

INTRODUCTION TO ROUNDABOUTS

OPERATIONS

Operational Analysis

- **Capacity**
- **Performance measures**
- **Field evaluation of existing roundabouts**

Capacity

- **What affects capacity?**
- **How can capacity be evaluated?**
- **How do I determine the capacity for each category of roundabout?**
- **What about the HCM?**
- **How do I use the data?**

What Affects Capacity?

- **Capacity of roundabouts defined by the capacity of each approach**
- **Capacity of a roundabout approach depends on:**
 - **Geometric elements of roundabout**
 - **Conflicting circulating flow**
 - **Gap acceptance characteristics**
- **All have an effect on critical gap**

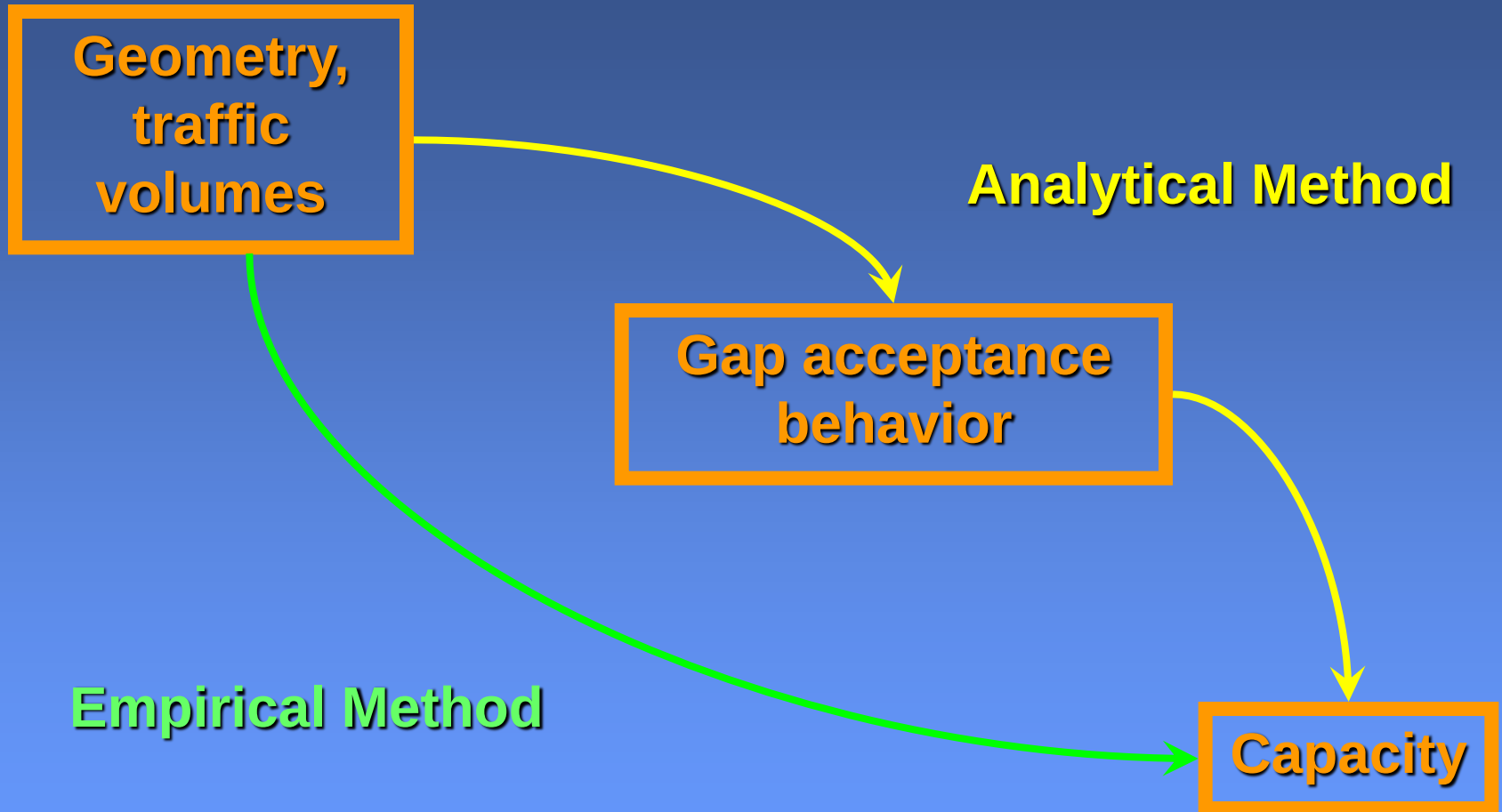
Capacity

- **What affects capacity?**
- **How can capacity be evaluated?**
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How Can Capacity Be Evaluated?

- **Two basic approaches:**
 - **Analytical method**
 - **Empirical method**
- **Also can use simulation**

Analytical vs. Empirical Methods



Analytical Method

- **Capacity is a function of, among others, the characteristics of the traffic stream**
- **Based on gap acceptance theory**
- **Similar to methodology in HCM for TWSC**
- **Method is generally more portable to other countries**
- **Gap acceptance logic used in simulation**

Australian Analytical Method

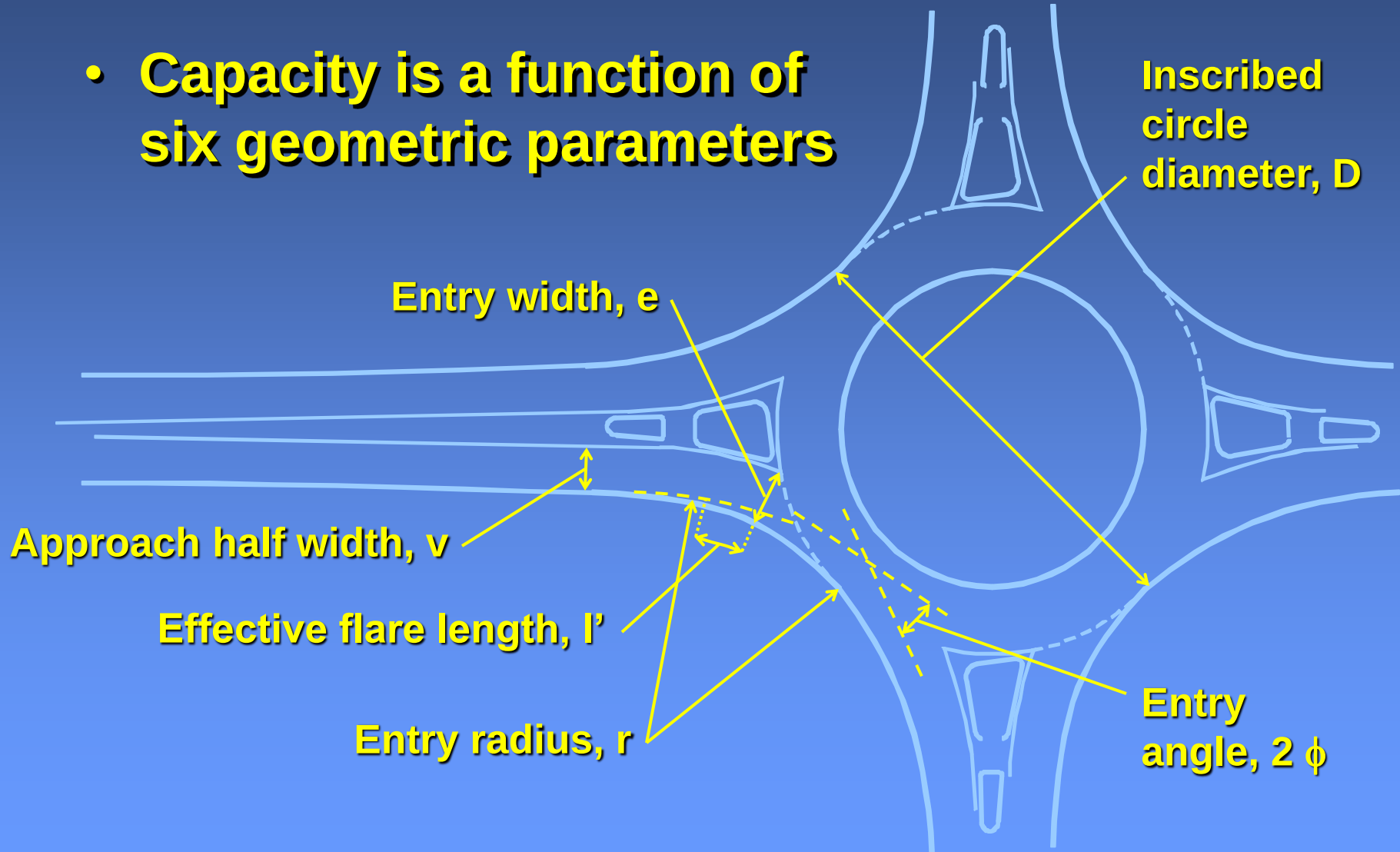
- **Capacity is a function of the following parameters:**
 - **Critical gap:** Minimum gap in major traffic stream that a minor vehicle will accept
 - **Follow-up time:** Additional time it takes a second minor vehicle to accept the same gap
 - **Proportion of bunched vehicles:** The degree to which approaching vehicles are platooned

Empirical Method

- **Capacity is a function of geometric features**
- **Linear regression of huge database**
- **Capacity directly measured in field**
- **Equations unique to each country**
- **Calibration requires:**
 - **operating at capacity**
 - **geometric variation**

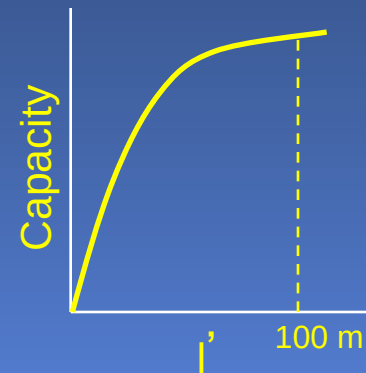
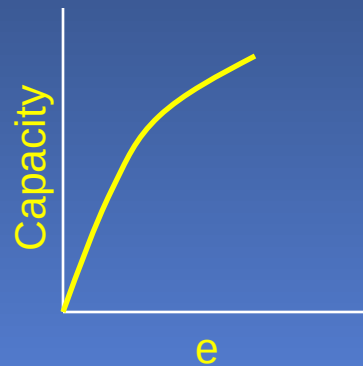
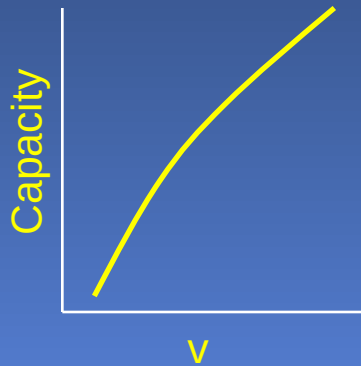
British Empirical Method

- Capacity is a function of six geometric parameters

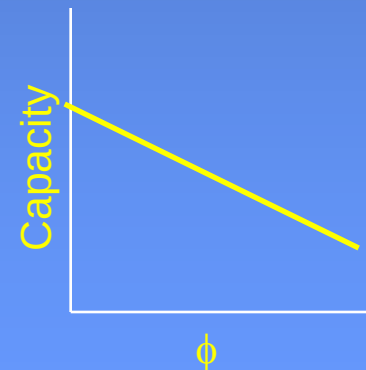
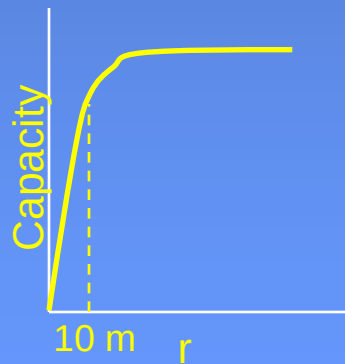
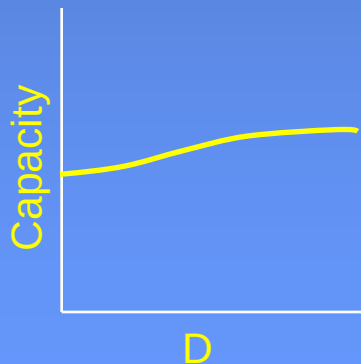


British Method: Geometric Sensitivity

Major effects: v , e , l'

