

Disclaimer: This website and documents are provided for use by persons outside of the Kansas Department of Transportation as information only. The Kansas Department of Transportation, the State of Kansas, nor its officers or employees, by making this website and documents available for use by persons outside of KDOT, does not undertake any duties or responsibilities of any such person or entity who chooses to use this website and documents. This website and documents should not be substituted for the exercise of a person's own professional judgment nor the determination by contractors of the appropriate manner and method of construction on projects under their control. It is the user's obligation to make sure that he/she uses the appropriate practices. Any person using this website and documents agrees that KDOT will not be liable for any commercial loss; inconvenience; loss of use, time, data, goodwill, revenues, profits, or savings; or any other special, incidental, indirect, or consequential damages in any way related to or arising from use of this website and documents.

Chapter 4 - Operations

4.1 Operational Analysis Tools	46
FHWA Analysis Procedure.....	47
Traffic Volumes	47
Single-lane Roundabout Capacity.....	47
Double-lane Roundabout Capacity	48
Capacity Effect of Short Lanes or Flared Entries	48
Pedestrian Effects on Entry Capacity.....	49
Queues.....	49
Delay	50
4.2 Operational Performance Measures	52

4.1 Operational Analysis Tools

An operational analysis is required for each proposed roundabout configuration to estimate the capacity and operational characteristics. The maximum flow rate that can be accommodated at a roundabout entry depends on two factors: the circulating flow in the roundabout that conflicts with the entry flow, and the geometric elements of the roundabout. The capacity is computed at each entry and compared with the demand traffic volume. **For design purposes, the maximum volume-to-capacity ratio (v/c ratio) threshold for a roundabout entry should be 0.85.** Higher degrees of saturation can lead to unstable operation in which high delays and lengthy queues may occur at the roundabout approach.

The operational methodology presented in Chapter 4 of the FHWA Roundabout Guide should be used as the initial method for evaluating a roundabout's capacity. The FHWA Roundabout Guide provides basic capacity models for urban compact roundabouts, typical single-lane roundabouts, and typical double-lane roundabouts. The only input to these models is the circulatory traffic volume. The resulting capacity forecasts were developed based on typical geometric parameters and simplified regression relationships from the British and German models. Capacity estimates may require adjustment to reflect the use of short lanes at flared entries and the level of pedestrian activity. In addition, delay and queue estimates should also be calculated based upon the procedures provided in section 4.4 of the FHWA Roundabout Guide.

For most applications where the degree of saturation is below 0.85, the FHWA procedures for determining operational characteristics are sufficient. However, as volumes approach capacity, control delay increases exponentially with small changes in volume, having large effects on delay. An accurate analysis under conditions near or over capacity should also consider such factors as the effect of residual queues and the metering effect of upstream oversaturated entries, which are not accounted for in the FHWA procedure.

For cases involving single lane roundabouts with volume-to-capacity ratios exceeding 0.70 and for all multilane roundabouts, use of a second analysis tool is recommended for comparison purposes and to provide a more detailed modeling. At this time, there are several acceptable methods for conducting performance analysis at roundabouts in addition to the FHWA procedure:

- aaSIDRA software package (Australia; gap acceptance);
- RODEL and ARCADY software packages (UK; empirical regression);
- Traffic simulation software packages.

These different methodologies generally yield similar results for roundabouts with moderate traffic volumes (moderate entry flows and/or moderate circulating flows). However, in cases with high entry flows opposed by low circulatory flow and vice versa, (i.e. highly directional/unbalanced flows), the models can yield significantly different results. Because there is little performance data on record for roundabouts in the United States, the worst-case capacity prediction should be chosen to produce a more conservative design.

