



## Facilities Development Manual

ORIGINATOR Director, Bureau of Highway Development		PROCEDURE 11-26-10
CHAPTER 11	Design	
SECTION 26	Roundabouts	
SUBJECT 10	Preliminary Design	

### **Introduction**

Designing the geometry of a roundabout involves balancing the needs for safety, capacity, operating performance and right-of-way constraints. A roundabout operates most safely when its geometry forces traffic to enter and circulate at slow speeds. Horizontal curvature and pavement widths are used to produce appropriate speed environment. Conversely, the capacity and safety of roundabouts can be negatively affected by low speed design elements. Geometric parameters for roundabouts are governed by the maneuvering requirements of the largest vehicles expected to travel through the intersection. Typically that is the WB-65<sup>1</sup> on the state highway system.

While the basic form and features of roundabouts are similar regardless of their location, many of the design techniques and parameters are different depending on speed, environment and desired capacity and safety at individual sites. Design techniques can vary substantially for low-volume, single-lane roundabouts versus high-capacity, multi-lane entry roundabouts. For these reasons design “principles” must be applied rather than strict “rules.” Relying on design principles provides the designer flexibility to best achieve the optimal operations for each site.

Read the Forward inside the front cover of the FHWA “Roundabouts: An Informational Guide” ([FHWA Roundabout Guide](#)) then refer to Chapter 6 for the fundamental design principles as guidance. This document provides guidelines for each geometric element. Further guidelines specific to two-lane entry are provided in the latter part of Chapter 6. Note that two-lane entry roundabout design is significantly more challenging than one-lane entry roundabout design. Many of the techniques used in one-lane entry roundabout design do not directly transfer to multi-lane design, especially the use of small exit radii that are preceded by reverse curvature between entry and exit.

Three-lane entry roundabout design is significantly more challenging than a two-lane entry design and requires a high level of expertise and years of design experience. This procedure provides recommended changes to [FHWA Roundabout Guide](#), Chapter 6. Therefore designers must become very familiar with Chapter 6 in the FHWA Roundabout Guide.

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<sup>1</sup> A WB-65 uses a 43 ft distance between the centerline of the king pin to the centerline of the rear duals. This is the maximum allowed by state statute.

As with all transportation projects, the impacts associated with a proposed roundabout need to be compared to the impacts of alternative improvements. At a minimum, include in the comparison an operational analysis, safety analysis, and a cost comparison of alternatives. The following additional impacts may also be considered: right-of-way, pedestrian/bicycle issues, system impacts, adjacent access and aesthetics, etc.

Conduct a detailed analysis to compare the operational performance of a roundabout with alternative intersection types. Complete a level of service analysis for all of the intersection alternatives. Perform a crash analysis comparing the theoretical safety benefits of a roundabout to other intersection types being considered.

## **Design Process**

The process of designing roundabouts requires a considerable amount of iteration among geometric layout, operational analysis, and safety evaluation. Minor adjustments in geometry can result in significant changes in the safety and/or operational performance. Thus, the designer often needs to revise and refine the initial layout to enhance its capacity and safety. It is not possible to produce an optimal geometric design on the first attempt.

Because roundabout design is an iterative process, it may be advisable to prepare the initial layout drawings at a sketch level detail. Although it is easy to get caught into the desire to design each of the individual components of the geometry such that it complies with the specification, it is much more important that the individual components are compatible with each other so that the roundabout will meet its overall performance objectives. Before the details of the geometry are defined, three fundamental elements must be determined in the primary design stage:

- The optimal roundabout size;
- The optimal position; and
- The optimal alignment and arrangement of the approach legs.

Below are design guidelines that apply to WisDOT design that differ from the FHWA Roundabout Guide by section.

1. Section 6.2.1.2, **Design speed**: WisDOT is designing for the urban single lane, urban multi-lane, rural single lane, and the rural multi-lane. At this time WisDOT is not evaluating the mini-roundabout or the urban compact.
2. Section 6.2.1.3, **Vehicle Paths**: Determine the smoothest, fastest path (spline curve) possible for a single vehicle, in the absence of other traffic and ignoring all lane line markings, traversing through the entry, around the central island, and out the exit. Usually the fastest path is the through movement, but in some situations it may be a right turn movement.

Fastest speed path is a critical element in the design of roundabouts. Use the [FHWA Roundabout Guide](#), Exhibit 6-5 and Exhibit 6-7 for single lane and rather simple multi-lane design with low pedestrian activity. Use Exhibit 6-5 to determine the radii values for R1, R2 and R3 fastest speed path. Use Exhibit 6-7 to determine the radius value for R5 fastest speed path. Do not use Exhibit 6-6 because the lane lines (the white dashed lines that separate traffic going in the same direction) shall be ignored on multi-lane roundabouts for fastest speed analysis. The R4 value for the roundabout design does not control the fastest speed path but may be checked to determine speed consistency.

