Analytical Analysis of Pedestrian Effects on Roundabout Exit Capacity

Lee A. Rodegerdts, P.E., Kittelson & Associates, Inc.
Glenn E. Blackwelder, P.E., Kittelson & Associates, Inc.
610 SW Alder, Ste. 700
Portland, OR 97205
The need for an analytical tool

- This method was developed for a project in Poway, CA with:
  - Two double-lane roundabouts
  - Large entry and exit flows
  - Unusual pedestrian characteristics (Equestrians)
  - Roundabouts projected to operate near maximum acceptable entry capacities

Photo: Berryman & Henigar
Poway Sketch-level Design

- Operations at the proposed roundabouts were borderline
- Both roundabouts had a large northbound exiting volume
- These factors suggest that exit queues were of particular concern
The Questions

- We were looking for a simple analytical method to answer the following questions:
  
  - Under what conditions are gaps in the vehicular traffic sufficient for pedestrians to cross without vehicular yielding?
  
  - If vehicular yielding occurs, what queuing effect can be expected?
  
  - What reduction in entry capacity might be expected due to exit queuing?
Other Methods

• No literature was found addressing the effects of exit blocking on upstream entry capacity

• Simulation can and has been used to address problems such as exit queue effects on roundabouts
Methodology

- Two operational bounding scenarios were identified
  - Pedestrians yielding to vehicles
  - Vehicles yielding to pedestrians

- These two regimes represent the boundaries of the problem - actual operations are somewhere in the middle
Pedestrian Yielding to Vehicles

- The Highway Capacity Manual provides a method for determining the number of available gaps in a traffic stream given
  - Gap duration
  - Conflicting vehicle volume

- If gaps occur frequently, most pedestrians will wait for a gap before crossing

- By assessing the number of available gaps, a judgment may be made regarding the probability of pedestrians yielding to vehicles
Gaps in the Vehicle Stream

\[ n = v_c \frac{e^{-v_c G/3600}}{1 - e^{-v_c G/3600}} \]

- Where:
  - \( n \) = Number of available gaps of size \( G \) (gaps/h)
  - \( v_c \) = Conflicting vehicular flow rate (veh/h)
  - \( G \) = Duration of adequate gap (s)

- Duration of gap is based on roadway width, walking speed of pedestrian, and perception/reaction time
Available Gaps Given Conflicting Flow and Gap Length

Gaps per Hour

Conflicting Volume (veh/hr)

5 sec gap

10 sec gap

20 sec

30 sec
When Vehicles Yield to Pedestrians

- When vehicles yield to pedestrians, we are interested in the magnitude and duration of the queue on the roundabout exit.

- The effects of the queue can be calculated if the following assumptions are made:
  - Vehicle arrivals are approximately Poisson distributed.
  - Vehicles queue whenever a pedestrian is in the crosswalk.
  - The time over which the queue accumulates is constant, i.e. pedestrian speed is constant and the time it takes the queue to clear is constant.
  - When a queue enters the circulating roadway, it blocks all entries to the roundabout.
Poisson Probability of Queue

\[ P_{\text{queue}}(q) = \frac{e^{-V_e\left(T_B + \frac{3600Q_{\text{avg}}}{S_E}\right)} \left[V_e\left(T_B + \frac{3600Q_{\text{avg}}}{S_E}\right)\right]^q}{q!} \]

- **Given:**
  - \( P_{\text{queue}}(q) \) = Probability that a queue of length \( q \) will occur during blocking event
  - \( Q_{\text{avg}} \) = Average expected queue
  - \( V_E \) = Vehicle flow rate on the exit being studied
  - \( T_B \) = Duration of blocking event
  - \( S_E \) = Saturation flow rate of exiting vehicles upon release from blocking event
  - \( q \) = Queue length (used in estimating probabilities of specific queue lengths)
Queue Duration - Varying Queue

- $Q_E$ max queue that doesn’t block the circulating roadway
- $t_{queue}$ is the time the queue extends into the circulating roadway and is calculated assuming queue arrivals are evenly distributed throughout the duration of the queue
Determining Average Blocking Time

\[ t_{avg} = \sum_{q=0}^{q=\infty} P_{queue}(q) \cdot t_{queue}(q) \]

- \( t_{avg} \) = Average duration of queue blocking on a per event basis
- \( P_{queue}(q) \) = Probability that a queue of length \( q \) will occur during a blocking event
- \( t_{queue}(q) \) = Duration over which a queue of length \( q \) exceeds queue length \( Q_E \)
- \( q \) = Queue length (used in estimating probabilities of specific queue lengths)
Capacity Reduction Due to Queue Blocking

\[ t_{block} = n_{event} \cdot t_{avg} \]

- \( t_{block} \) = Total time during the study time period that the circulatory roadway is blocked
- \( n_{event} \) = Number of blocking events occurring during the study time period
- \( t_{avg} \) = Average duration of queue blocking on a per-event basis

\[ C_{adj} = C_{base} \left(1 - \frac{t_{block}}{3600}\right) \]

- \( C_{adj} \) = Adjusted capacity of a subject entry [veh/h]
- \( C_{base} \) = Base capacity of a subject entry [veh/h]
Example 1: Assumptions

A Moderate Volume Roundabout:

- $V_E = 500$ vehicles per hour on the study exit
- $n_{\text{event}} = 15$ pedestrian crossings requiring vehicles to yield during the study hour
- $Q_E = 2$ vehicles (a crosswalk is located 25 feet from the roundabout; the second vehicle will block the circulating roadway)
- $T_B = 10$ seconds (vehicle stopped time required for a pedestrian to cross the exit)
- $S_E = 1800$ veh/hr (i.e. 2 s headways)
Example 1: Results

- **Key quantities/results**
  - 166 gaps (10 sec or more) in the exiting traffic during the peak hour.
  - $Q_{avg} = 2 \text{ veh}$
  - $t_{avg} = 2.3 \text{ seconds}$
  - $t_{block} = 35 \text{ seconds}$
  - $C_{adj} = 0.99C_{base}$

- For this case (moderate volumes), the capacity effects are minimal, on the order of a 1% reduction
Example 2: Assumptions

A Higher Volume Roundabout:

- $V_E = 1000$ veh/hr on the study exit
- $n_{event} = 25$ pedestrian crossings requiring vehicles to stop during the study hour
- All other quantities are same as Example 1
Example 2: Results

- **Key quantities**
  - 66 gaps (10 sec or more) in the exiting traffic during the peak hour
  - $Q_{avg} = 6$ veh
  - $t_{avg} = 14$ seconds
  - $t_{block} = 350$ seconds
  - $C_{adj} = 0.90C_{base}$

- For this case (high volumes), the capacity effects are more substantial, on the order of a 10% reduction
Implications for Design

• The methodology suggests potential design measures to offset or minimize loss of capacity in high volume intersections such as the following:
  - Increase distance between circulating roadway and crosswalk
  - Add entry capacity to offset exit effects
  - Narrow exit to reduce pedestrian crossing times
  - Remove crosswalk

• This method can also be used to estimate the effects of crosswalk signalization on roundabout capacity
Poway Results

- As a result of the analysis, a recommendation was made to remove the crosswalks on the north approach of the intersection.
- The removal of the crosswalks is a factor that will argue against installation of roundabouts at these locations.
Conclusions

• The methodologies provided are a simple set of analytical tools for initial estimates of roundabout capacity changes

• These methodologies are simple in nature, and may not necessarily apply in complex cases -- but they can provide a quick estimate of potential impacts

• Simulation remains a tool for analysis of more complicated cases
Questions?

Photo: Lee Rodegerdts