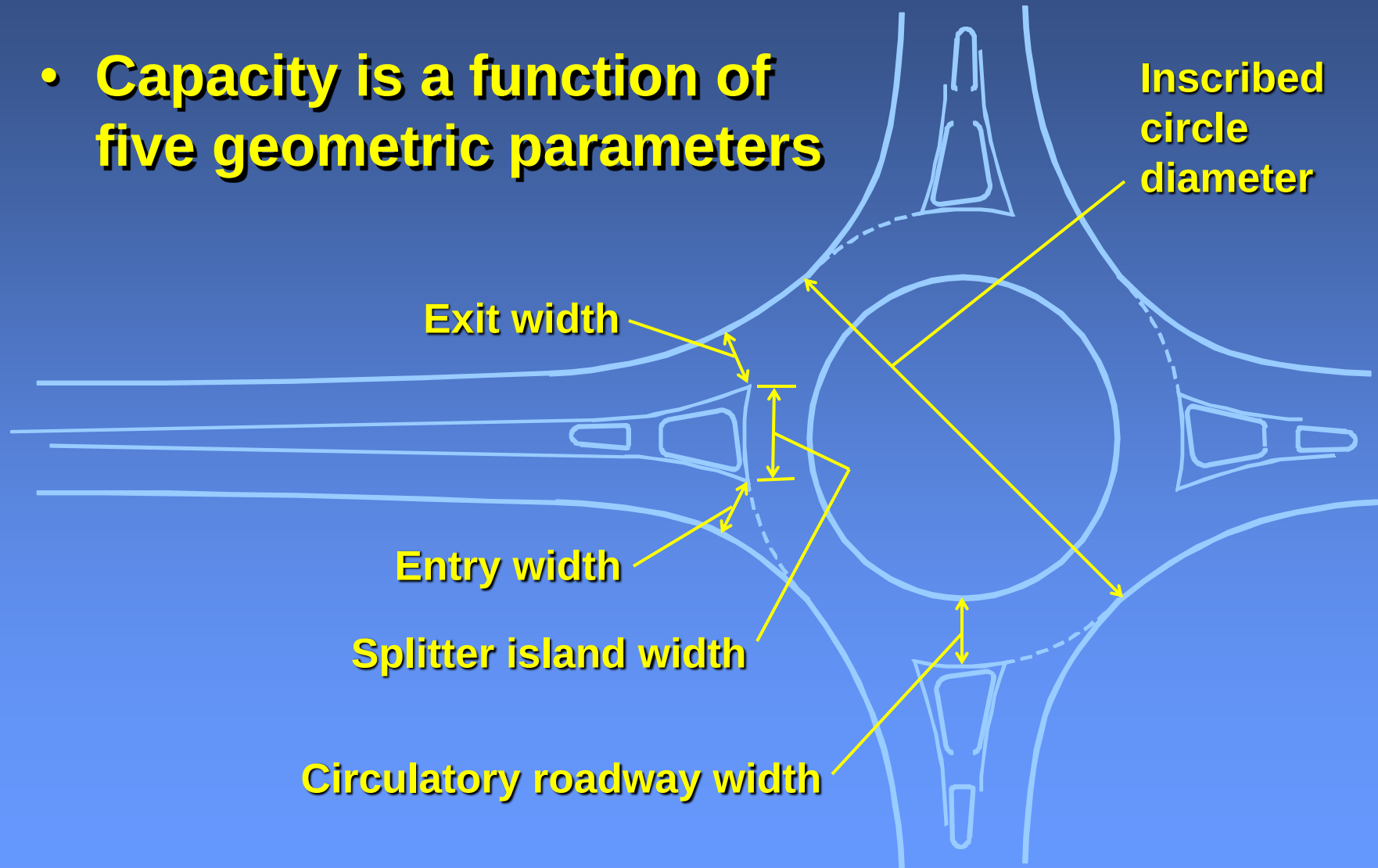


Minor effects: D , r , ϕ



French Empirical Method

- **Capacity is a function of five geometric parameters**



German Empirical Method

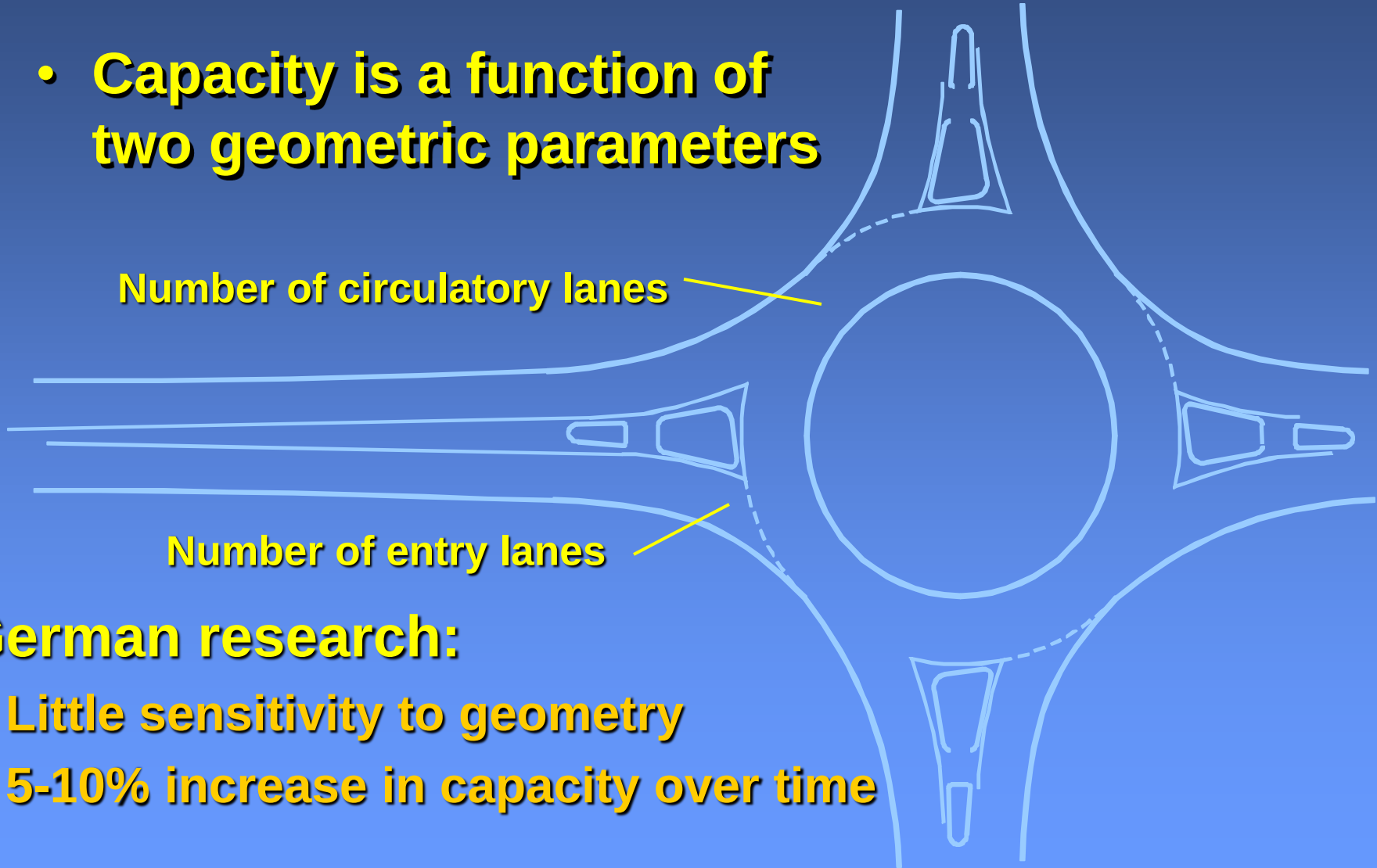
- **Capacity is a function of two geometric parameters**

Number of circulatory lanes

Number of entry lanes

German research:

- Little sensitivity to geometry
- 5-10% increase in capacity over time



Summary of Analysis Methodologies

- **Variety of model forms**
- **Each has been custom-tailored to the design philosophies and driver behavior of each country**
- **FHWA guide matches models to design philosophy for each roundabout category**
- **As more research is done in the U.S., expect to see U.S.-specific methodology**

Capacity

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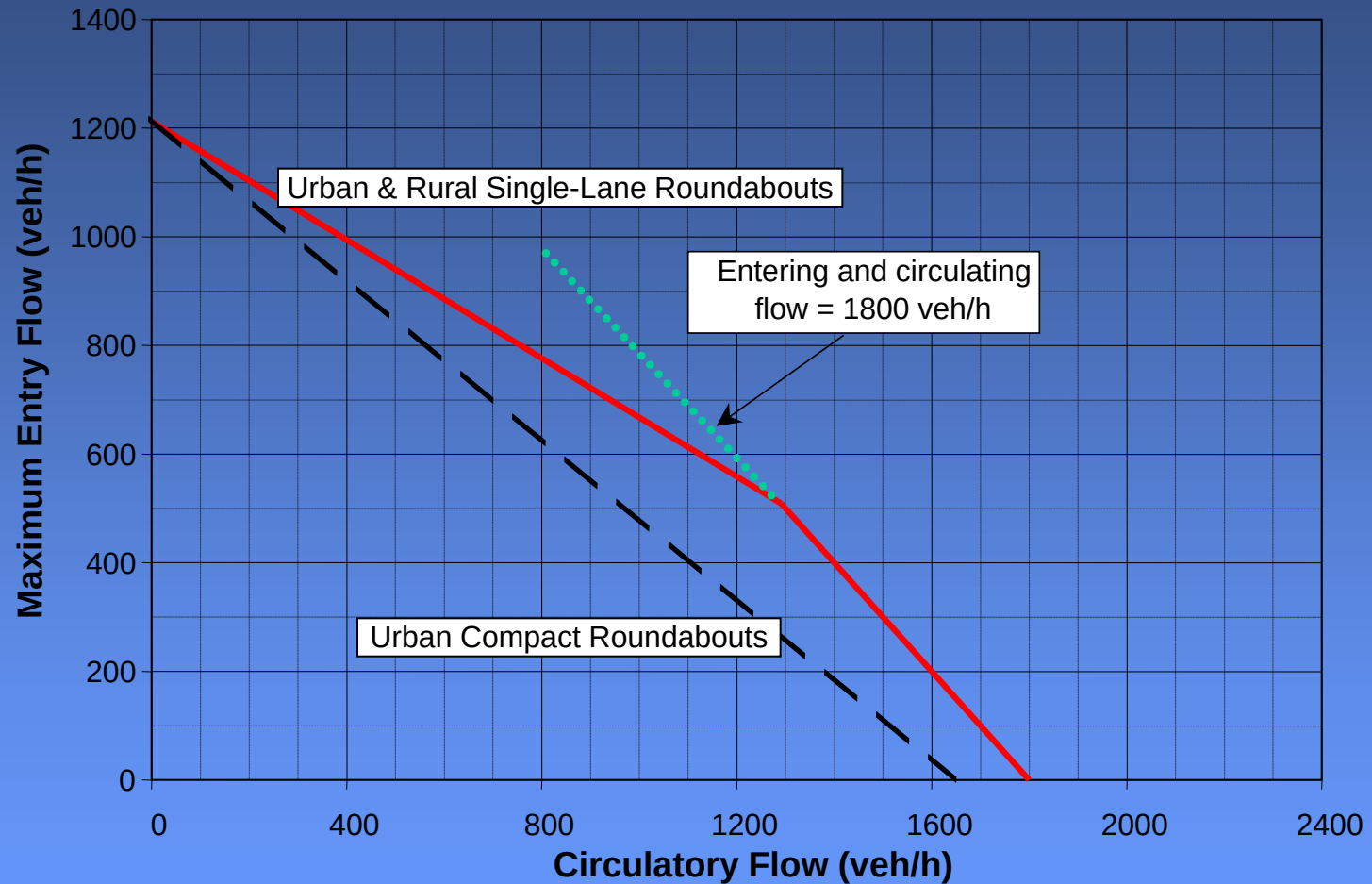
How Do I Determine the Capacity for Each Category of Roundabout?