FHWA Analysis Procedure

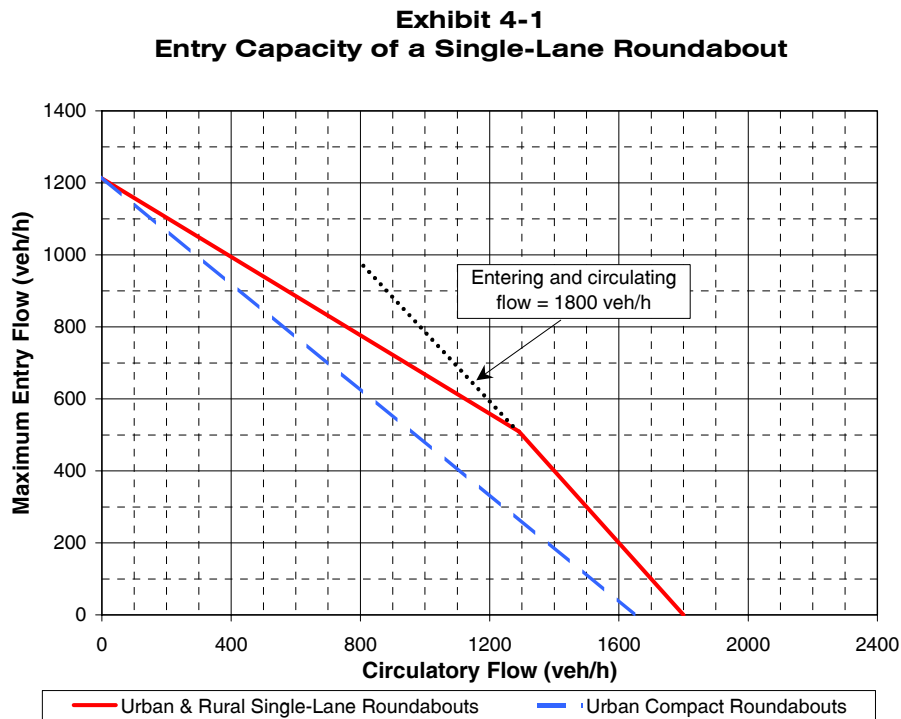
The FHWA Roundabout Guide provides basic capacity models for urban compact roundabouts, typical single-lane roundabouts, and typical double-lane roundabouts. For background discussion and more detailed information on this capacity model, please refer to the Chapter 4 of the FHWA Roundabout Guide.

Traffic Volumes

The analysis method requires the specification of traffic volumes for each approach to the roundabout, including the hourly flow rate for each directional movement. Hourly volumes must be converted to *passenger car equivalents* (pce), using the standard conversion factors and methodology from the *Highway Capacity Manual*. Intersection turning movement flows must then be converted to roundabout flows. This process will result in an *entry volume* and a *circulatory volume* at each entry to the roundabout. For more details on how to convert intersection turning movement volumes to roundabout flows, please refer to the Chapter 4 of the FHWA Roundabout Guide.

Single-lane Roundabout Capacity

Exhibit 4-1 shows the expected capacity of a single-lane roundabout for both the urban compact and typical single-lane designs.



The equations for entry capacity at single-lane roundabouts and urban compact roundabouts, respectively, are expressed below:

Single-lane Roundabouts: $Q_E = \text{Min}\{(1212 - 0.5447Q_C), (1800 - Q_C)\}$

Urban Compact Roundabouts: $Q_E = 1218 - 0.74Q_C$

where:

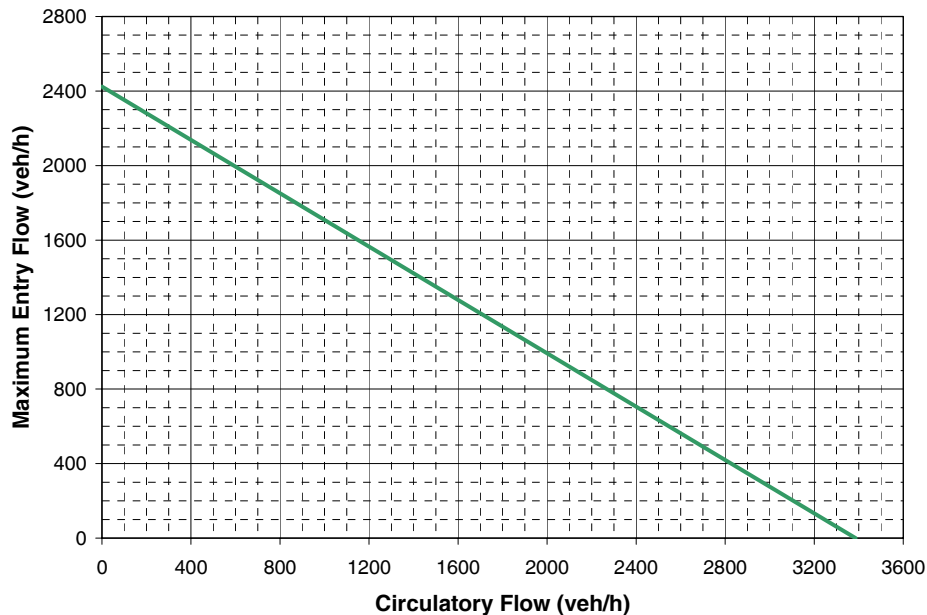
Q_E = entry capacity, pce/h

Q_C = circulating flow, pce/h

Double-lane Roundabout Capacity

Exhibit 4-2 shows the expected capacity of a typical double-lane roundabout.