Determine the fastest speed paths using a 3.28 ft (1 m) offset to the critical controlling feature location (i.e. raised curb median, central island, or centerline between opposing traffic) on three-lane entries. This fast path method uses a maximum R1 radius of 330 ft (100 m). This method may also be used when designing complex multi-lane roundabouts or to check the design speed control of sensitive designs where the pedestrian activity is anticipated to be medium to high.

3. Section 6.2.1.5, **Speed Consistency**: In addition to achieving the appropriate design speed for the fastest movements, the relative speeds between consecutive geometric elements should be minimized and the relative speeds between conflicting traffic streams should be minimized. Ideally, the relative differences between all speeds within the roundabout will be no more than 6 mph. However, it is often difficult to achieve this goal, particularly at roundabouts that must accommodate large trucks. In these cases, the maximum speed differential between movements is to be no more than 12 mph. Typically the R2 values for radius and speed are lower than the R1 values on single-lane entries. However, this is seldom achievable with multi-lane entries. With either single- or multi-lane entries, R2 values should be lower than the R3 values.
4. Section 6.2.2, **Design Vehicle**: The standard design vehicle for the state highway system in Wisconsin is the WB-65. There may be situations where community sensitive design considerations suggest that larger or smaller vehicle accommodations may be warranted.
5. Section 6.2.4, **Alignment of approaches and entries**: Exhibit 6-18 is an example of a “rule” rather than a principle and applies to single-lane roundabouts but does not apply to multi-lane roundabouts.
6. Section 6.3.2, **Entry width**: For capacity reasons, if the required entry width exceeds 16 feet consider widening to approximately 22 feet and pavement mark it as a two-lane entry. The effective flare length (L') will have a dramatic effect on capacity. Effective flare length may be as short as 15 feet or as long as 330 feet. Once the effective flare length exceeds 330 feet it will begin to have a minimal impact to increase capacity and adding a full approach lane would be advised.
7. Section 6.3.10.2, **Length of conflicting leg of sight triangle**: The critical gap for entering the major road,  $t_c$ , equals 4.5 seconds instead of 6.5 seconds. This changes the computed distance in the FHWA Roundabout Guide Exhibit 6-33 to those provided in Table 1.

**Table 1. Roundabout Intersection Sight Distance**

Conflicting Approach Speed (mph)	Computed Distance (ft)
10	66.1
15	99.1
20	132.1
25	165.2
30	198.2

8. Section 6.3.11.2, **Exhibit 6-37**: When designing the circulatory roadway pavement cross section, consider the pavement type that will be used, asphaltic or concrete. On a roundabout with at least one, two-lane entry consider sloping two thirds of the width toward the inner circle and one third of the width to the outside. An alternative cross

section may be to slope one half the width inward and one half outward. Also, consider the minimum screed width of the paver and the total width of the circulatory roadway.

The truck apron design has flexibility in terms of the curb, or curb and gutter to use between the circulatory roadway and the slope on the truck apron. Design this curb to be unfriendly for SUV's to traverse, but with a rounded top so that it is kind to large truck tires. The curb, or curb and gutter between the roadway and the truck apron may be 4-inch vertical or 6-inch sloped. A Type J or G curb and gutter may be appropriate or the Type A or D, 18-inch, with a sloped curb that requires a special detail, may be appropriate. The truck apron slope may vary between 2 and 4 percent toward the circulatory roadway.

9. Section 6.3.12 **Bicycle provisions:** Design the bike ramps between the roadway and the shared path such that they angle up to the path where the bicycles exit and angle down toward the roadway where the bicycles re-enter the roadway. Do not provide a perpendicular ramp between the two surfaces such that a bicyclist must stop, or nearly stop the forward motion to enter one facility or the other. All urban and suburban roundabout locations shall include bicycle ramps between the roadway and a shared use path.
10. Section 6.4.2 **Vehicle path overlap** and methods to avoid path overlap: Designing multi-lane roundabouts is significantly more complex than single-lane roundabouts. Factors include the additional conflicts present with multiple traffic streams entering, circulating and exiting the roundabout in adjacent lanes. The natural path of a vehicle is the path it will take based on the speed and orientation imposed by the roundabout geometry. While the fastest path assumes a vehicle will intentionally cut across the lane markings to maximize speed, the natural path assumes there are other vehicles present and all vehicles will attempt to stay within the proper lane.

Designers should determine the natural path by assuming the vehicles stay within their lane up to the yield point. At the yield point, the vehicle will maintain its natural trajectory into the circulatory roadway. The vehicle will then continue into the circulatory roadway and exit with no sudden changes in curvature or speed. If the roundabout geometry tends to lead vehicles into the wrong lane, this can result in operational or safety deficiencies.

Path overlap occurs when the natural paths of vehicles in adjacent lanes overlap or cross one another. It occurs most commonly at entries, where the geometry of the right-hand lane tends to lead vehicles into the left-hand circulatory lane. Figure 1 illustrates an example of path overlap at a multi-lane roundabout entry. Here the left lane geometry directs the approach vehicle into the central island. The right lane geometry also directs the approach vehicle toward the central island and into the adjacent lane, thus creating a condition to cause a crash.