- **Determine base capacity for the appropriate category:**
 - **Single-lane roundabouts**
 - **Double-lane roundabouts**
- **Adjust the capacity for other factors**

Single-Lane Roundabouts

- **Urban compact roundabouts**
 - Design based on German-style design
 - Capacity equation based on German data
- **Single-lane roundabouts**
 - Design based on British-, French-, and Australian-style design
 - Equation based on British data

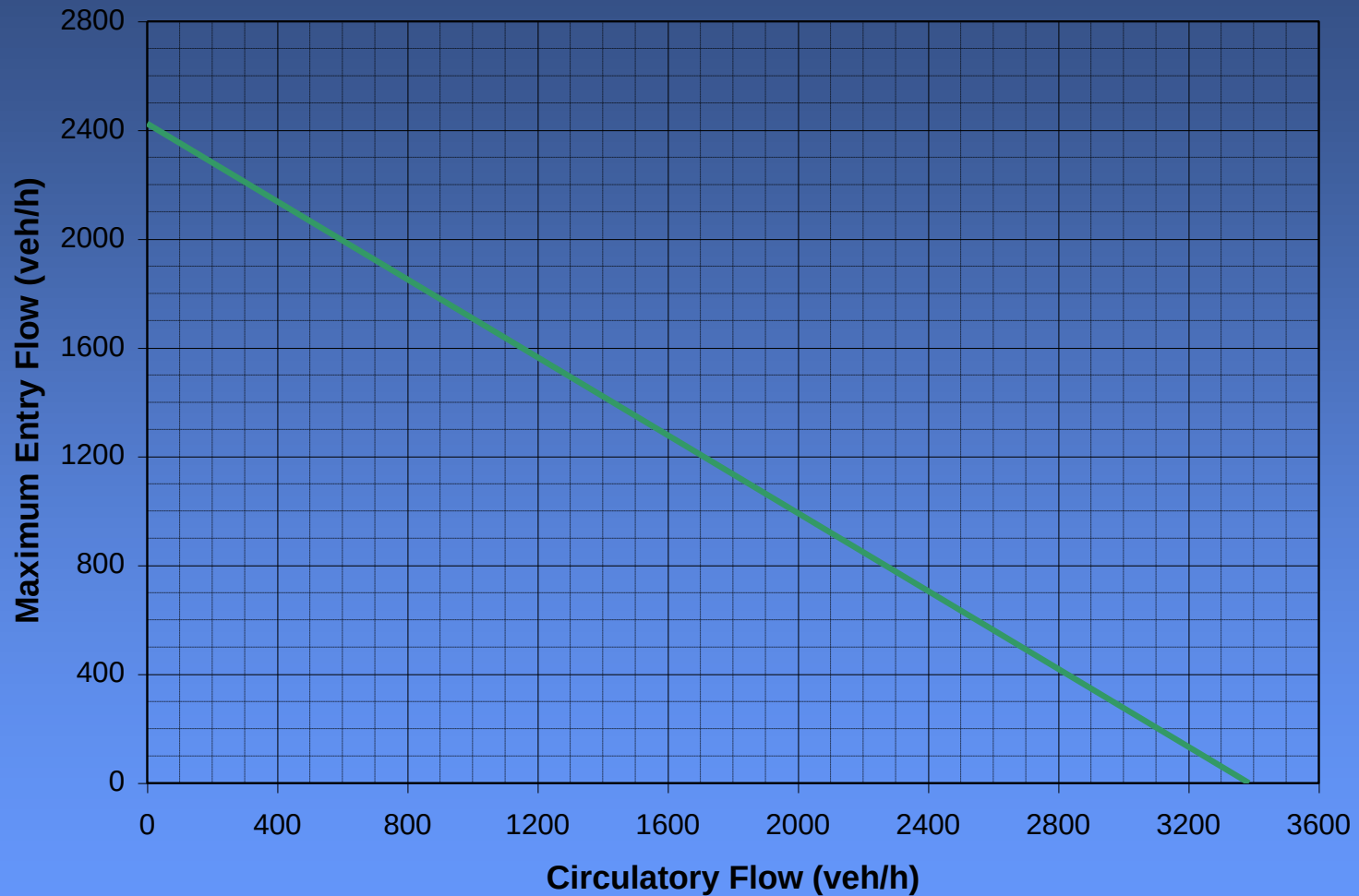
Single-Lane Roundabouts



Double-Lane Roundabouts

- **Design based primarily on British-style design**
- **Equation based on British data**

Double-Lane Roundabouts



Capacity Adjustments

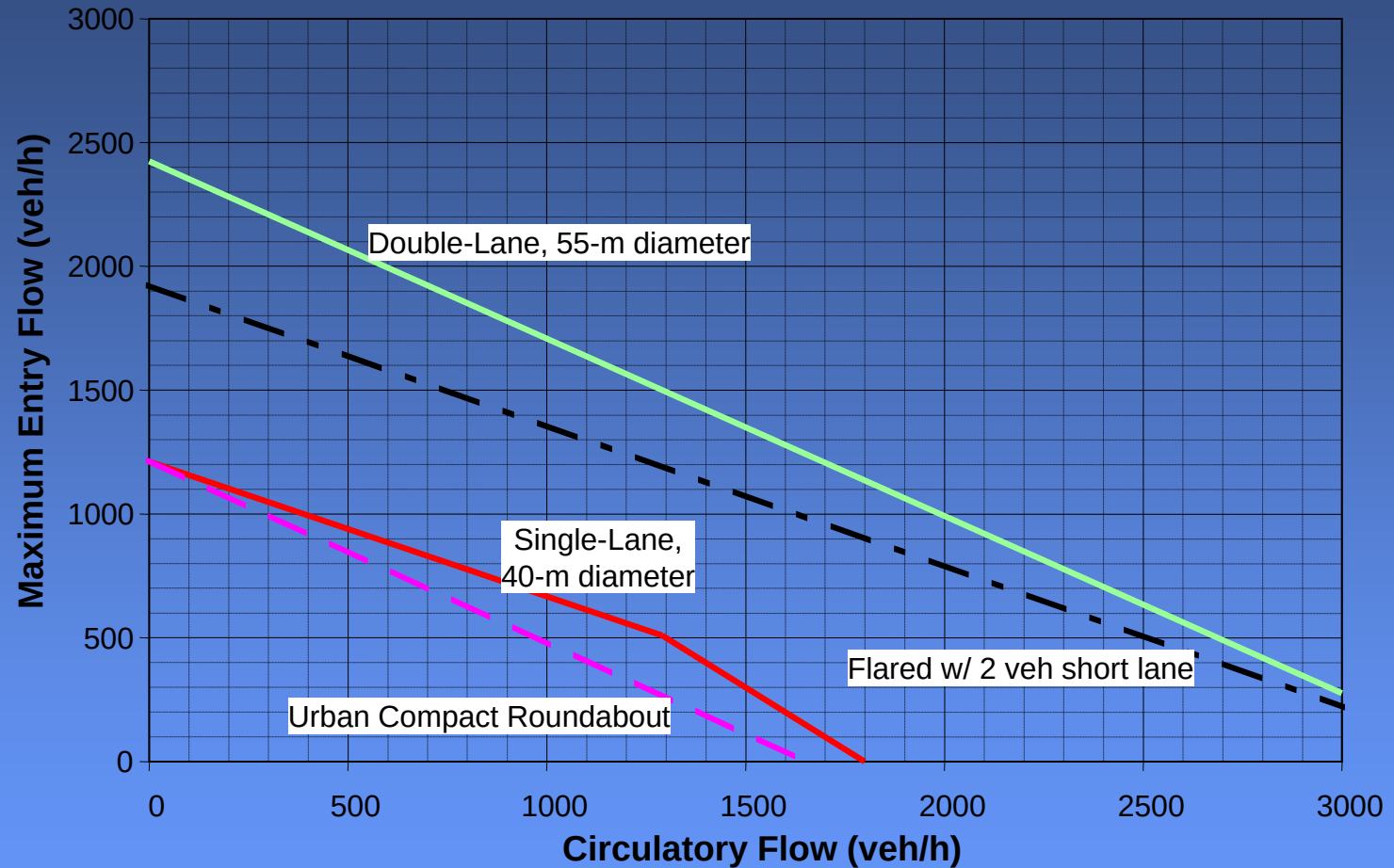
- **Short lanes (flared approaches)**
- **Pedestrians**

Capacity adjustments: Short lanes

- Short lanes are the additional partial lanes added when flaring a roundabout from one to two lanes**

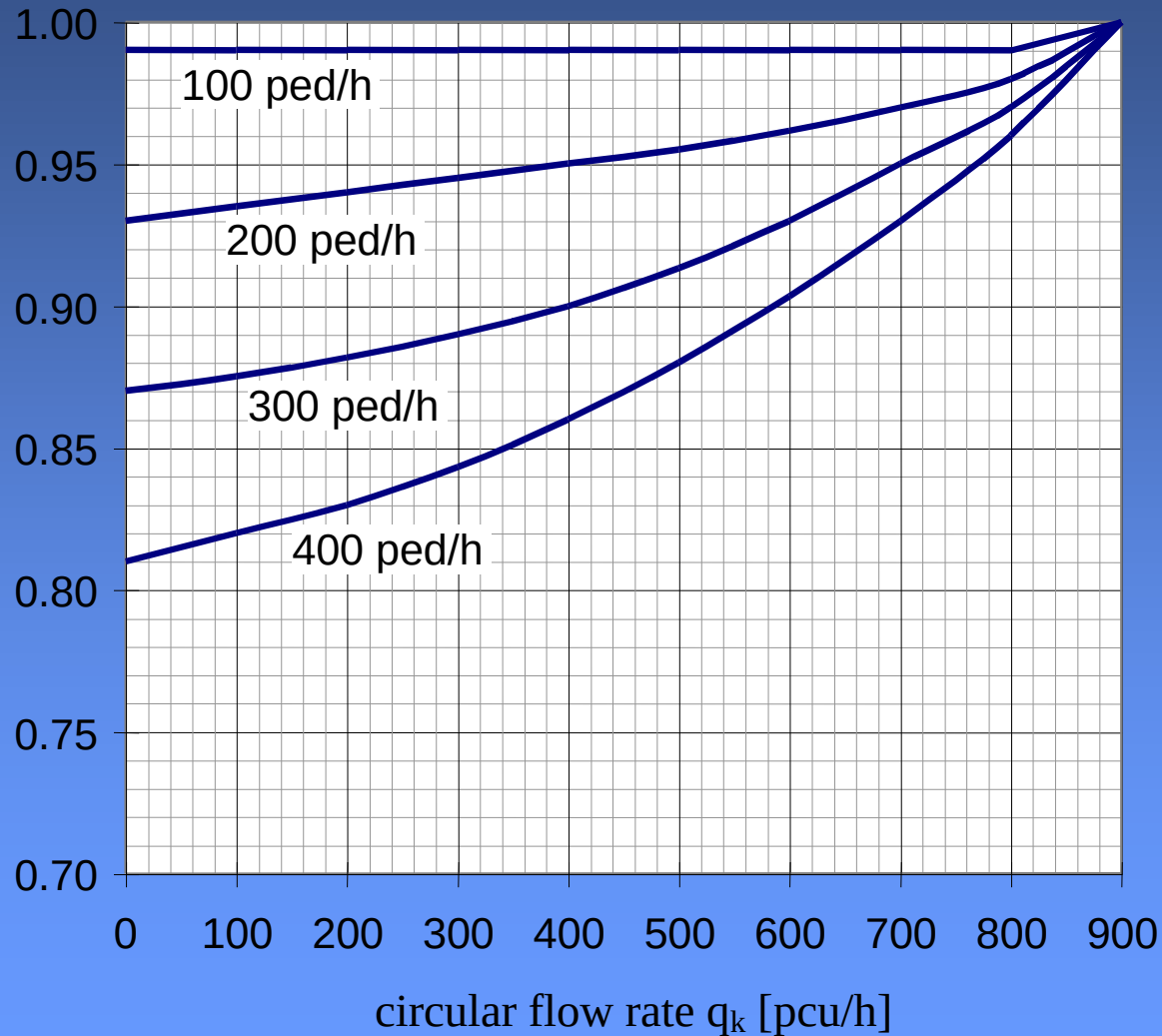
No. of vehicle spaces in short lane	Capacity factor (applied to double-lane approach capacity)
0 (single-lane approach)	0.500
1	0.707
2	0.794
4	0.871
6	0.906
8	0.926
10	0.939