Exhibit 4-2
Entry Capacity of a Double-Lane Roundabout



The equation for a double-lane roundabout entry is expressed below:

Double-lane Roundabouts: $Q_E = 2424 - 0.7159Q_C$

where: Q_E = entry capacity, pce/h
 Q_C = circulating flow, pce/h

Capacity Effect of Short Lanes or Flared Entries

In some cases, a single-lane approach may be widened (or *flared*) to two lanes at the roundabout entry to improve the performance. This additional entry lane is referred to as a short lane because it is typically only added for a short distance from the entrance line of the roundabout. The amount of additional capacity achieved depends on the length of the short lane.

The capacity of a flared approach is determined by first determining the capacity of a standard double-lane entry, and then applying a reduction factor based on the short lane length. Exhibit 4-3 displays the capacity reduction factors to be applied for various lengths of short lane. It can be assumed that each vehicle space is equivalent to 25 ft (7.5 m).

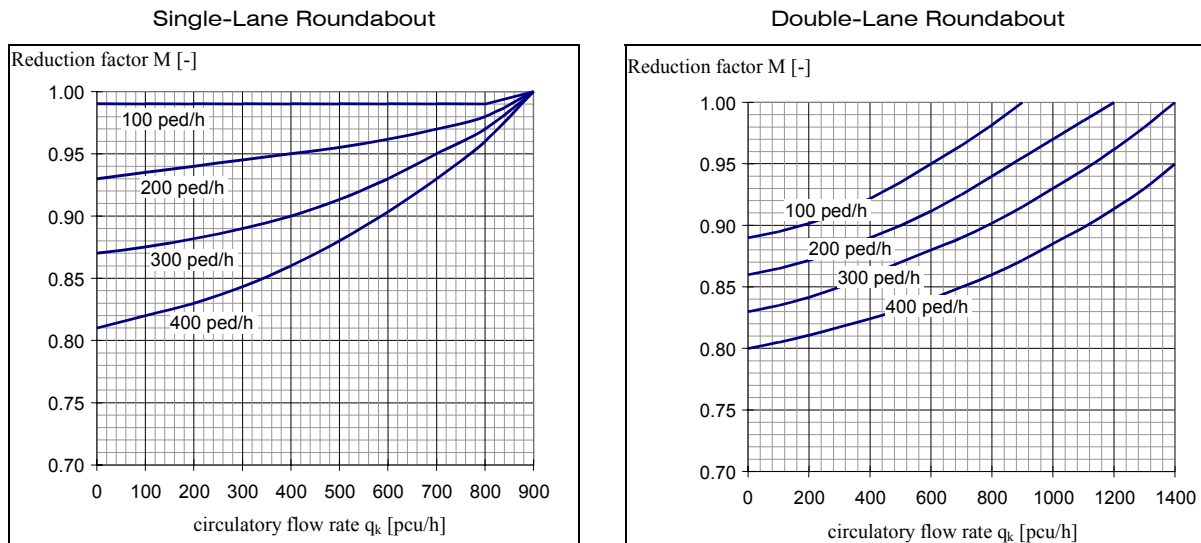
**Exhibit 4-3
 Capacity Reduction Factors for Short Lanes**

Number of vehicle spaces in the short lane, n_f	Factor (applied to double-lane approach capacity)
0	0.500
1	0.707
2	0.794
4	0.871
6	0.906
8	0.926
10	0.939

Pedestrian Effects on Entry Capacity

Pedestrians have priority over entering motor vehicles at all roundabout entries. At intersections with high volumes of pedestrians, the crossings can have a significant effect on entry capacity. In such cases, the vehicular capacity is reduced by the reduction factors (M) shown in Exhibit 4-4. Note that the pedestrian impedance decreases as the circulatory flow rate (in front of the subject approach) increases.