Figure 1. Path Overlap

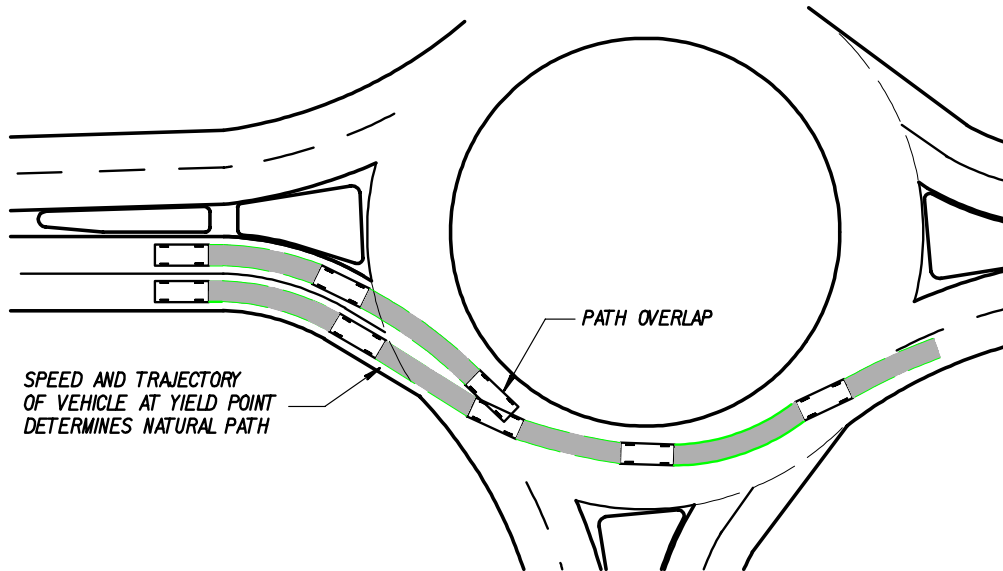
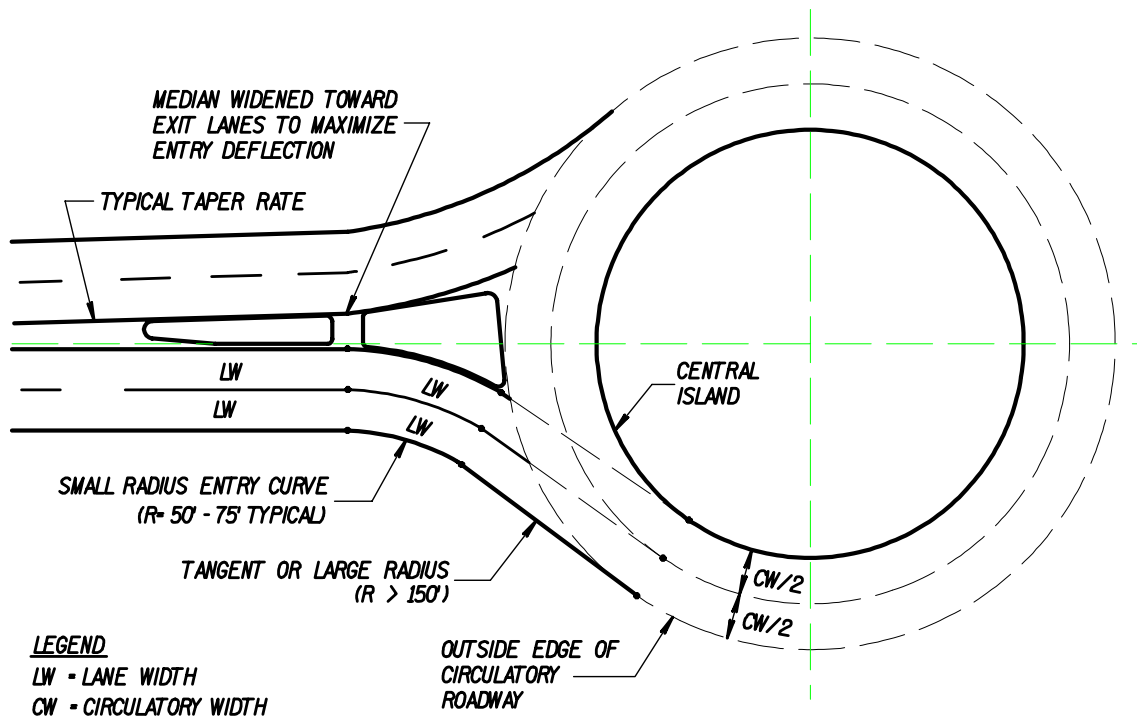


Figure 2 shows the preferred method to avoid path overlap. Start with an inner entry curve designed so when the edge of the splitter island curve is extended across the circulatory roadway the line is tangent to the central island as shown. Once the lane geometry is determined to avoid path overlap then design the adjacent lane(s). The small radius entry curve will vary depending on the approach geometry and the fastest speed path but will typically range from 50-100 feet. A tangent or large-radius (greater than 150 feet) curve is then fitted between the entry curve and the outside edge of the circulatory roadway.