Capacity Comparison



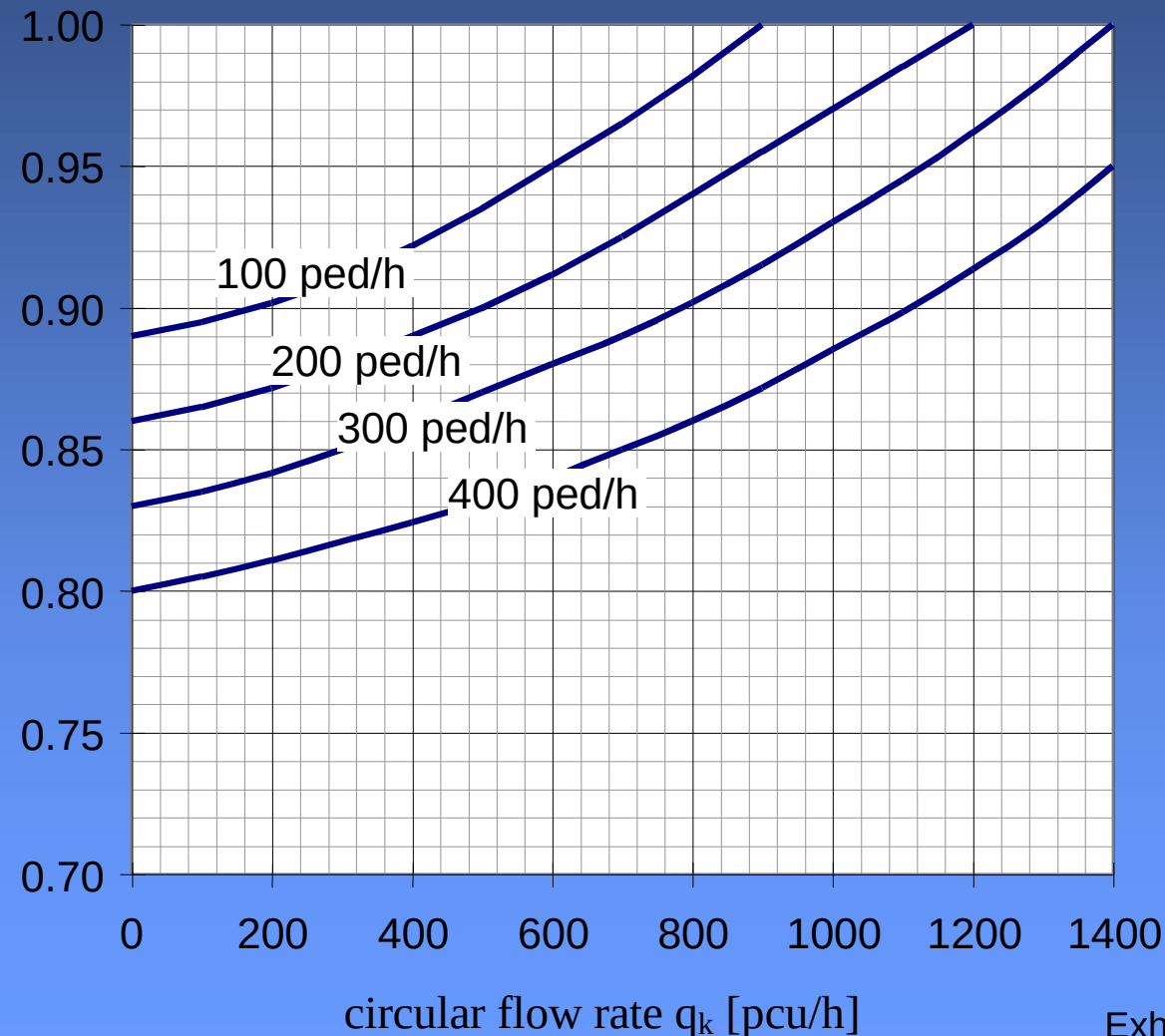
Capacity adjustment: Pedestrians at single-lane roundabout

Reduction factor M [-]



Capacity adjustment: Pedestrians at double-lane roundabout

Reduction factor M [-]



Other Situations

- **What about larger roundabouts (three- and four-lane entries)?**
 - Have been used in U.S. (Colorado, California)
 - FHWA document does not provide specific guidance
 - Requires use of other methodologies, primarily UK
- **Requires careful design to ensure adequate operational and safety performance**

Exit Capacity

- **Single-lane exits preferred**
 - Shorter pedestrian crossings
 - Better speed control on exit
- **Capacity**
 - 1,400 veh/h with tangential alignment, no peds or bikes
 - 1,200-1,300 veh/h for normal urban conditions
- **Rule of thumb:**
 - >1,200 veh/h → double lane exit**

Degree of Saturation

- **For each approach, determine entry volume and entry capacity**
- **Degree of saturation = volume / capacity**
- **Critical approach: approach with highest degree of saturation**
- **Typical desirable maximum = 0.85**
- **Higher degrees of saturation lead to more unstable operation, increased delay and queuing**

Capacity

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- **What about the HCM?**
- **How do I use the data?**

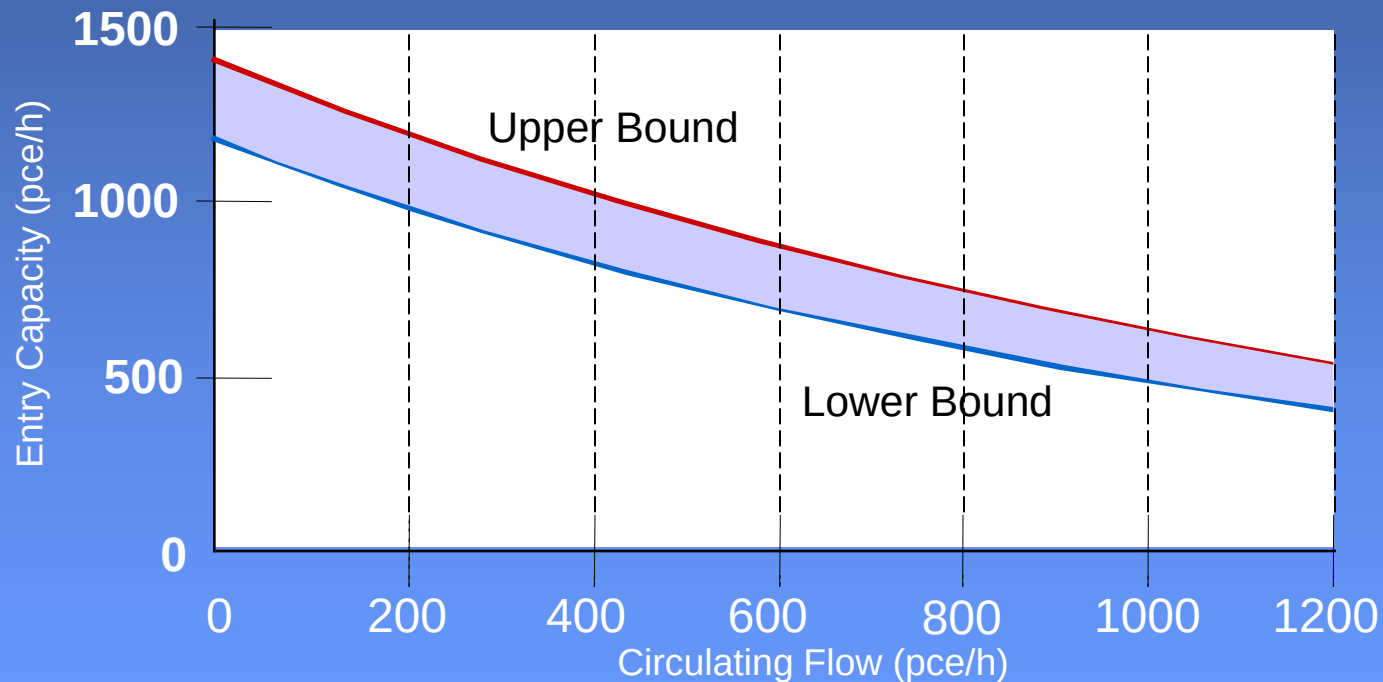
What about the HCM?

- **Roundabouts introduced in 1997 HCM**
- **Method unchanged in HCM 2000**
- **Uses analytical method**
- **Only estimates capacity; no guidance on delay or level of service**

	Critical gap (sec)	Follow-up Time (sec)
Upper-bound solution	4.1	2.6
Lower-bound solution	4.6	3.1

HCM 2000 Method

- **Applies only to single-lane roundabouts**
- **Only estimates capacity; no delay or LOS**



Source: HCM 2000

Capacity

- **What affects capacity?**
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How do I use the data?

**Turning
movements**

**Roundabout
volumes**



Step 1: Convert to passenger car equivalents

- **Convert trucks and other vehicle types to passenger car equivalents (pce)**

Vehicle Type	Passenger Car Equivalent (pce)
Car	1.0
Single-unit truck or bus	1.5
Truck with trailer	2.0
Bicycle or motorcycle	0.5

Step 2: Apply Peak Hour Factor (PHF)

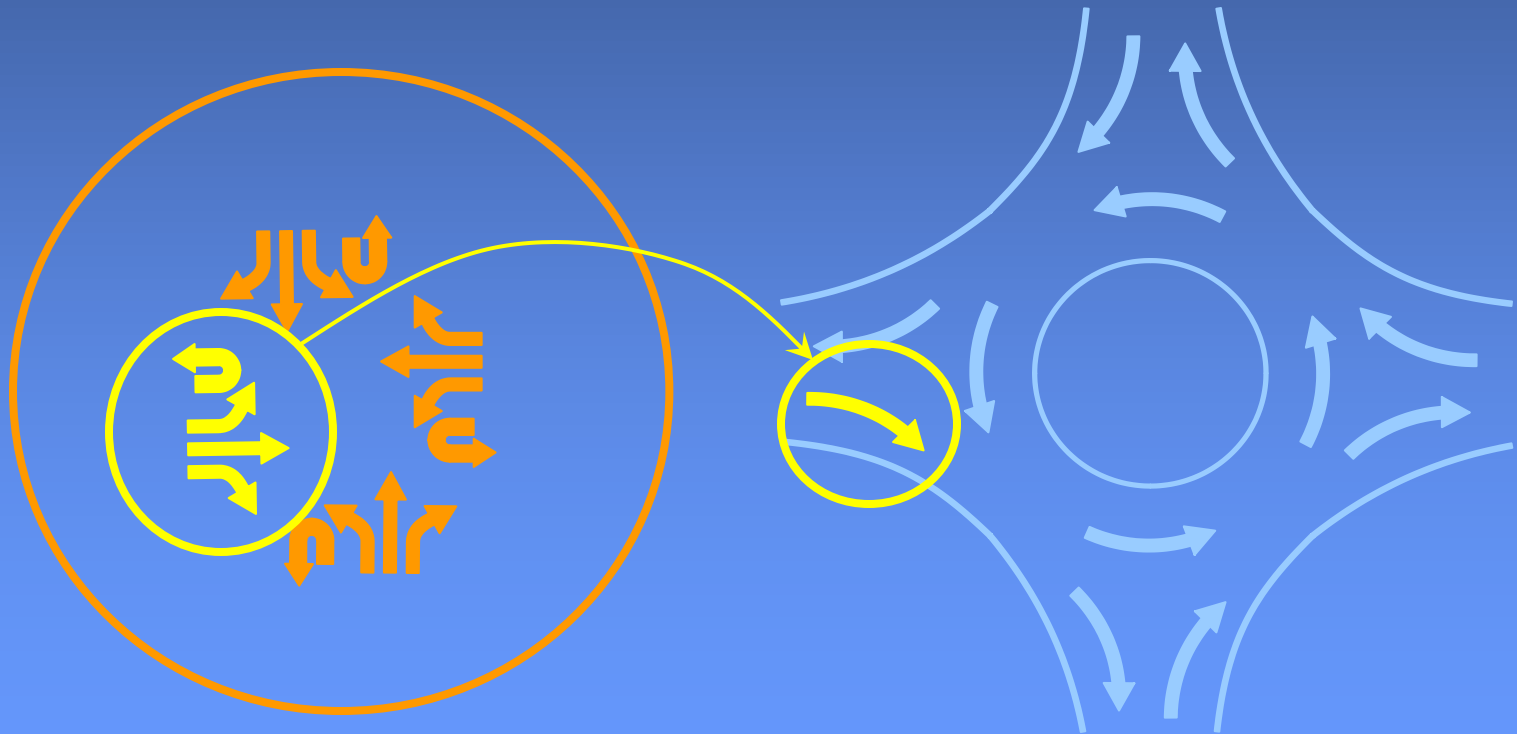
- **Peak Hour Factor is the ratio of the hourly volume to the peak 15-minute flow rate**
- **Use of PHF is consistent with HCM**

Formula (HCM):