**Exhibit 4-4
 Capacity Reduction Factors Due to Pedestrians**

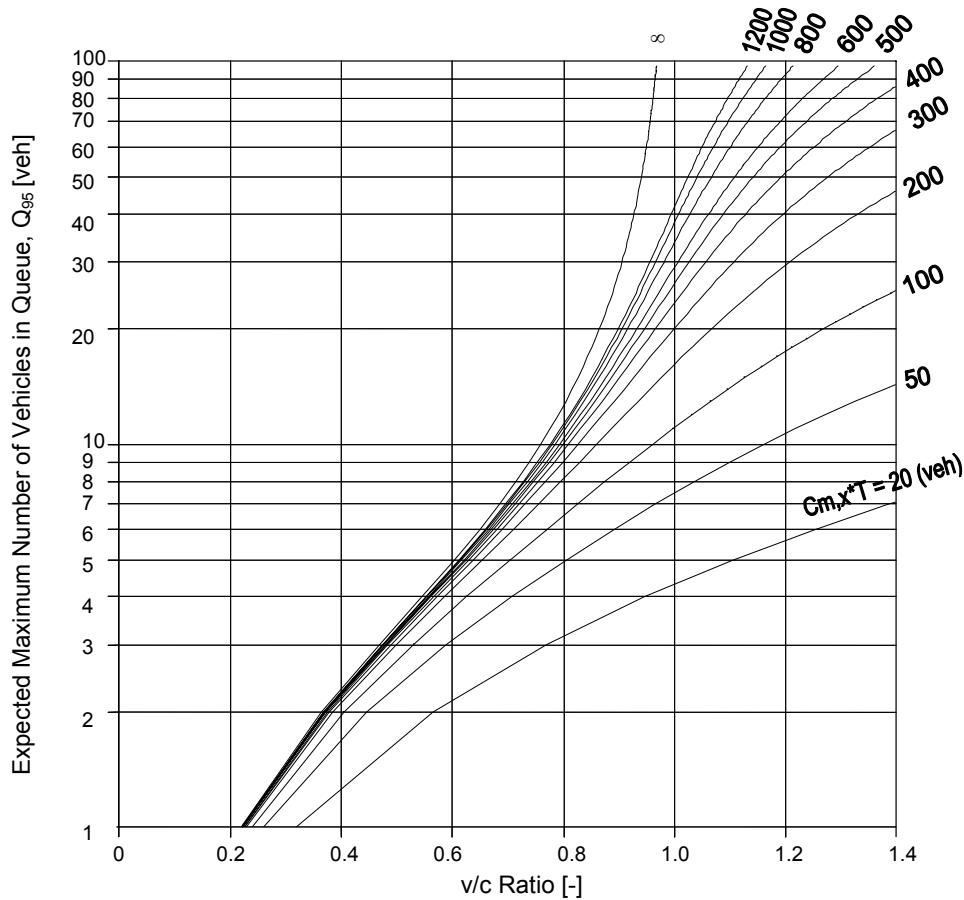


Queues

For design purposes, Figure 4-5 shows how the 95th-percentile queue length varies with the volume-to-capacity ratio of an approach. Individual lines are shown for the product of T and entry capacity. To determine the 95th-percentile queue length during time T , enter the graph at the computed volume-to-capacity ratio. Move vertically until the computed curve line is reached. Then move horizontally to the left to determine the 95th-percentile queue length.

In most cases, T should be 0.25 hours to represent the analysis of the peak 15-minute period. If the analysis has been conducted for the peak 1-hour condition, then T should be 1.0.

**Exhibit 4-5
95th-Percentile Queue Length Estimation**



Delay

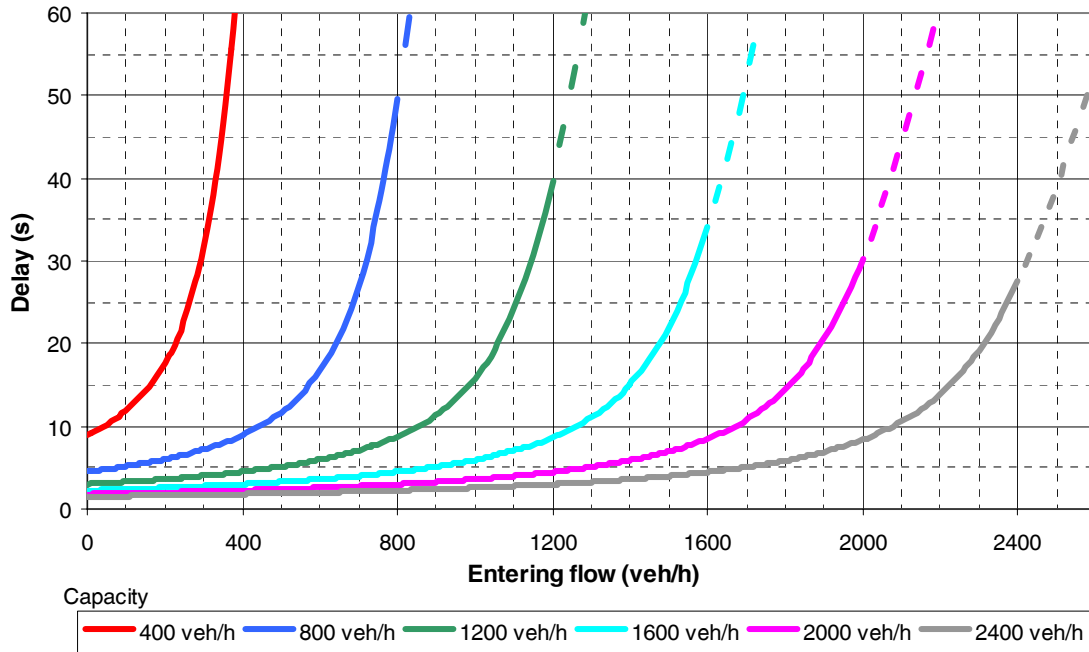
The FHWA procedure cites the use of the Highway Capacity Manual (HCM) delay equation for calculation of delay at roundabouts. Currently, the HCM only includes control delay, the delay attributable to the control device. Geometric delay is the second component of delay, which is the delay experienced by a single vehicle with no conflicting flows due to geometric features encountered when negotiating the intersection. This delay is computed using the following formula:

