# Analytical Analysis of Pedestrian Effects on Roundabout Exit Capacity

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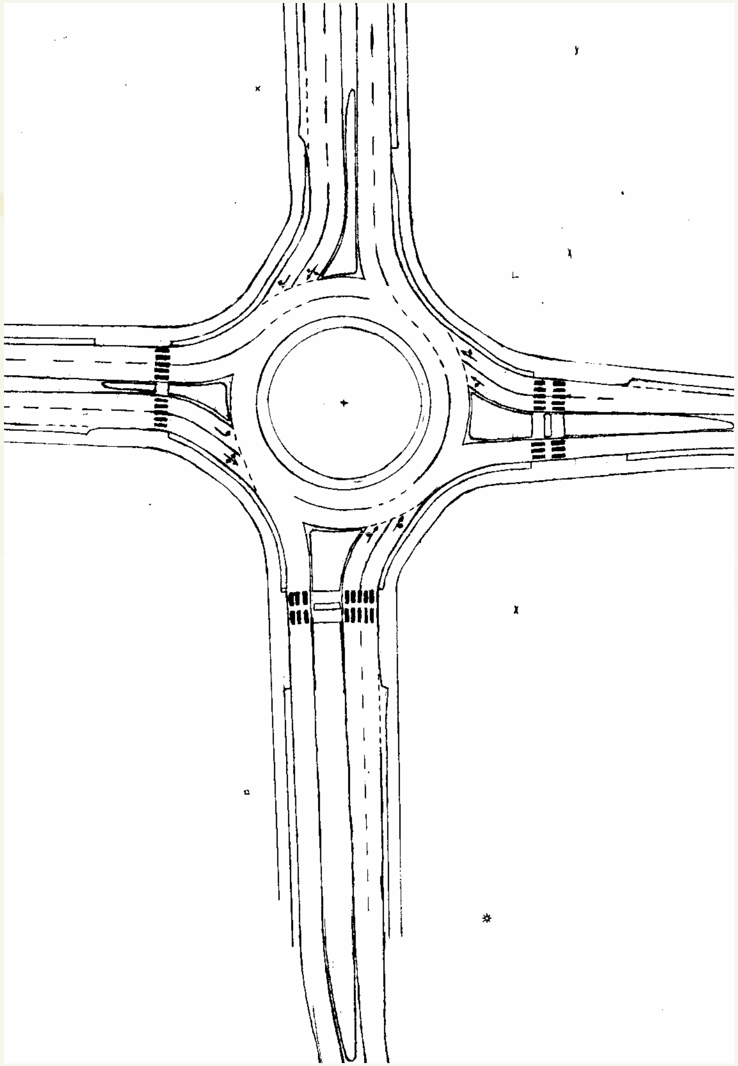
# The need for an analytical tool

