

ROUNDABOUT FLARE OPTION

This Option is acceptable for use on Non-State Routes.
Notes for Figures 402-1 and 402-2 and Other Details

1. This distance should be at least long enough to allow proper advance placement of warning signs for a typical lane reduction, based on OMUTCD guidelines. The lane is then merged at a taper rate as shown in Note 2 below.

2. The taper distance is calculated from:

   Design Speed of 50 mph or more: 
   \[ L = WS \]

   Design Speed of less than 50 mph:
   \[ L = W S^2 / 60 \]

3. May be reduced or eliminated in urban areas if intersection spacing or storage is constraining.

4. Lane addition and removal on 3-lane or more highways is similar. Dropping of additional lanes shall be based on OMUTCD guidelines or at next intersection as shown on Figure 402-1.

5. Figures are not intended to show pavement striping. Striping is based upon the OMUTCD.

6. For the relationship of departure and approach taper layouts see Figure 401-7.

7. In general, it is desirable to place all tapers on tangents or on curves with normal crown superelevation.

8. If driveways are present, distance to beginning of lane drop taper may need to be increased. See details below for drive and taper configurations.
### Volume Thresholds for Determining the Number of Entry Lanes Required (Planning Level)

<table>
<thead>
<tr>
<th>Volume Range</th>
<th>Number of Lanes Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1,000</td>
<td>• Single-lane entry likely to be sufficient</td>
</tr>
</tbody>
</table>
| 1,000 - 1,300| • Two lane entry may be needed  
• Single-lane may be sufficient based upon more detailed analysis |
| 1,300 - 1,800| • Two lane entry is likely to be sufficient |
| 1,800+       | • More than two entry lanes may be required  
• A more detailed capacity evaluation should be conducted to verify lane numbers and arrangements |

### Planning-Level Daily Intersection Volumes

![Graph showing planning-level daily intersection volumes](image)
### Roundabout Critical Design Parameters

**Project - County Route Section**

**PID**

<table>
<thead>
<tr>
<th>Design Parameters</th>
<th>Leg 1</th>
<th>Leg 2</th>
<th>Leg 3</th>
<th>Leg 4</th>
<th>Leg 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inscribed Circle Diameter, FT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entry Width, FT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entry Angle PHI φ, DEG</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exit Width, FT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circulatory Roadway Width Upstream of Entry, FT</td>
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</table>

<table>
<thead>
<tr>
<th>Fastest Path Speed</th>
<th>Leg 1</th>
<th>Leg 2</th>
<th>Leg 3</th>
<th>Leg 4</th>
<th>Leg 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>R₁, Radius/Speed, FT/MPH</td>
<td></td>
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<tr>
<td>R₂, Radius/Speed, FT/MPH</td>
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<tr>
<td>R₃, Radius/Speed, FT/MPH</td>
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<td></td>
</tr>
<tr>
<td>R₄, Radius/Speed, FT/MPH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R₅, Radius/Speed, FT/MPH</td>
<td></td>
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</tr>
<tr>
<td>R₅, Bypass Radius/Speed, FT/MPH</td>
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</table>

<table>
<thead>
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<th>Minimum Sight Parameters</th>
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<th>Leg 3</th>
<th>Leg 4</th>
<th>Leg 5</th>
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<tbody>
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<td>Approach Stopping Sight Distance, FT/MPH</td>
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<tr>
<td>Circulatory Stopping Sight Distance, FT/MPH</td>
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<td></td>
</tr>
<tr>
<td>Exit (Crosswalk) Stopping Sight Distance, FT/MPH</td>
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<tr>
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<thead>
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<td>Design Vehicle(s)</td>
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<tr>
<td>Truck Apron Width, FT</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Designer:**

**Signature:**

**Date:**

[Link to editable Excel File]

January 2019