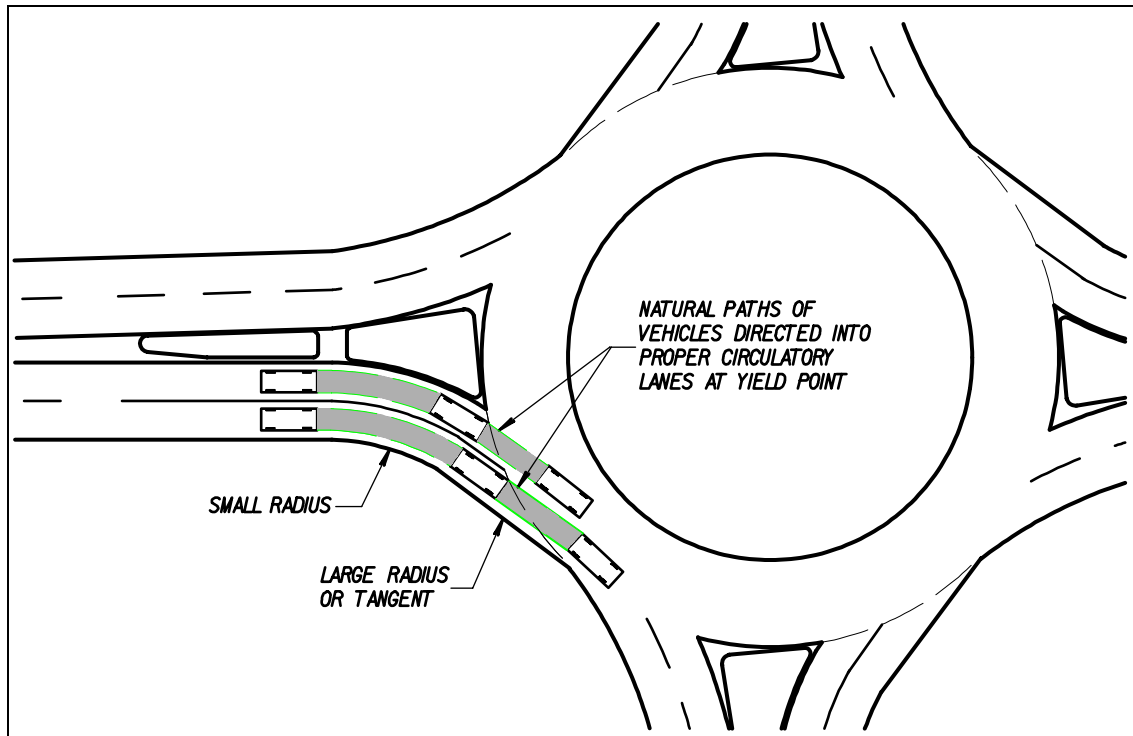
Figure 2. Design Techniques to Avoid Path Overlap



A second method is to start with a larger sweeping inner curve and provide a smaller radius curve near the approach that is tangent to the central island. This method is also described in the FHWA roundabout guide, Section 6.4.3.1.

The primary objective of this design technique is to locate the entry curve at the optimal placement so that the projection of the inside entry lane at the yield point forms a line tangent to the central island. This inner curve design concept is essential for multi-lane design and is recommended for single lane entries as well. Figure 3 illustrates the result of proper entry design.

**Figure 3. Multi-Lane Entry Design**



The location of the entry curve directly affects path overlap. If it is located too close to the circulatory roadway, it can result in path overlap. However, if it is located too far away from the circulatory roadway, it can result in inadequate deflection (i.e. entry speeds too fast).

