Interrupted Flow

1. Modern Roundabouts

The capacity of modern roundabouts is principally a function of the availability of entering vehicles to accept gaps in the conflicting circulating traffic stream. Because roundabouts (typically) do not have traffic signals installed, the capacity emerges from the geometric characteristics of the roundabout itself, and the behavioural characteristics of the drivers. In fact, two different schools of thought exist for how roundabout capacity is derived.

One approach to roundabout capacity is to emphasize the effects of geometrics, which is the underlying principle of the British roundabout methodology that has since been adopted by several other countries. In this approach, roundabout entry capacity is described through a regression equation as a function of entry number of lanes and width, circulating lane and width, as well as specific geometric attributes that include flare angles and curvature. This approach is largely independent of driver behavioral characteristics, and as such readily allows the comparison of different geometries. However, it does not take into account the human factors element, and assumes that all drivers behave consistently given a certain roundabout geometry, regardless of their familiarity with the site or level of assertiveness.

The second approach is one anchored in empirical observations of driver behaviour and based on gap acceptance theory . It uses the concepts of critical gap and follow-up headway, which are then used to estimate the capacity. Geometric effects of roundabout geometry (e.g., number of lanes) are not explicitly used in the capacity model, but rather implicitly through their effect on the gap acceptance attributes. The behavioural roundabout capacity was probably first developed in Australia, and has since also been used in the United States and various other countries.

Regardless of the underlying methodology and theory, the roundabout capacity will be sensitive to geometry (at least number of lanes), as well as the conflicting flow rates on the circulating lanes. This last point is critical, as it means that the roundabout entry capacity at a given approach is not fixed over the course of the day, but rather varies as a function of traffic volumes. During off-peak periods with low circulating flows, gaps in that conflicting flow are frequent and large, which results in high entering capacities. During peak periods, however, circulating traffic may increase, which reduces gap availability and thereby capacity. This principle of decreasing entry capacity with increasing circulating flow is common for all roundabout models, both geometry-based and behavioral. One example of the behaviour of these models is presented in Figure below for the HCM roundabout procedure.