Peak 15-min flow rate (veh/h) = Volume (veh/h) / PHF

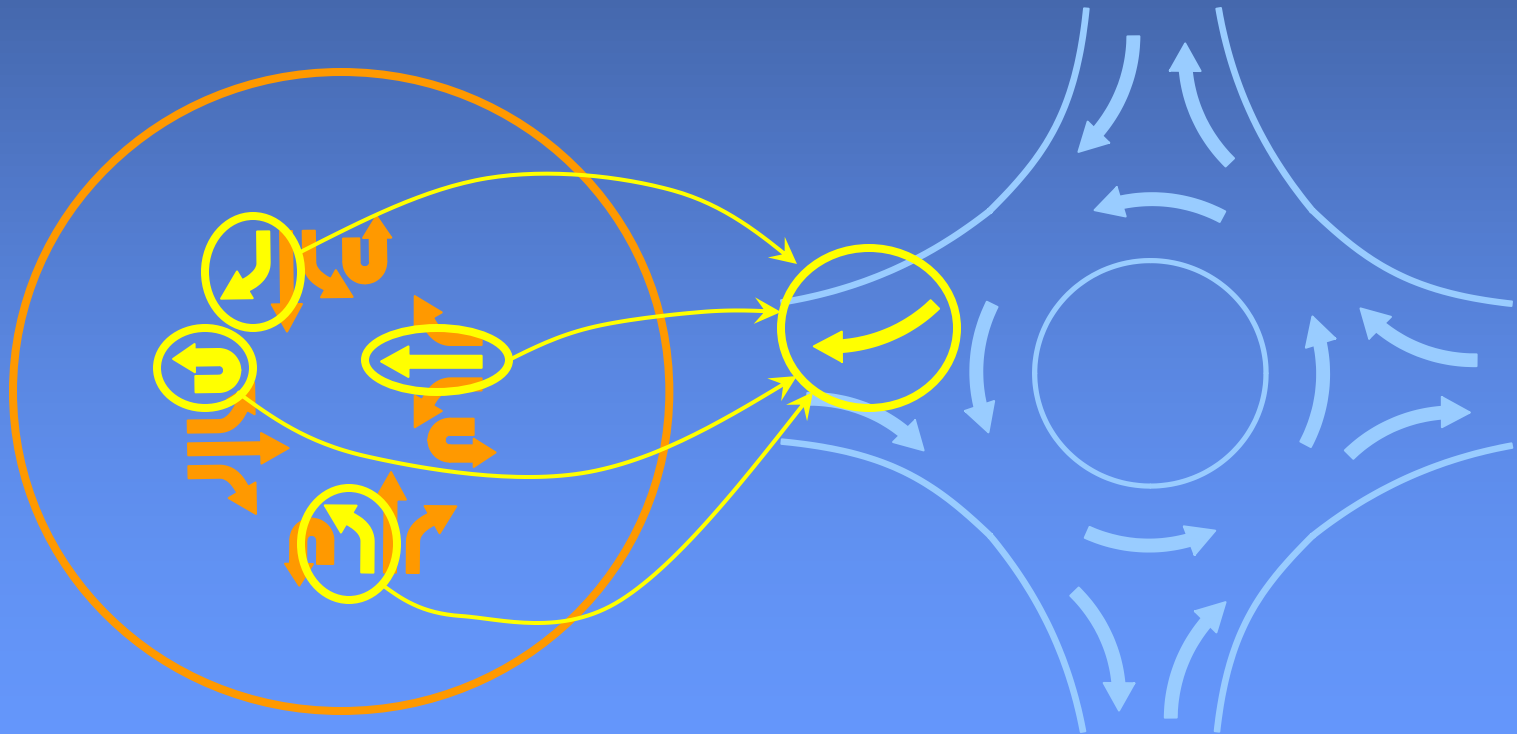
Step 3: Calculate Entry Volume

- **Entry volume = sum of entering turning movements**



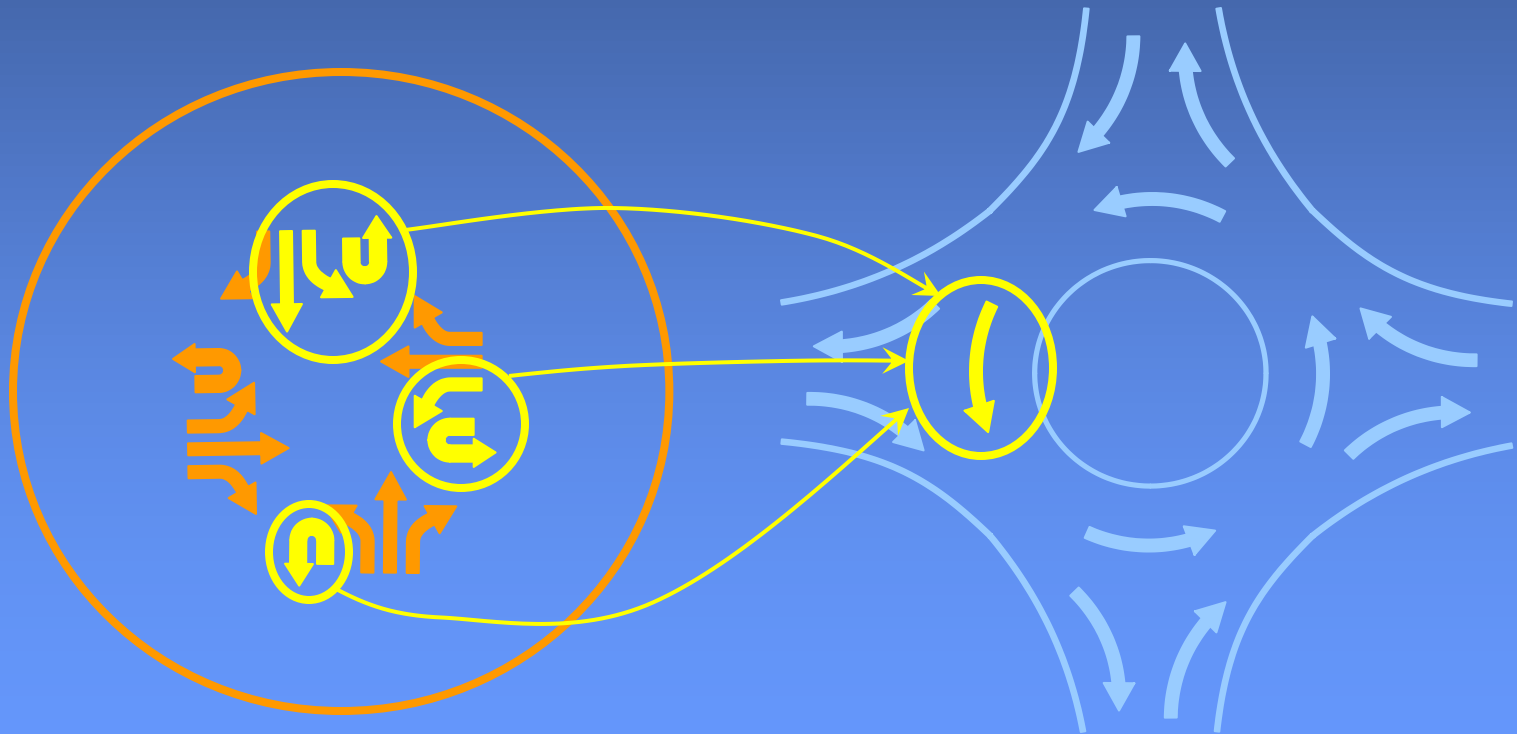
Step 4: Calculate Exit Volume

- **Exit volume = sum of turning movements as shown**



Step 5: Calculate Circulatory Volume

- **Circulatory volume = sum of turning movements as shown**



Example: Volume Conversion

Turning
movements

Roundabout
volumes

PHF = 0.94



East/west:
2% SU trucks/
buses

North/south:
4% SU trucks/buses,
2% combo trucks



Example Step 1: PCE Calculation

- SB TH: 530 veh (4% SU/bus, 2% combo)**

$$\% \text{ cars } (0.94) \times 1.0 \text{ pce/veh} = 0.94$$

$$\% \text{ SU/bus } (0.04) \times 1.5 \text{ pce/veh} = 0.06$$

$$\% \text{ combo } (0.02) \times 2.0 \text{ pce/veh} = 0.04$$

$$f_{hv} = 1.04$$

$$\times 530 \text{ veh}$$

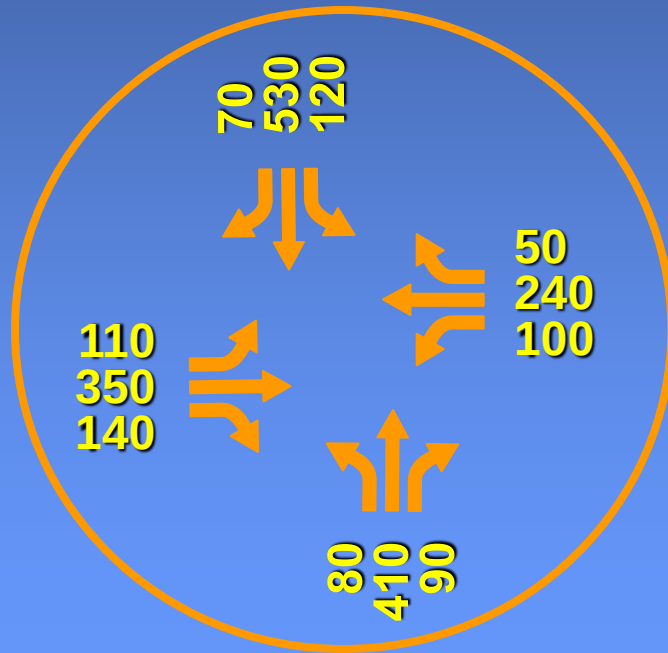
$$\underline{\hspace{1cm}} \\ \mathbf{551 \text{ pce}}$$

Vehicle Type	Passenger Car Equivalent (pce)
Car	1.0
Single-unit truck or bus	1.5
Truck with trailer	2.0
Bicycle or motorcycle	0.5

Example Step 1: Completed PCE Calculation

Raw Counts

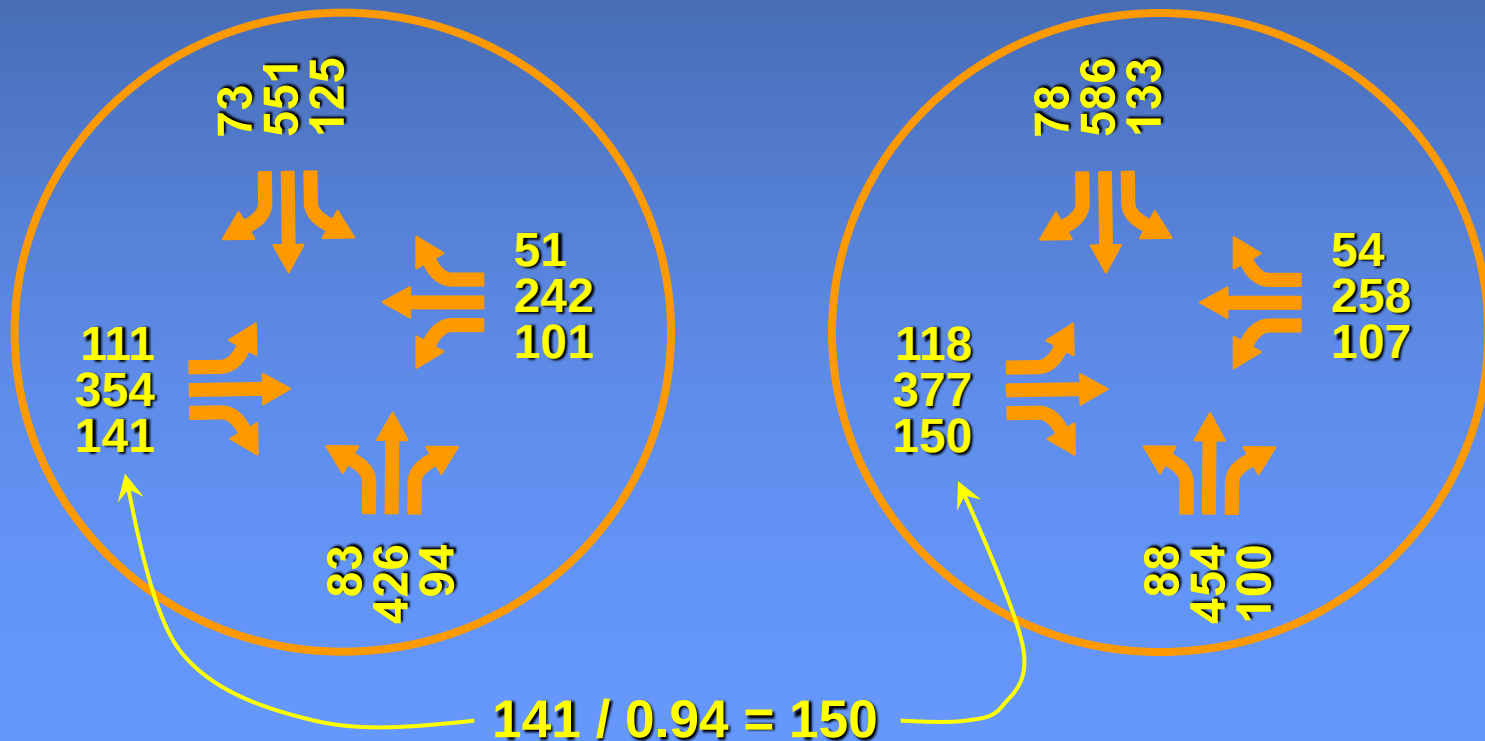
PCEs



Example Step 2: PHF Factor

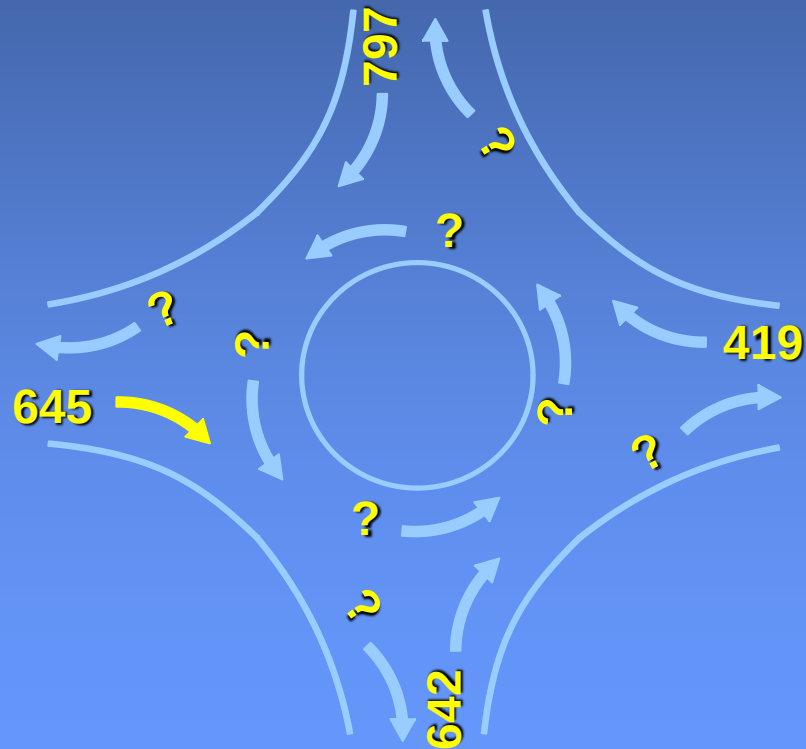
PCEs (hourly)