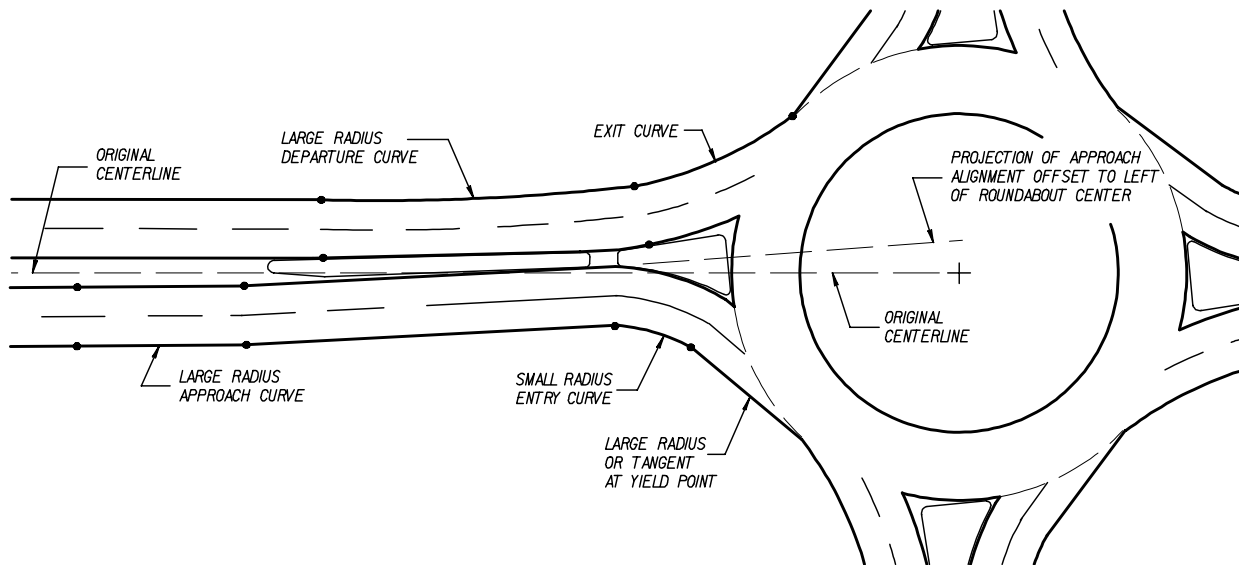
#### Design Techniques to Increase Entry Deflection.

Designing multi-lane roundabouts without path overlap while achieving adequate deflection to control entry speeds can be difficult. The same measures that improve path overlap issues generally result in increased fastest path speeds. One technique for reducing the entry speed without creating path overlap is to increase the inscribed circle diameter of the roundabout. Often the inscribed circle of a double lane roundabout must be 175-200 feet in diameter, or more, to achieve a satisfactory entry design. However, increasing the diameter will result in slightly faster circulatory speeds. Therefore, the designer is challenged to balance the entry speeds and circulatory speeds. This often requires many iterations of design, speed checks, and path overlap checks.

Approach Offset to Increase Entry Deflection,

The technique of offsetting the approach alignment left of the roundabout center is effective at increasing entry deflection (see Figure 4). However, it also reduces the deflection of the exit on the same leg. The geometry should maintain a level of deflection at exits to keep speeds relatively low within the pedestrian crosswalk location. Therefore, the distance of the approach offset from the roundabout center should generally be kept to a minimum to maximize safety for pedestrians. Always remember that the fastest speed paths are a critical element of design. Another effective method may be to increase the inscribed diameter or perhaps, on rare occasions, move the centerline to the right of the normal centerline.

**Figure 4. Approach Offset**



11. Section 6.5.2 **Curbing**: Curbs are required at rural roundabouts also. It is important to modify the rural cross section by introducing a vertical curb/gutter as the highway approaches the roundabout. Vertical curbs are necessary in the rural roundabout area to control the fastest speed path. Reduce the shoulder width by tapering a vertical curb and gutter toward the travel lane using a shifting taper (refer to [Procedure 11-25-1, Figure 2](#) for shifting taper design). The curb/gutter taper should reach the travel lane width approximately 300 feet in advance of the yield point. Consider drainage in the area of the curb/gutter by providing a flume or inlet structure.

**Roundabout Design Criteria**

The critical design parameters in Table 2 must be provided to the reviewer at the 30% level of design completion. Revised values must be included in the Design Study Report at the 60% project complete effort.

**Table 2. Critical Design Parameters**

Intersection	Leg 1	Leg 2	Leg 3	Leg 4	Leg 5	Leg 6
Half width, ft, (V=)						
Entry width, ft, (E=)						
Effective Flare, ft, (L'=)						
Entry Radius, ft, (R=)						
Entry Angle ( $\varnothing$ =)						
R1, Radius/speed						
R2, Radius/speed						
R3, Radius/speed						
R4, Radius/speed						
R5, Radius/speed						
Inscribed Circle Dia., ft, =						

- Design Vehicle: \_\_\_\_\_
- Circulating Roadway Width: \_\_\_\_\_
- Truck Apron Width, if present: \_\_\_\_\_
- Stopping Sight Distance: \_\_\_\_\_
- Intersection Sight Distance: \_\_\_\_\_
- Circulating Roadway Cross Slope (Typical section)
- Control of Access & Parking near the roundabout: \_\_\_\_\_
- Pedestrian/Bicyclist Accommodations: \_\_\_\_\_

Remove any reverse curvature between the entrance and exit radii and join the radii with straight curb sections. The entry width of a single lane entry will be dictated by truck movement needs. Slow entry speed control is dictated by the relationship of R1 and R2. This speed control is necessary to preserve pedestrian safety at both the entrances and exits. It may be desirable for operational and capacity reasons to provide a dual lane entry when the width must be 16 feet, and consider increasing each entry lane to 11-foot width at the widest point.

**Operation**

An operational analysis produces two kinds of estimates: (1) the capacity of a facility, i.e., the ability of the facility to accommodate various streams of users, and (2) the level of performance, often measured in terms of one or more measures of effectiveness, such as delay and queues.