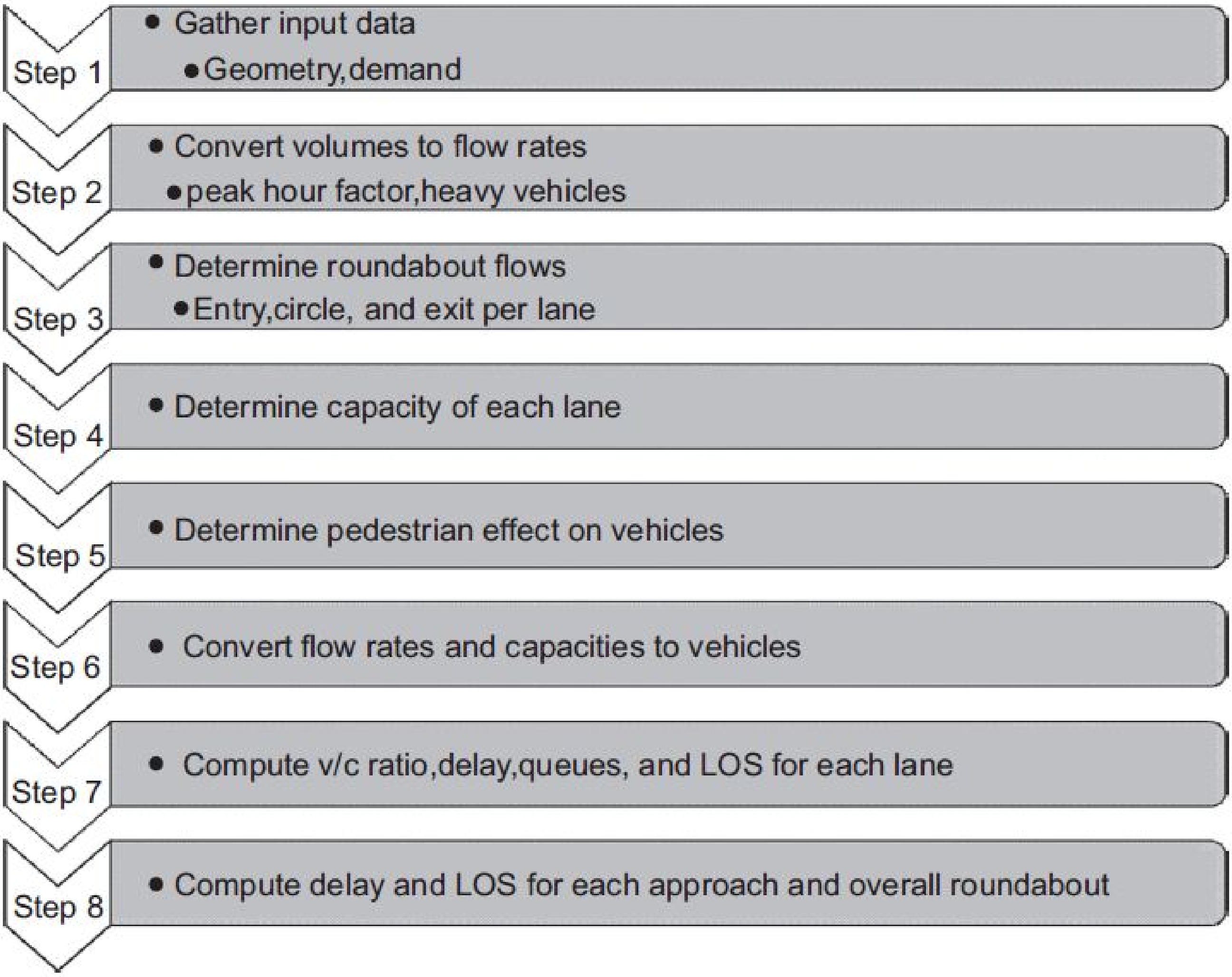

Figure: Methodology steps for roundabout procedure.

1.1 Methodology

The HCM roundabout procedure is illustrated in Figure below, where it is summarized in eight steps. All steps are described in detail in the following sections.

Step 1: Gather Input Data

As with all operations procedures, the first step is to gather input data. For the roundabout procedure this involves geometric data (mostly number of lanes on all approaches and in the circle) and traffic volume data.

The latter are principally the turning movement counts (left, through, right) for all approaches, the heavy vehicle percentage, and global parameters such as the peak hour factor.

Step 2: Convert Volumes to Flow Rates

In the second step, the volumes (in units of vehicles per hour) are converted to 15-min flow rates in units of passenger cars per hour. To do this, the volumes are adjusted for peak hour factor and heavy vehicle percentage, as shown in Eqs. below.

$$v_{i,PCE} = \frac{V_i}{PHF \times f_{HV}}$$

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)}$$

where:
$v_{\mathrm{i,PCE}}$ =demand flow rate for movement i (passenger cars/h).
V_{i}=demand volume for movement i (veh/h).
PHF=peak hour factor.
f_{HV} =heavy-vehicle adjustment factor.
P_{T}=proportion of demand volume that consists of heavy vehicles.
E_{T}=passenger car equivalent for heavy vehicles, which is 2.0 for roundabouts.

Step 3: Determine Roundabout Flows

As a third step, the turning movement flow rates (left, through, right) are used to estimate the circulating and exiting flow rates at the various roundabout approaches. For example, to estimate the capacity of the south (northbound) roundabout entry in Figure below, the conflicting circulating flow, $v_{\mathrm{C,NB}}$ is the sum of several flows (black arrows), including:

- The through, left-turn, and U-turn movement from the west approach.
- The left turn and U-turn from the north approach.
- The U-turn from the east approach Similarly, the exiting flows at the south approach is the sum of three flows (gray arrows):
- The right-turn movement from the west approach.
- The through movement from the north approach.
- The left from the east approach.
- The U-turn from the south approach.