PCEs (peak 15 minutes)



Example Step 3: Calculate Entry Volume

- **Entry volume = sum of entering turning movements**



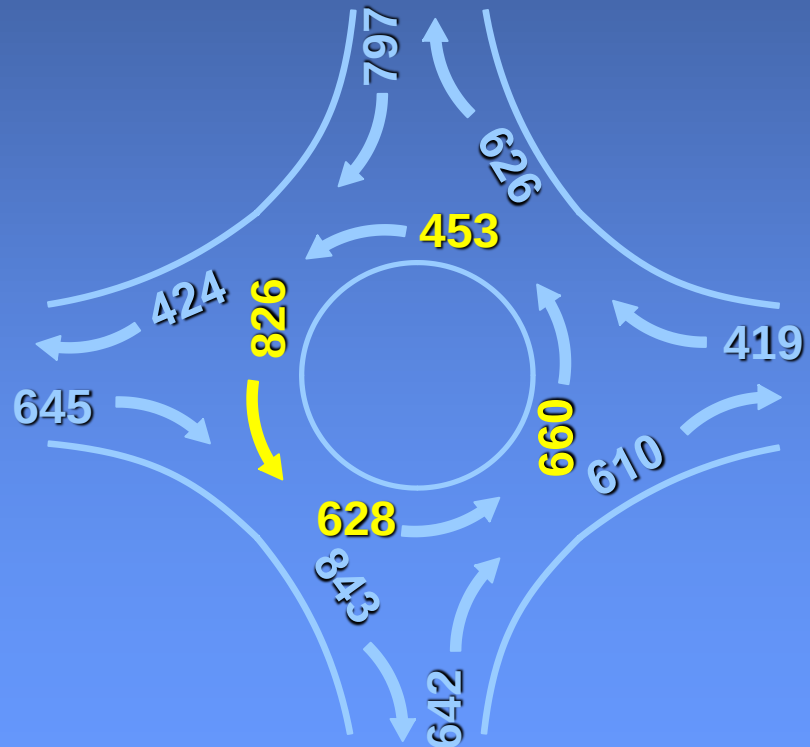
Example Step 4: Calculate Exit Volume

- Exit volume = sum of turning movements as shown



Example Step 5: Calculate Circulatory Volume

- Circulatory volume = sum of turning movements as shown**



Example: Solution

Turning
movements

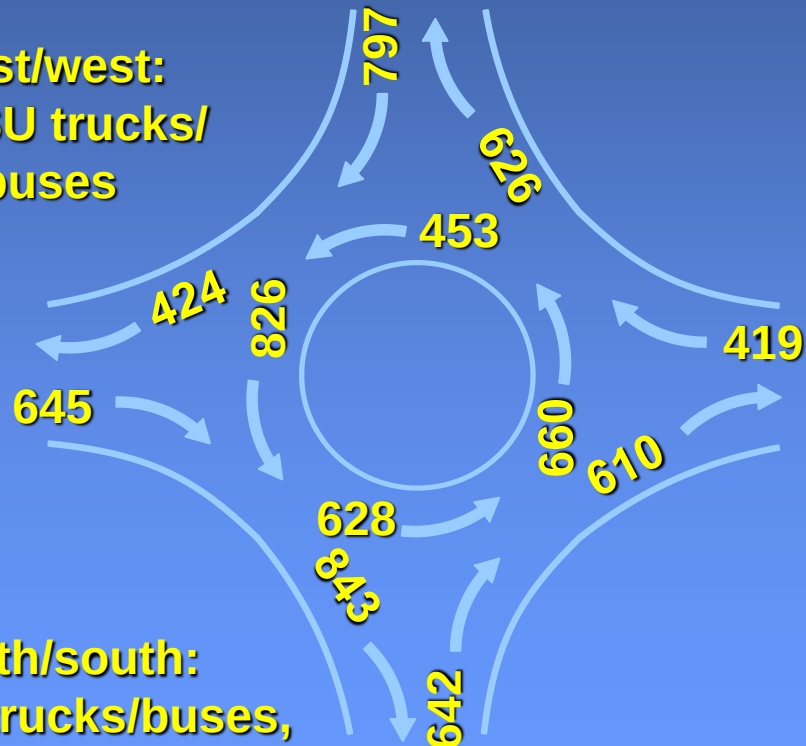
Roundabout
volumes

PHF = 0.94



East/west:
2% SU trucks/
buses

North/south:
4% SU trucks/buses,
2% combo trucks



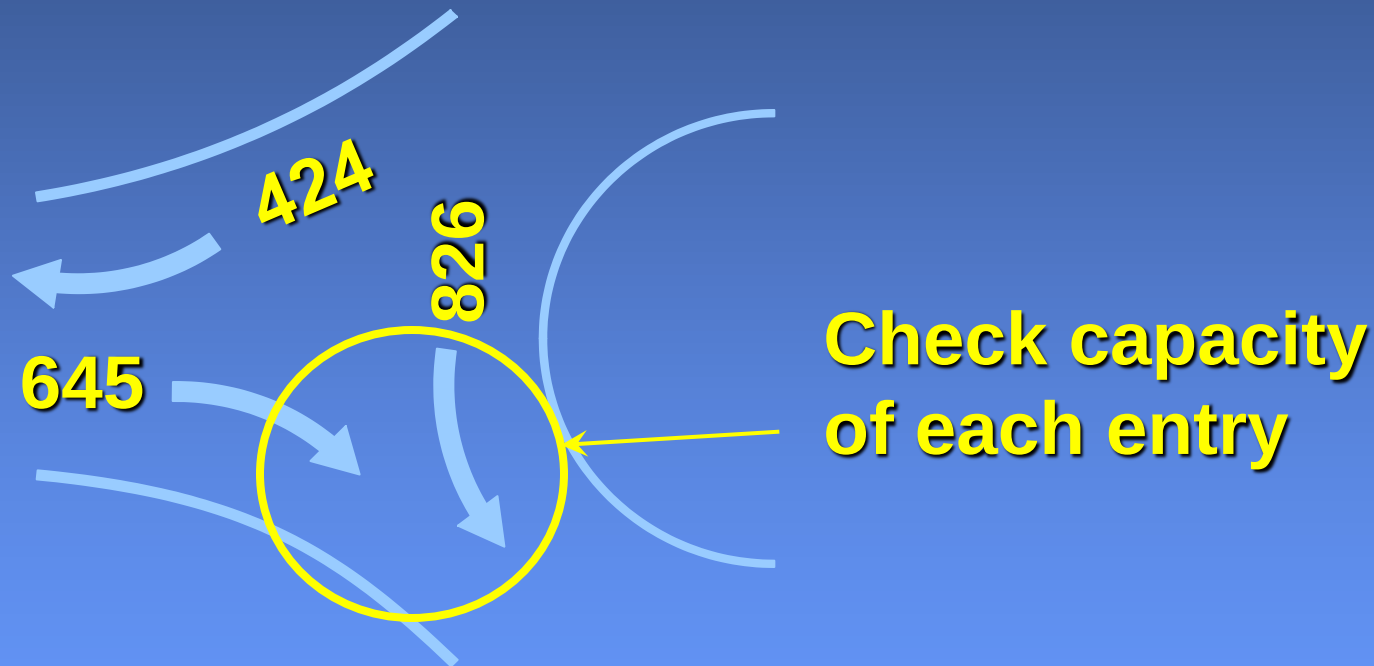
Example: Capacity Calculation

Roundabout
volumes

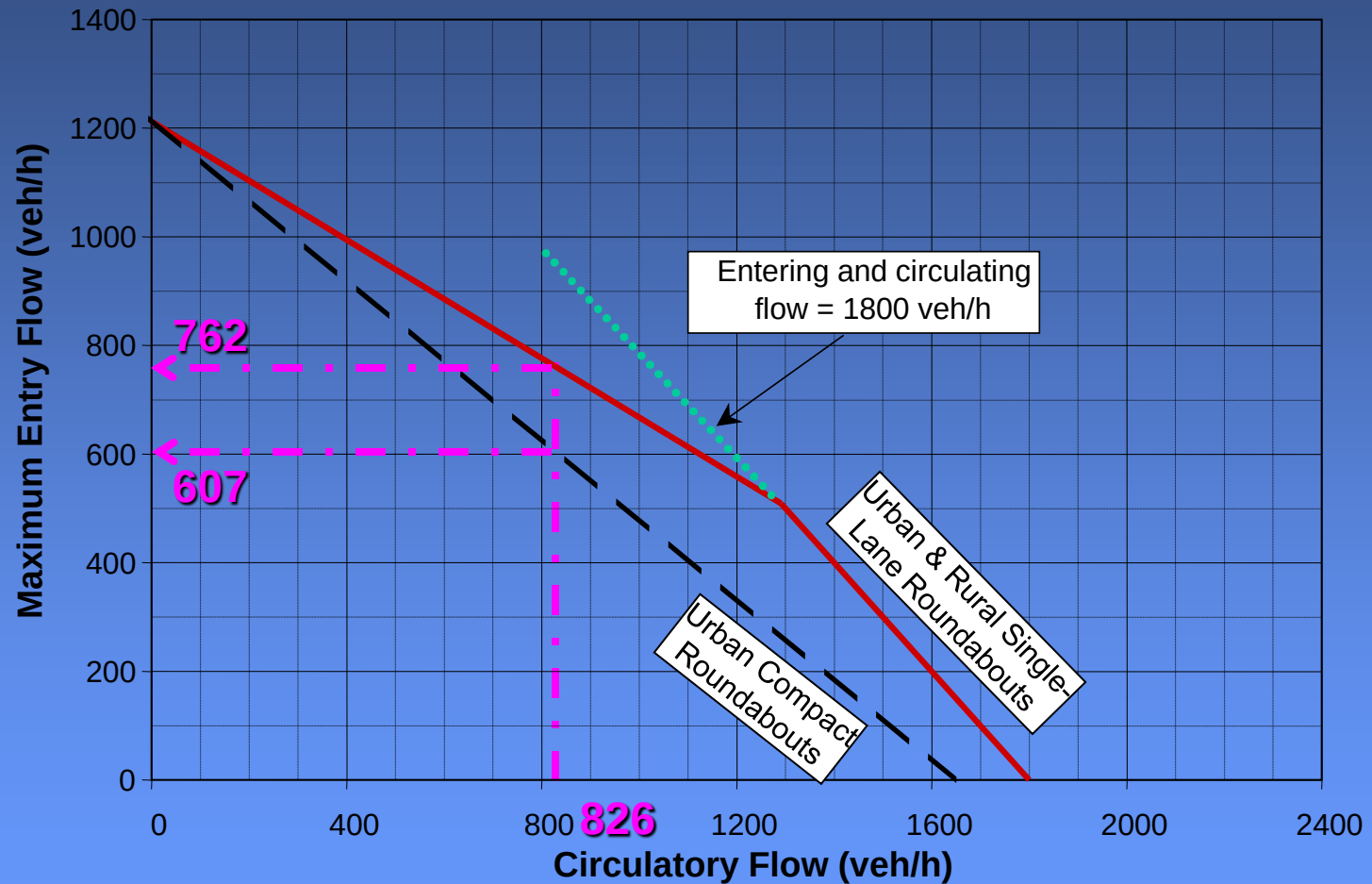
Roundabout
category?