The Highway Capacity Manual (**HCM**) defines the capacity of a facility as "the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions." While capacity is a specific measure that can be defined and estimated, level of service (**LOS**) is a qualitative measure that "characterizes operational conditions within a traffic stream and their perception by motorists and passengers." Delay is the measure of effectiveness that is used to define level of service at intersections, as perceived by users. While an operational analysis can be used to evaluate the performance of an existing roundabout during a base or future year, its more common function may be to evaluate new roundabout designs.

Use the RODEL software model to calculate delay. RODEL is based on the premise that certain geometric features contribute to roundabout performance. Further information on RODEL is contained in *RODEL 1 Interactive Roundabout Design*.

The FHWA Roundabout Guide covers the manual method of calculating roundabout performance.

### Traffic Operation at Roundabouts

#### Driver Behavior and Geometric Elements:

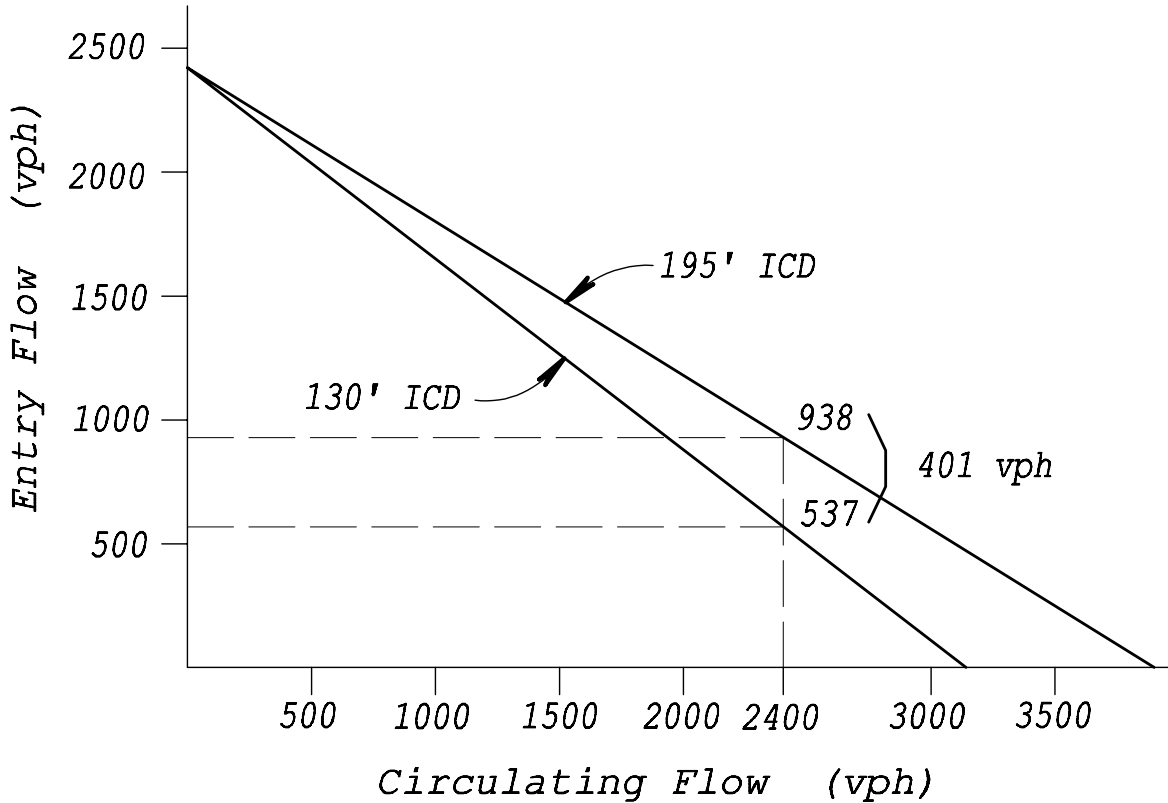
A roundabout brings together conflicting traffic streams, allows the streams to safely merge and traverse the roundabout and diverge to their desired directions. The geometric elements of the roundabout provide guidance to drivers approaching, entering, and traveling through a roundabout.

Drivers approaching a roundabout must slow to a speed that will allow them to safely interact with other users of the roundabout and to negotiate the roundabout. The width of the approach roadway, the curvature of the roadway, and the volume of traffic present on the approach govern this speed. As drivers approach the yield point, they must check for conflicting vehicles already on the circulatory roadway and determine when it is safe and prudent to enter the circulating stream. The widths of the approach roadway and entry determine the number of vehicle streams that may form side-by-side at the yield point and govern the rate at which vehicles may enter the circulating roadway. The size of the inscribed circle affects the radius of the driver's path, which in turn determines the speed at which drivers travel on the roundabout. The width of the circulatory roadway determines the number of vehicles that may travel side-by-side on the roundabout.