- **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**

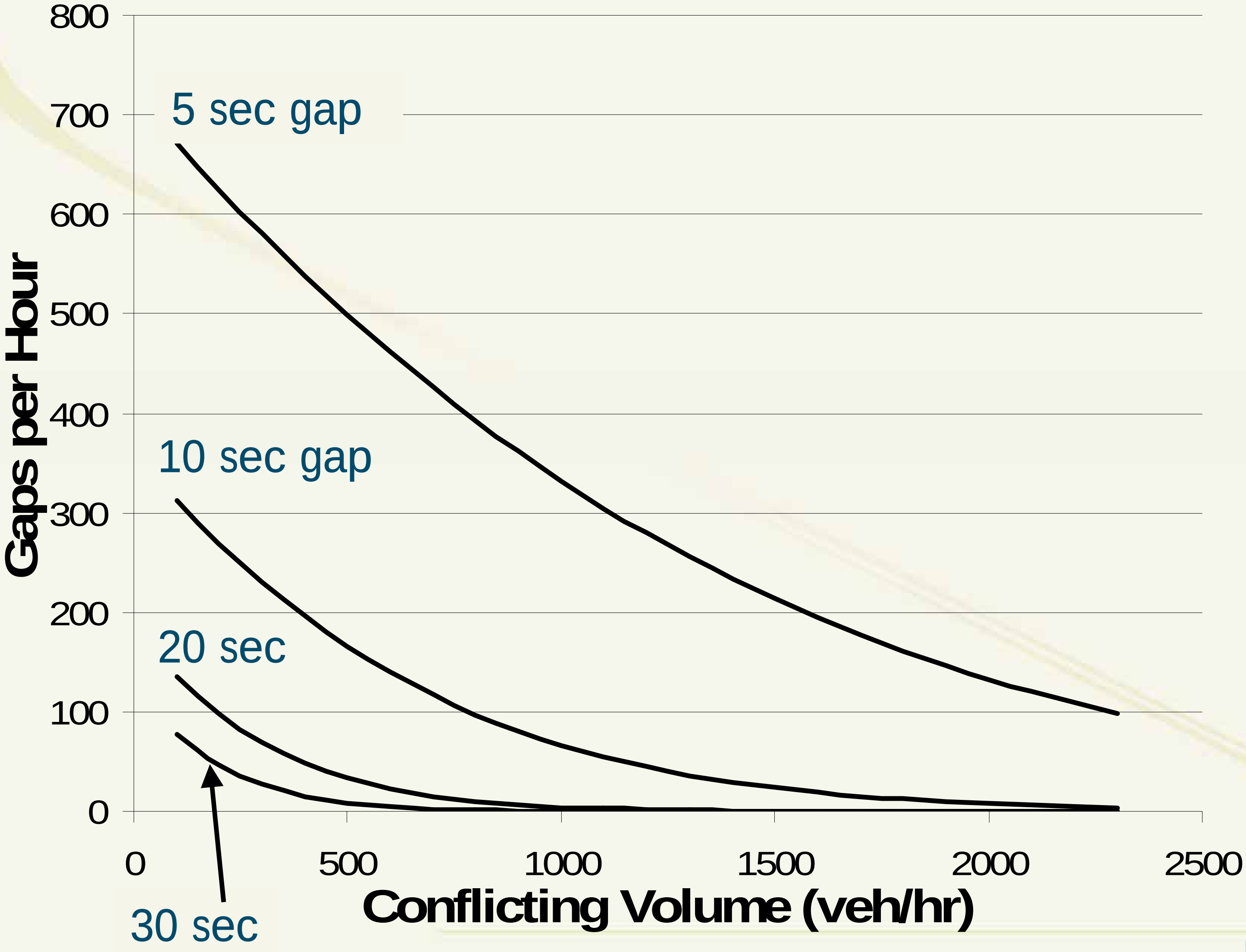
- **By assessing the number of available gaps, a judgment may be made regarding the probability of pedestrians yielding to vehicles**

# 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



# 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**

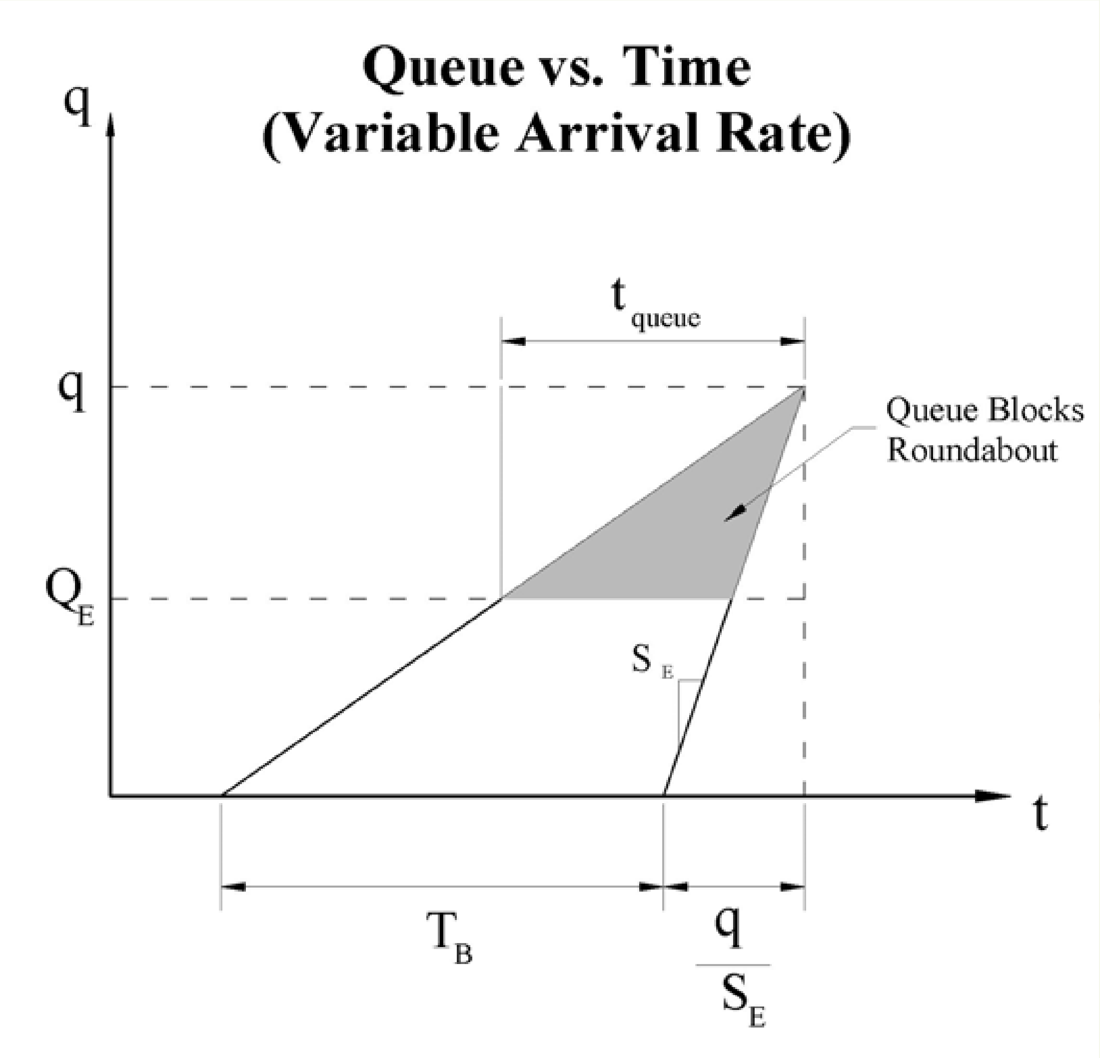
- **The effects of the queue can be calculated if the following assumptions are made:**
  - Vehicle arrivals are approximately Poisson distributed
  - Vehicles queue whenever a pedestrian is in the crosswalk
  - The time over which the queue accumulates is constant, i.e. pedestrian speed is constant 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