Example: Capacity Calculation



Example: Capacity check

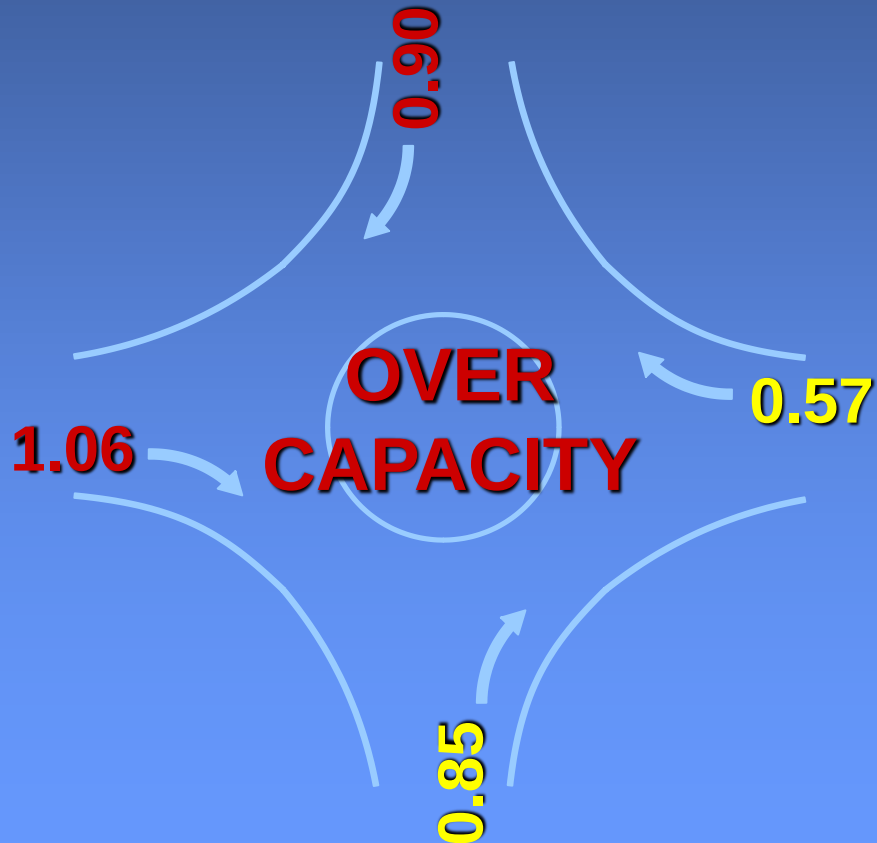


Example: Capacity Check

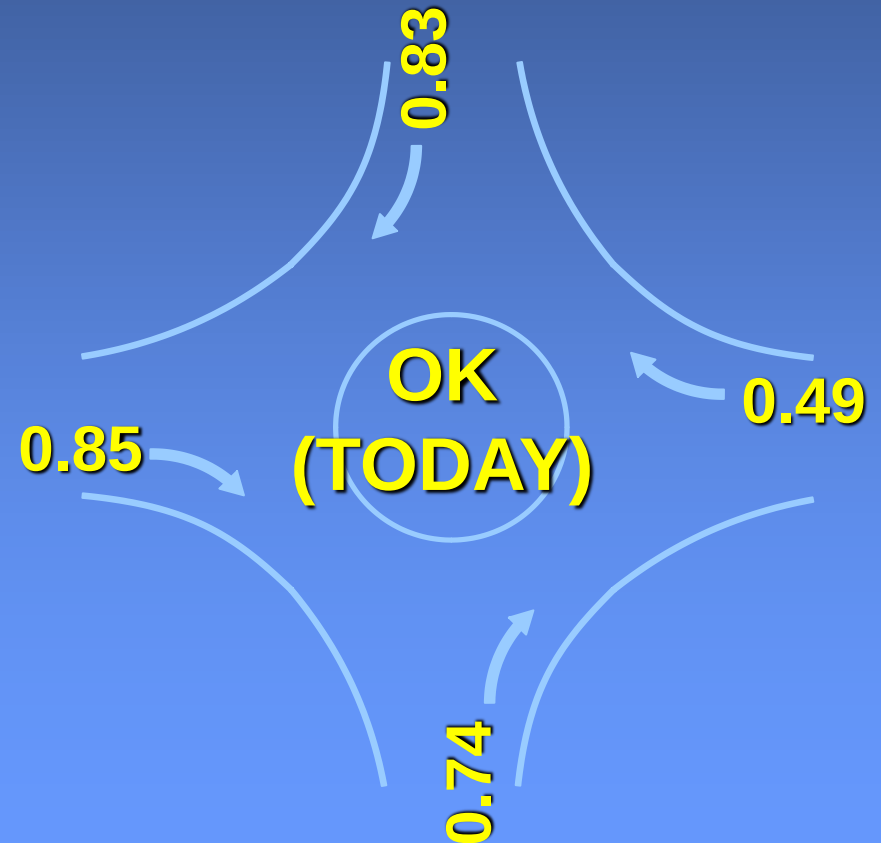
- **Entering volume = 645 pce/h**
- **Capacity of entry:**
 - **Single-lane: 762 pce/h**
 - **Urban compact: 607 pce/h**
- **Volume-to-capacity ratio:**
 - **Single-lane: $645 / 762 = 0.85$ AT**
 - **Urban compact: $645 / 607 = 1.06$ OVER**
- **Repeat calculation for other approaches**

Solution: Capacity Calculation

Urban Compact



Single-Lane



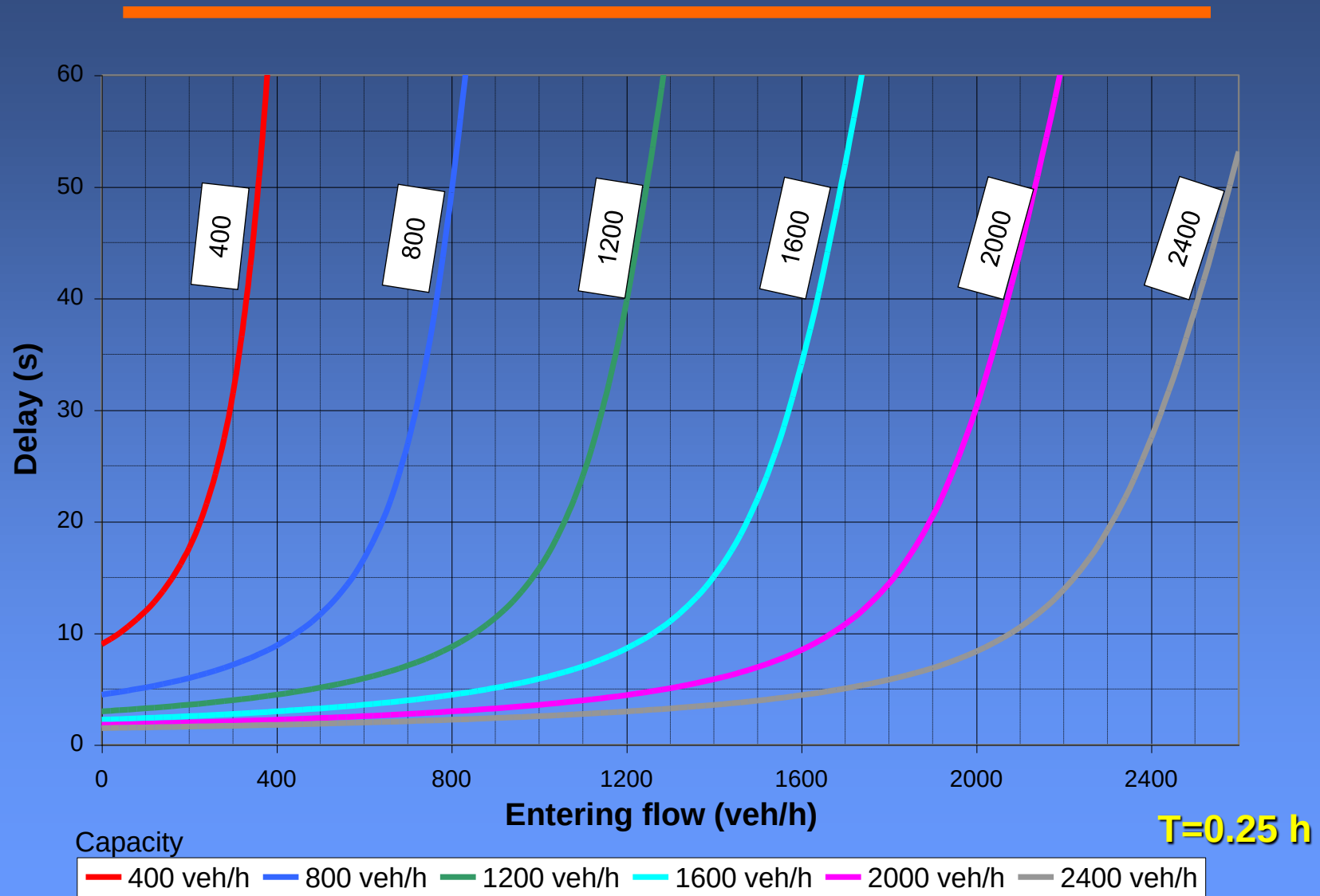
Operational Analysis

- **Capacity**
- **Performance measures**
 - Delay
 - Queues
 - Level of service
- **Field evaluation of existing roundabouts**

Delay

- **Control delay**
 - Includes initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay
- **Geometric delay**
 - Delay experienced by a single vehicle with no conflicting flows
 - Caused by geometric features
- **Total delay = Control + Geometric**
- **Typical measure used: control delay**

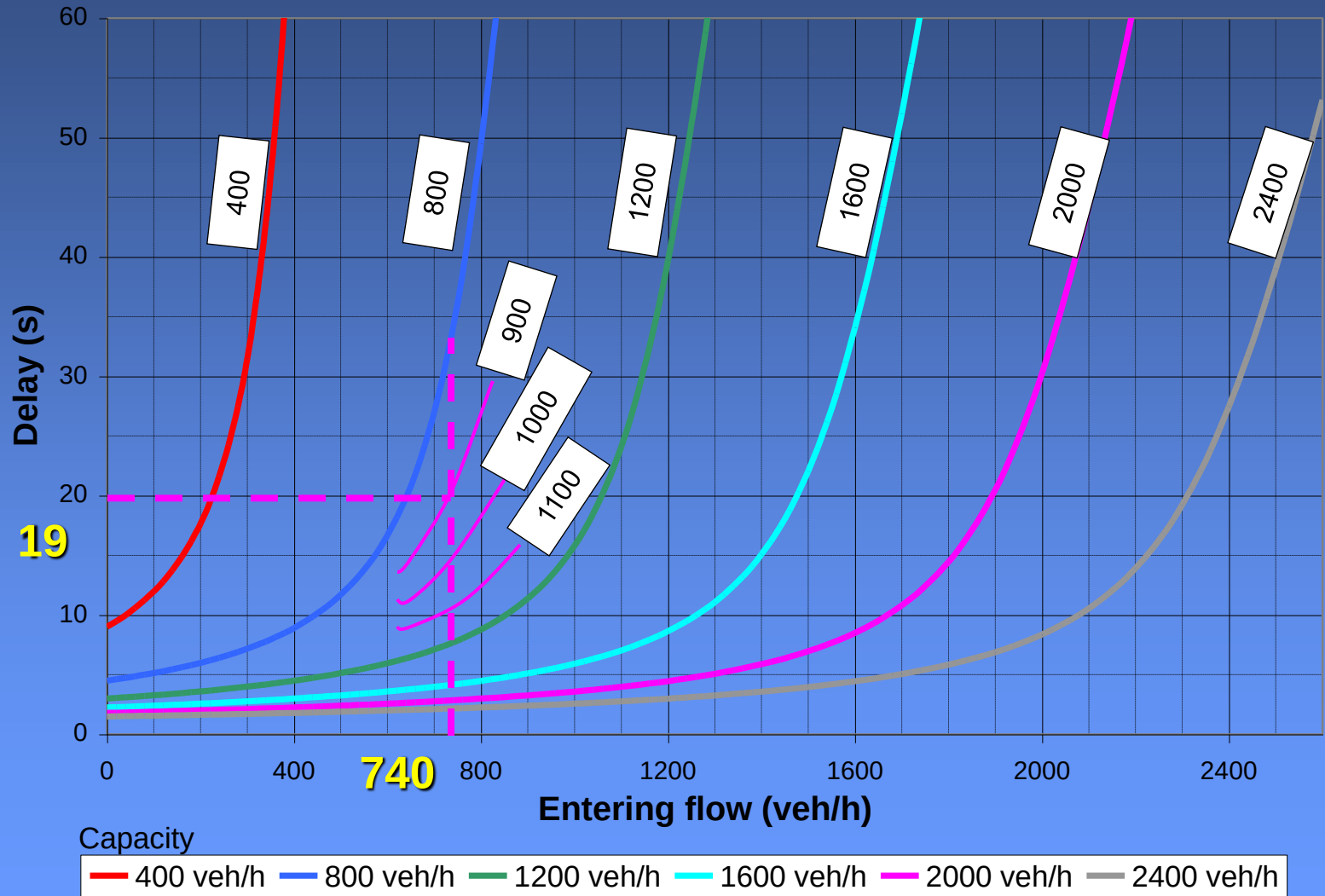
Control Delay



Delay: Example

- **Approach with following characteristics:**
 - Capacity = 900 veh/h
 - Entering flow = 740 veh/h
 - $T = 15 \text{ min (0.25 h)}$
- **Delay = ?**