RODEL is based on empirical relationships that directly relate capacity to both traffic characteristics and roundabout geometry. The empirical relationships reveal that small changes in the geometric parameters produce significant changes in capacity. For instance, if the approach is flared, additional short lanes may be provided. The use of a flare from one lane to two lanes can nearly double the approach capacity, without requiring a two-lane roadway prior to the roundabout. A flared entrance is designed to have equal width and taper and there is no long or short lane. Wider entries require wider circulatory roadway widths. This provides for more opportunities for the circulatory traffic to bunch together, thus increasing the number of acceptable opportunities for vehicles to enter the roundabout. The number of vehicles entering into an acceptable gap in the circulating traffic is quite small. Because drivers frequently use short lanes to reduce the queue length, short lanes can be very effective in increasing vehicle group sizes and the resultant increase in roundabout capacity.

British research indicates that approach width, entry width, effective flare length, and entry angle have the most significant effect on entry capacity. When circulating flows are high, increasing the inscribed circle diameter (**ICD**) will substantially increase capacity also. [Figure 5](#) shows that the capacity on one leg of the roundabout is increased by 401 vehicles per hour when the ICD is increased from 130 ft to 195 ft. This increased capacity can happen on more than one leg.

Figure 5 Capacity vs. Inscribed Circle Diameter



The entry radius has little effect on capacity provided that it is 65 feet or more. Using an entry radius significantly lower than 45 ft reduces capacity with increasing severity. A small entry radius tends to produce large entry angles and the converse is also true. The use of perpendicular entries (70 degrees or more) and small entry radii (less than 50 feet) will reduce capacity. The RODEL model allows designers to perform sensitivity analyses by manipulating geometric design elements to determine both the operational and safety effects of these elements on their designs. Thus, the geometric elements of a roundabout, together with the volume of traffic desiring to use a roundabout at a given time, determine the efficiency of roundabout operation.

Roundabout Capacity:

The capacity of each entry to a roundabout is the maximum rate at which vehicles can reasonably be expected to enter the roundabout from an approach during a given time period under prevailing traffic and roadway (geometric) conditions. An operational analysis considers a precise set of geometric conditions and traffic flow rates defined for the design hour volume (DHV) for each roundabout entry. Analysis of the peak hour time period is critical to assess the level of performance of the roundabout and its individual components. The capacity of the entire roundabout is not considered, as it depends on many factors. The focus in this section is on the roundabout entry. It is similar to the operational analysis methods used for other forms of intersections. In each case, the capacity of the entry or approach is computed as a function of traffic on the other (conflicting) approaches, the interaction of these traffic streams, and the intersection geometry.

For a properly designed roundabout, the yield point is the relevant point for capacity analysis. The approach capacity is the capacity provided at the yield point. This is

determined by a number of geometric parameters in addition to the entry width. On multilane roundabouts it is important to balance the traffic use of each lane, otherwise some lanes may be overloaded while others are under used. Also, poorly designed exits may influence driver behavior and cause lane imbalance and congestion at the opposite leg.

### **Data Requirements**

The analysis method described in this section requires the specification of traffic volumes for each approach to the roundabout, including the flow rate for each directional movement. Volumes are typically expressed in passenger cars per hour (pcph), for the specified peak-hour analysis period. To account for trucks, set RODEL to Vehicle (VEH) for FLOWTYPE and the input under the Passenger Car Unit (PCU) heading to (1+ % trucks). Example: A 12% truck condition would have 1.12 entered for the PCU value.

Traffic volume data for roundabouts is needed for each directional movement for at least the morning and evening peak periods, because the various movements, and thus approach and circulating volumes, may peak at different times. Typically, intersection volume counts are made at the intersection stop bar, with an observer noting the number of cars that pass that point over a specified time period. However, when demand exceeds capacity (i.e., when queues do not dissipate within the analysis period), the stop bar counts reflect only the volume that is served, not the demand volume. In this case, collect data upstream of the end of a queue so that true demand volumes are available for analysis.

The relationship between the standard origin-to-destination turning movements at an intersection and the circulating and entry flows at a roundabout is important, yet is often complicated to compute, particularly if an intersection has more than four approaches. RODEL takes the standard origin-to-destination turning movements and converts them to entering and circulating flows. For existing roundabouts, data collection can be troublesome. It is recommended that the site be videotaped during peak-hour operations and typical directional turning movements be carefully observed and recorded based on the video recording.

### **Capacity**

The maximum flow rate that can be accommodated at a roundabout entry depends on two factors: the circulating flow on the roundabout that conflicts with the entry flow, and the geometric elements of the roundabout.

When the circulating flow is low, drivers at the entry are able to enter the roundabout without significant delay. The larger gaps in the circulating flow are more useful to the entering drivers and more than one vehicle may enter each gap. As the circulating flow increases, the size of the gaps in the circulating flow decreases, and the rate at which vehicles can enter also decreases.