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

- **Given:**
  - $P_{queue}(q)$ = Probability that a queue of length $q$ will occur during blocking event
  - $Q_{avg}$ = 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
- $n_{event}$ = 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 veh
  - $t_{avg}$ = 2.3 seconds
  - $t_{block}$ = 35 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

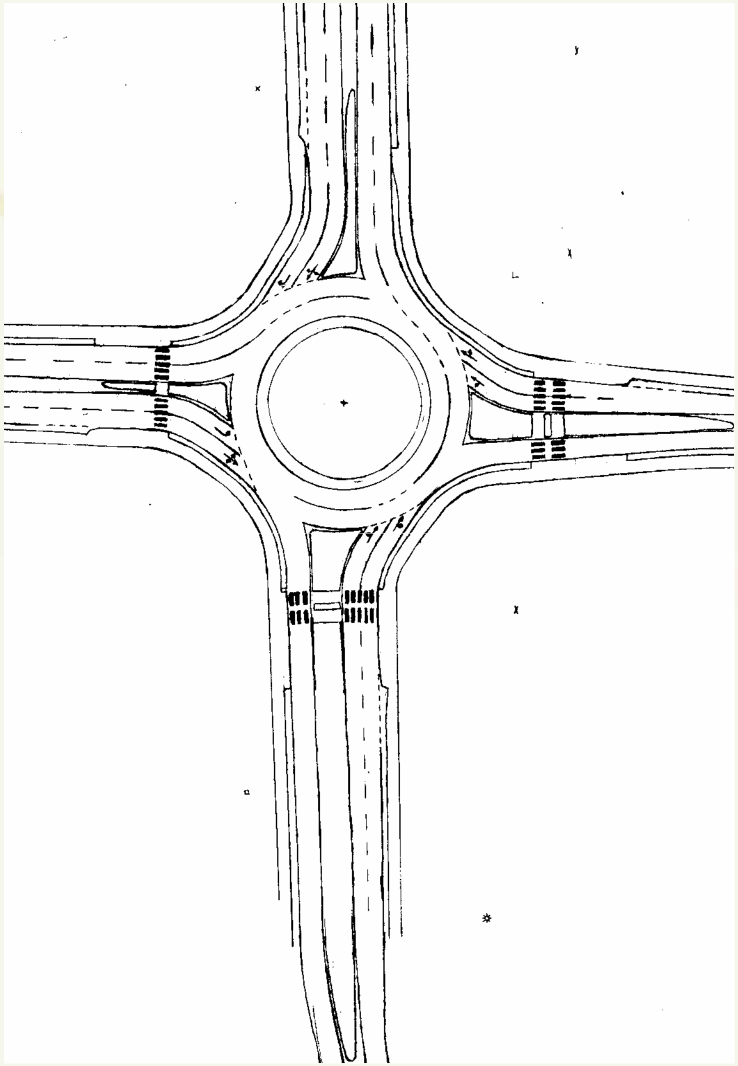
- **Key quantities**
  - 66 gaps (10 sec or more) in the exiting traffic during the peak hour
  - $Q_{avg}$ = 6 veh
  - $t_{avg}$ = 14 seconds
  - $t_{block}$ = 350 seconds
  - $C_{adj} = 0.90C_{base}$
- **For this case (high volumes), the capacity effects are more substantial, on the order of a 10% 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