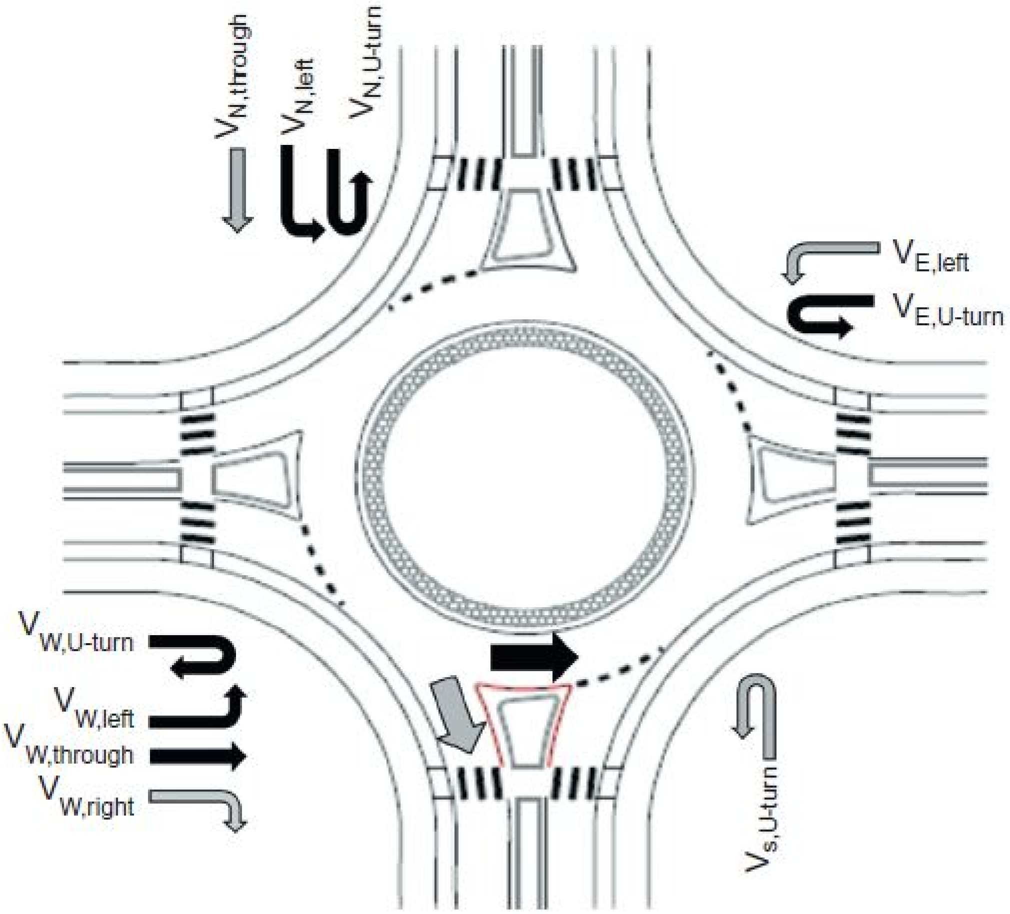

Figure: Illustration of roundabout flows.

For multilane roundabouts, one additional step is needed to distribute the total approach volume across the two lanes. This is a function of the lane assignment (striping of roundabout entry), and the relative turning movement flow rates. The HCM distinguishes five cases, summarized in Table below. The volumes are for each respective approach.

For approaches with multiple left or right-turn lanes, additional guidance for estimating the percentage of traffic in the left lane (%LL) and right lane (%RL) is found in the HCM or can be estimated based on analyst judgment.

Table: Lane utilization for multilane roundabouts.

Case	Assumed lane assignment	Left lane	Right lane
1	L, TR	$\nu_U + \nu_L$	$\nu_T + \nu_R$
2	LT, R	$\nu_U + \nu_L + \nu_T$	ν_R
3	LT, TR	$(\%LL)\nu_e$	$(\%RL)\nu_e$
4	L, LTR	$(\%LL)\nu_e$	$(\%RL)\nu_e$
5	LTR, R	$(\%LL)\nu_e$	$(\%RL)\nu_e$

Step 4: Determine Capacity of Each Lane

The capacity of each roundabout entry is then determined as a function of the conflicting circulating flow using Eq. below. The equation uses an intercept term, a, and a slope parameter, b, which are shown in Table below for five different cases:

$$c_{entering} = a \times e^{-b \times v_{circulating}}$$

1. Single entry lane with single circulating lane (131)
2. Single entry lane with two circulating lanes (132)
3. Two entry lanes with single circulating lane (231)
4. Two entry lanes with two circulating lanes - right lane (232)
5. Two entry lanes with two circulating lanes - left lane (232)

For the last geometry, the table shows different terms for the right and left entering lanes. For roundabouts with right-turn bypass lanes that are under yield control, the one-lane entry equations are used depending on whether the bypass lane has one or two conflicting lanes (131 and 132 models, respectively). Two-lane bypass lanes are uncommon at roundabouts. Bypass lanes with continuous lane adds are assumed to be free-flowing.