The geometric elements of the roundabout also affect the rate of entry flow. The most important geometric element is the width of the entry and circulatory roadways, or the number of lanes at the entry and on the roundabout. Two entry lanes permit nearly twice the rate of entry flow as does one lane. Wider circulatory roadways allow vehicles to travel alongside, or follow, each other in tighter bunches and so provide longer gaps between bunches of vehicles. The effective flare length can also substantially affect capacity. The inscribed circle diameter and the entry angle have minor effects on capacity.

### Single-lane Roundabout Capacity:

Roundabout capacity is site specific since it is related to the geometric features of each site. For planning purposes, single-lane roundabouts can be expected to handle an AADT of approximately 25,000 veh/day and peak-hour flows between 2,000 vph and 2,500 vph. This rate exceeds 1,900 vph, which is the typical single-lane capacity of a signalized intersection (reported in passenger car equivalents per hour of green time per lane; 2000 *Highway Capacity Manual*, Chapter 16). This rate can be achieved for several reasons. First, this is the total of all the approaches, not a single approach. Second, because of separated approaches and right turns, much of the traffic does not conflict. Exit flows exceeding 1,200 vph may indicate the need for a double-lane exit. Sites with AADTs or DHV approaching these limits must be evaluated carefully to ensure desired and optimal performance.

### Multilane Roundabout Capacity

For planning purposes, multilane roundabouts can be expected to handle AADT between 40,000 and 55,000 vpd and peak-hour flows between 4,000 vph and 5,500 vph. The expected capacity can be even higher with the use of by-pass lanes.

### Pedestrian Effects on Entry Capacity

Pedestrians crossing at a marked crosswalk that have priority over entering motor vehicles can have a significant effect on the entry capacity. In such cases, if the pedestrian crossing volume and circulating volume are known, multiply the vehicular capacity by a factor M according to the relationship shown in Exhibit 4-7 or 4-8 of the [FHWA Roundabout Guide](#) for single-lane and double-lane roundabouts, respectively. Note that the effects of conflicting pedestrians on the approach capacity decrease as conflicting vehicular volumes increase, as entering vehicles become more likely to have to stop regardless of whether pedestrians are present. Consult the Highway Capacity Manual for additional guidance on the capacity of pedestrian crossings if the capacity of the crosswalk itself is an issue.

Enter the reduction factor, M, into RODEL under the Capacity Factor (CAPF) input field. If Flow Factor (FLOF) is the present option, press F4 to change it to CAPF.

### Exit Capacity

It is difficult to achieve an exit flow on a single lane of more than 1,400 vph, even under good operating conditions for vehicles (i.e., tangential alignment, and no pedestrians and bicyclists). Under normal urban conditions and LOS, the exit lane capacity is in the range of 1,200 vph to 1,300 vph. Therefore, exit flows exceeding 1,200 vph may indicate a lower LOS or the need for a multilane exit.

## **Performance Analysis**

Two measures are typically used to estimate the performance of a given roundabout design: delay, and queue length. Each measure provides a unique perspective on the quality of service of a roundabout under a given set of traffic and geometric conditions.

### Delay

Delay is a standard parameter used to measure the performance of an intersection. The Highway Capacity Manual identifies delay as the primary measure of effectiveness for both signalized and un-signalized intersections, with level of service determined from the

delay estimate. RODEL determines the average and maximum delay in seconds for each approach at a roundabout, as well as the roundabout's overall average delay in seconds. This overall average delay is used in determining the roundabout's level of service.

### Queue Length

Queue length is important when assessing the adequacy of the geometric design of the roundabout approaches. RODEL calculates an average and maximum queue for each approach, in vehicles. The approach roadway should have adequate storage capacity so that the queue does not obstruct driveway access or another intersection. Depending on location, a queue of 10 vehicles may be unacceptable at one site while a queue of 50 vehicles at another site may not present a problem. The RODEL queue length is the mean of the random queue length distribution. The random 95% queue is about two times the RODEL queues. If the roundabout is operating well with RODEL set at the 85% capacity confidence level, then the 50% queue lengths will be small.

### Capacity Analysis

The two performance measures, delay and queue length, need to be checked at two different confidence levels with RODEL. Do a RODEL analysis at both the 50% and 85% confidence levels (**CL**)<sup>2</sup>. The 50% CL analysis represents real expectations of the modern roundabout's performance and provides for an equal comparison to other intersection types because a 50% CL is built into other software programs used to evaluate other types of intersections. The 85% confidence level analysis is a sensitivity check for excessive delay on any of the approaches when there are minor changes in traffic flow and capacity. A sharp rise in delay on any approach leg indicates that design of that entry is approaching a high v/c ratio. This provides information to the designer to check if a modest geometric layout refinement will provide a lower v/c ratio and consequently prolong the life of the intersection by avoiding failure of that leg.

In short, a design with an acceptable level of service at 85% confidence level is desired, but not required. Use engineering judgment to determine if a design resulting in an unacceptable level of service at the 85% confidence level is still the best alternative at the specific location. Regardless of the level of service reported using an 85% confidence level, use the results from RODEL at the 50% CL when doing a comparison with other intersection alternatives. ★

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<sup>2</sup> RODEL CL can be set to various levels.