$$d = \frac{3600}{C_{m,x}} + 900T \times \left[\frac{v_x}{C_{m,x}} - 1 + \sqrt{\left(\frac{v_x}{C_{m,x}} - 1\right)^2 + \frac{\left(\frac{3600}{C_{m,x}}\right)\left(\frac{v_x}{C_{m,x}}\right)}{450T}} \right]$$

- where: d = average control delay, sec/veh;
- v_x = flow rate for movement x , veh/h;
- $c_{m,x}$ = capacity of movement x , veh/h; and
- T = analysis time period, h ($T = 0.25$ for a 15-minute period)

Exhibit 4-6 shows how control delay at an entry varies with entry capacity and circulating flow.

Exhibit 4-6
Control Delay as a Function of Capacity and Entering Flow



4.2 Operational Performance Measures

Three key performance measures should be determined for use in assessing the operating performance for a particular roundabout design:

- Degree of Saturation
- Delay
- Queue Length

Degree of saturation is the ratio of the demand at the roundabout entry to the capacity of the entry. The resulting ratio is typically referred to as the volume-to-capacity ratio (v/c ratio) and provides a direct assessment of the sufficiency of a given design. *For design purposes, the maximum volume-to-capacity ratio should be 0.85 for satisfactory operation.*

Delay is a standard parameter used to measure the performance of an intersection. There are two general components of the total delay at a roundabout: the control delay and the geometric delay. The control delay is the delay attributable to the control device, while the geometric delay is the delay experienced by a single vehicle with no conflicting flows due to geometric features encountered when negotiating the intersection. Calculation of geometric delay requires additional data such as the proportion of vehicles that must stop at the entrance line, as well as knowledge of the roundabout geometry as it affects vehicle speed. *Typically, the control delay is the standard measure used to represent the delay component of a roundabout performance, as it is the same measure used to represent the delay for other types of intersections.* For the FHWA Roundabout Guide procedure, the Highway Capacity Manual delay formula is used, which currently only considers the control delay.

Queue length is important in assessing the adequacy of the geometric design of the roundabout approaches. For design purposes, the 95th-percentile queue length is determined to estimate the maximum resulting queue for a given approach.

For each proposed roundabout, these three performance measures shall be determined for each approach (intersection leg) and summarized in a tabular format such as the example shown in Exhibit 4-7.

**Exhibit 4-7
 Example Operational Analysis Summary Table**

Intersection Parameter	Analysis Method	2020 Weekday AM Peak Hour				2020 Weekday PM Peak Hour			
		NB	WB	SB	EB	NB	WB	SB	EB
Number of entry/exit lanes	-	# / #	# / #	# / #	# / #	# / #	# / #	# / #	# / #
Volume-to-Capacity Ratio (v/c)	FHWA								
	(fill in) ¹								
Average Delay (sec/veh)	FHWA								
	(fill in) ¹								
95th Percentile Queue per Lane (# of Vehicles)	FHWA								
	(fill in) ¹								

¹If Applicable

Where two or more roundabout configuration options are being considered simultaneously, it may be helpful to compare the two designs in a simplified format. Exhibit 4-8 shows a sample table that may be used to compare two designs based upon the critical roundabout approach (approach with the worst operating parameters).

**Exhibit 4-8
 Example Option Comparison Table**

Intersection Parameter	Option 1		Option 2	
	AM Peak Hour	PM Peak Hour	AM Peak Hour	PM Peak Hour
Critical Approach				
Volume-to-Capacity Ratio (v/c)				
Average Delay (sec)				
95th %tile Queue per Lane	Number of Vehicles			
	Length (ft)			