The five capacity equations are illustrated graphically in Figure below:

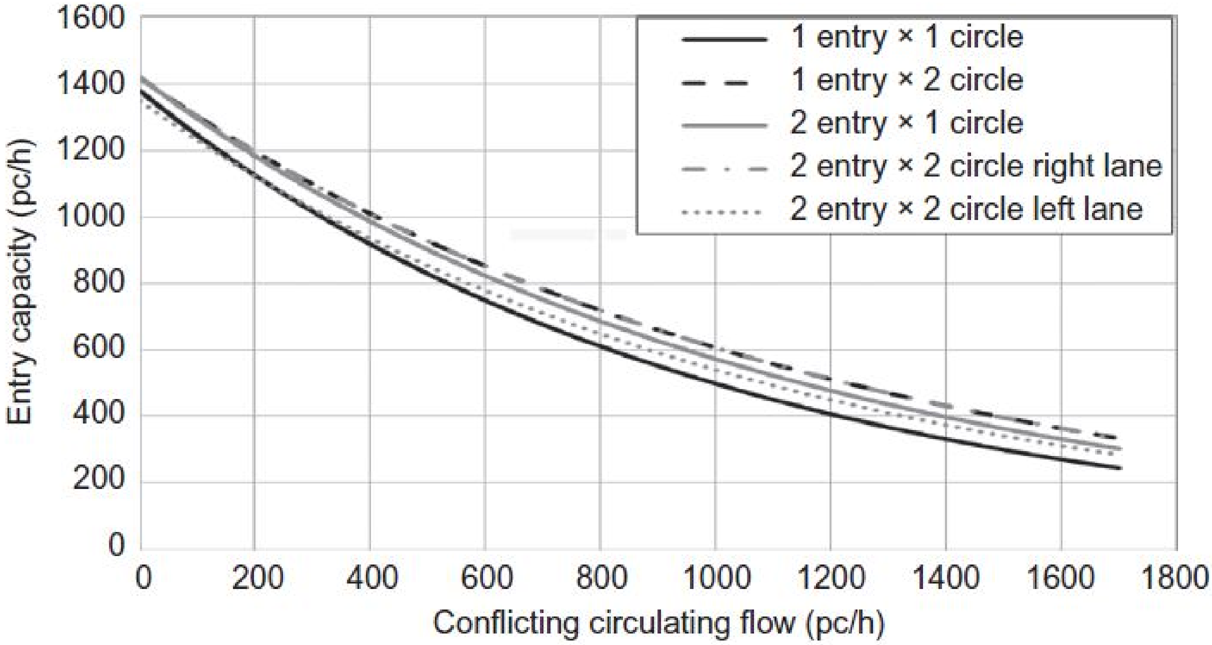

Figure: Plot of roundabout capacity models.

Step 5: Determine Pedestrian Effect on Vehicles

The entering capacity is next adjusted for the presence of pedestrians. Research undertaken in Germany found that as drivers yield to pedestrians at roundabouts, the entering capacity is reduced by a reduction factor, f_{ped}. This effect is strongest at low conflicting circulating flow rates, which would otherwise have high entry capacities. As the circulating vehicle flow increases, entering vehicles are more likely to be delayed or queued at the entry already, thereby offsetting the added effect from pedestrians. The pedestrian effect increases further with increasing pedestrian volumes.

Figures below show the pedestrian effect on roundabout entry capacity for single-lane and two-lane entries, respectively. One important caveat in the application of these charts is that the research was done in Germany, where the yield compliance is generally very high (close to 100%). As a result, the net effect in a location where yielding is lower (say 50%) is expected to also be less (assume half the base effect).

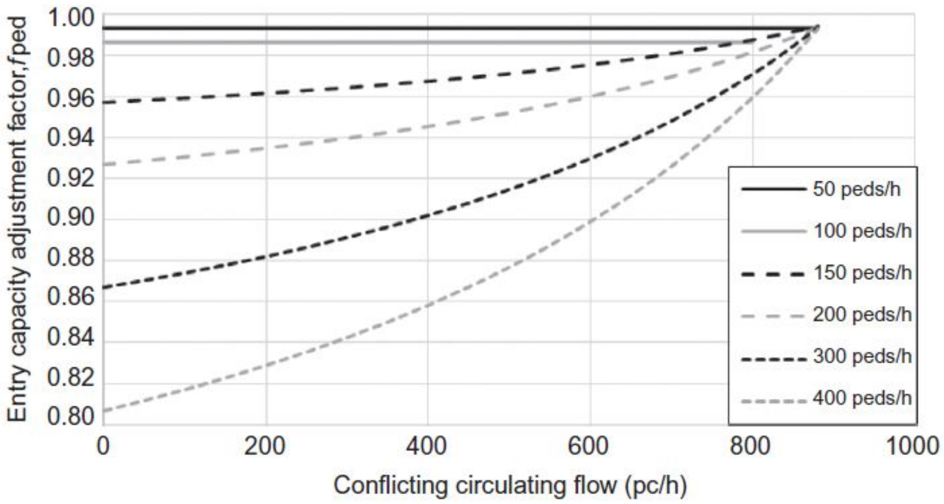

Figure: Pedestrian effect on roundabout single-lane entry capacity.

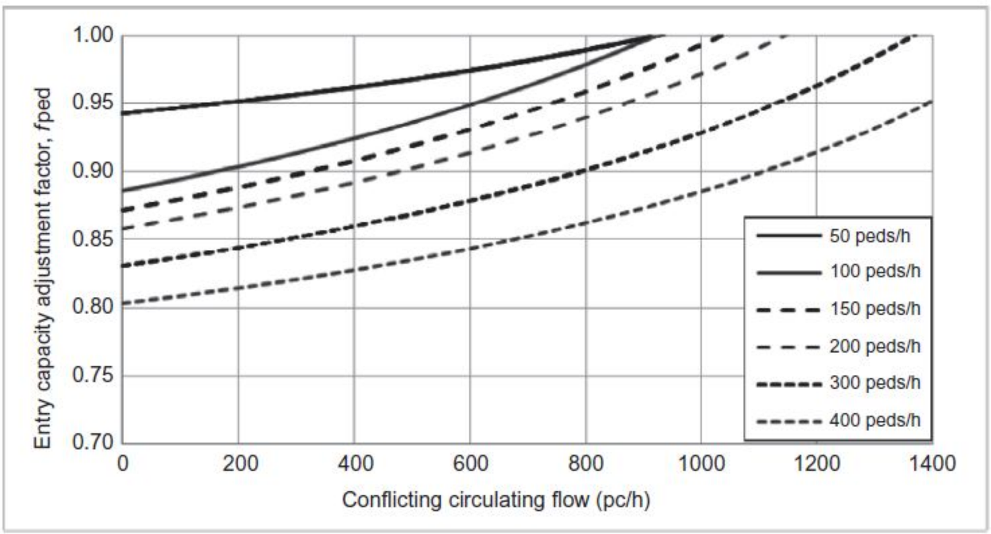

Figure: Pedestrian effect on roundabout two-lane entry capacity.

Step 6: Convert Flow Rate and Capacities to Vehicles

For step 6, the resulting flow rates and capacities are converted back to units in vehicles per hour before proceeding with the computations. Volumes are obtained by multiplying the flow rates by the heavy vehicle factor, f_{HV}. Capacities are obtained by multiplying the PCE capacities by f_{HV} and by the pedestrian adjustment factor, f_{ped}. In cases where different percentages of trucks enter the roundabout from different approaches, a weighted average heavy vehicle adjustment factor can be calculated, by weighting each factor by its corresponding traffic volume.

Step 7: Compute v/c Ratio, Delay, Queues, and LOS for Each Lane

With volumes, v_i, and capacities, c_i, available for each entry, the volume to-capacity ratio for each approach, x_i, can be calculated from Eq. below:

$$x_i = \frac{v_i}{c_i}$$

The volume-to-capacity ratio is the key input in Eq. below to estimate control delay, and other Eq. to calculate the 95th percentile queue length. The level of service for a roundabout is defined based on the average control delay in seconds per vehicle with LOS thresholds given in Table below.

$$d = \frac{3600}{c} + 900T\left[x - 1 + \sqrt{(x-1)^2 + \frac{\left(\frac{3600}{c}\right)x}{450T}}\right] + 5 \times \min[x, 1]$$

where:

d=average control delay (s/veh).
x=volume-to-capacity ratio of the subject lane.
c=capacity of the subject lane (veh/h).
T=time period (h) (T=0.25 h for a 15-min analysis).

$$Q_{95} = 900T\left[x - 1 + \sqrt{(1-x)^2 + \frac{\left(\frac{3600}{c}\right)x}{150T}}\right]\left(\frac{c}{3600}\right)$$

where:

Q_{95}=95th percentile queue (veh).
x=volume-to-capacity ratio of the subject lane.
c=capacity of the subject lane (veh/h).
T=time period (h) (T=1 for a 1-h analysis, T=0.25 for a 15-min analysis).

Step 8: Compute Delay and LOS for Each Approach and Overall Roundabout

As a final step in the methodology, the control delay can be aggregated to the approach level, by weighting the delay of each lane by its corresponding volume. Similarly, the overall roundabout control delay can be calculated as the weighted average of the approach delays. The LOS for the approach or the intersection is then determined using the same thresholds given in Table below.

Table: LOS threshold for roundabouts.

LOS	Control delay (s/veh)
A	≤ 10
B	$>10-15$
C	$>15-25$
D	$>25-35$
E	$>35-50$
F	>50 or v/c ratio > 1.0