Delay: Example



Delay: Example

- **Approach with following characteristics:**
 - **Capacity = 900 veh/h**
 - **Entering flow = 740 veh/h**
 - **$T = 15 \text{ min (0.25 h)}$**
- **Delay = 19 s (19.5 s by equation)**

Average Delay for the Entire Intersection

- Use for comparison with signalized and AWSC intersections

$$D_{\text{intersection}} = \frac{\sum_i D_i V_i}{\sum_i V_i}$$

where:

$D_{\text{intersection}}$ = intersection delay, s/veh

$D_{\text{approach } i}$ = delay on approach i , s/veh

$V_{\text{approach } i}$ = volume on approach i , veh/h

Queue Estimation

- **Average queue (50th percentile)**
 - Equivalent to vehicle-hours of delay per hour on an approach
 - Useful for comparing performance with other intersection forms
- **Maximum queue (95th percentile)**
 - Used for design purposes
 - Most common queue parameter

50th Percentile (Average) Queue Estimation

Little's rule:

$$L = v * d / 3600$$

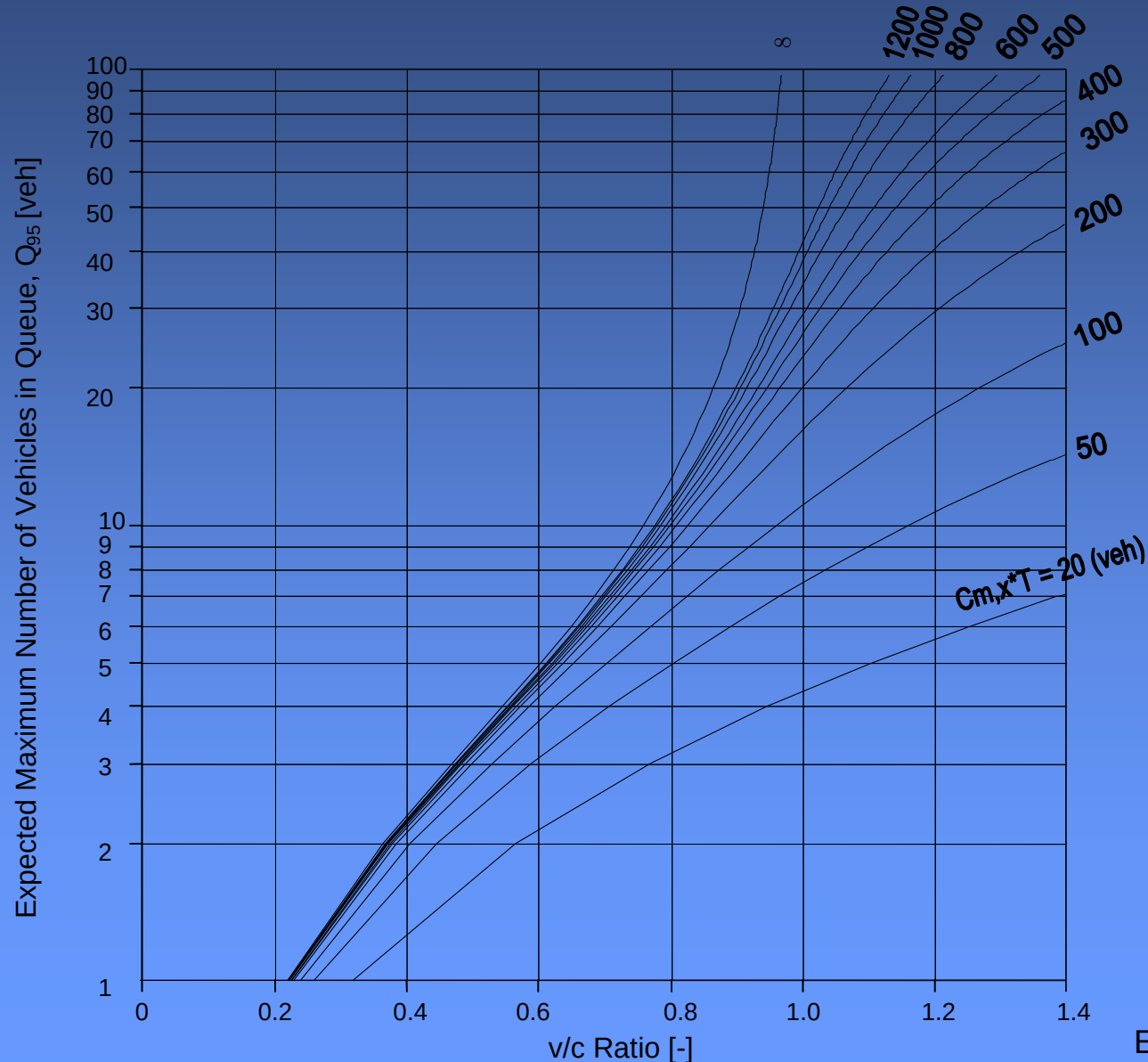
where:

L = queue length, veh

v = entry flow, veh/h

d = average delay, s/veh

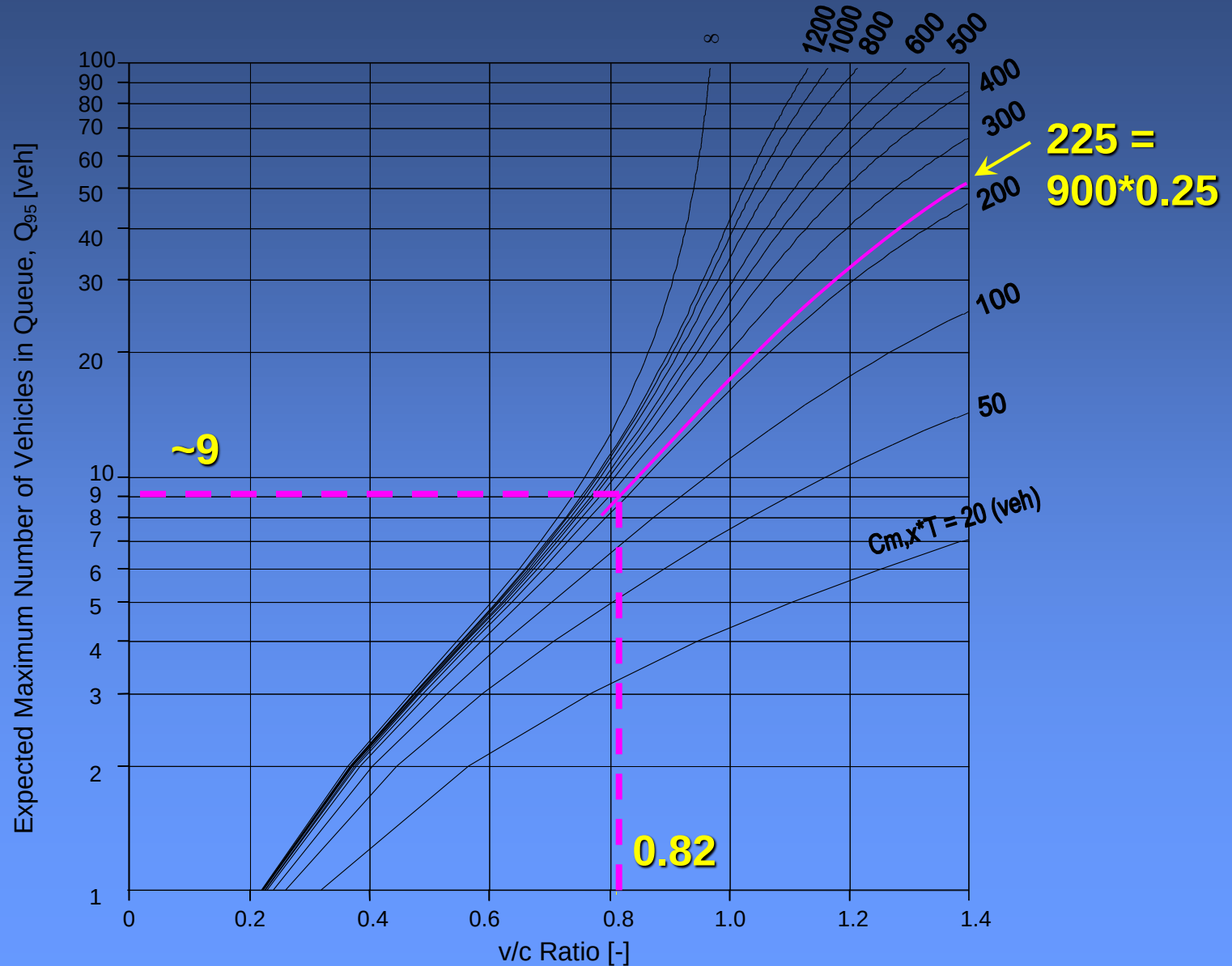
95th Percentile Queue Estimation



Queue: Example

- **Same approach as for delay example:**
 - Capacity = 900 veh/h
 - Entering flow = 740 veh/h ($v/c = 0.82$)
 - $T = 15$ min (0.25 h)
- **Design (95th %ile) Queue = ?**

Queue: Example



Queue: Example

- **Same approach as for delay example:**
 - **Capacity = 900 veh/h**
 - **Entering flow = 740 veh/h ($v/c = 0.82$)**
 - **$T = 15$ min (0.25 h)**
- **95th %ile Queue = 9-10 veh (9.4 by eqn)**
- **Design Queue = 10 veh**

Level of Service

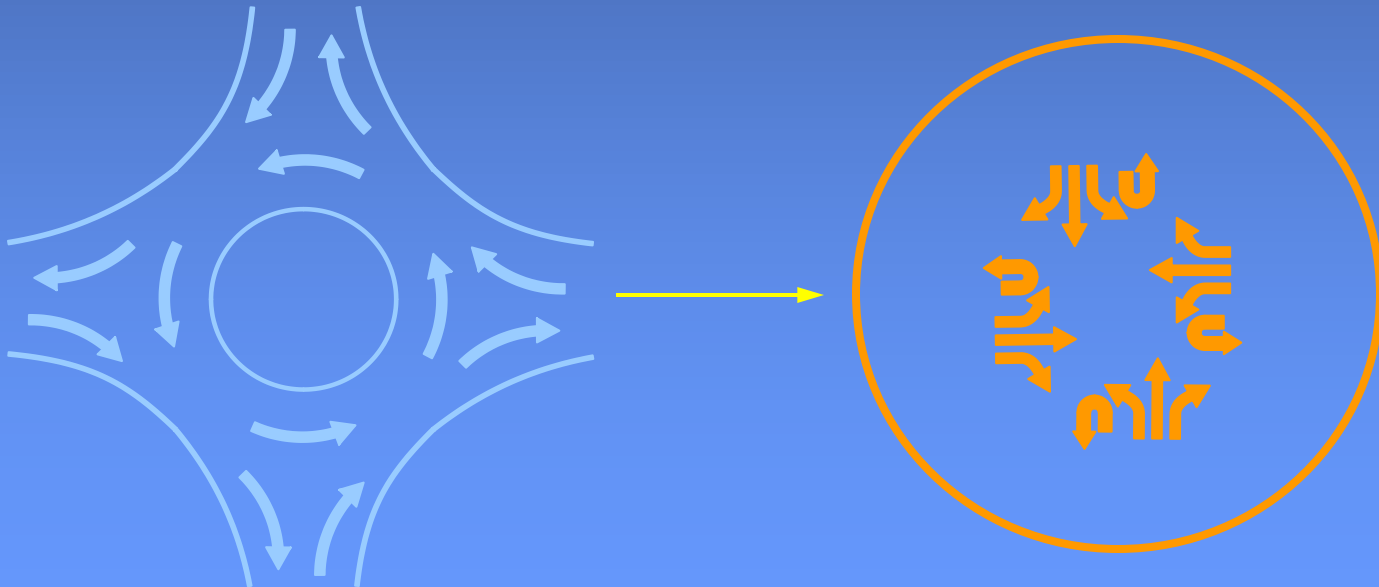
- **Level of service not currently defined for roundabouts in HCM**
- **The dilemma:**
 - **Delay for all movements, critical approach, or critical movement?**
 - **What thresholds between letter grades?**
- **As substitute, report degree of saturation and delay**

Operational Analysis

- **Capacity**
- **Performance measures**
- **Field evaluation of existing roundabouts**

Field Evaluation of Existing Roundabouts

- **Three methods**
 - **Direct turning movement count**
 - **Hose counts + O-D sample**
 - **Hose counts + right turns**



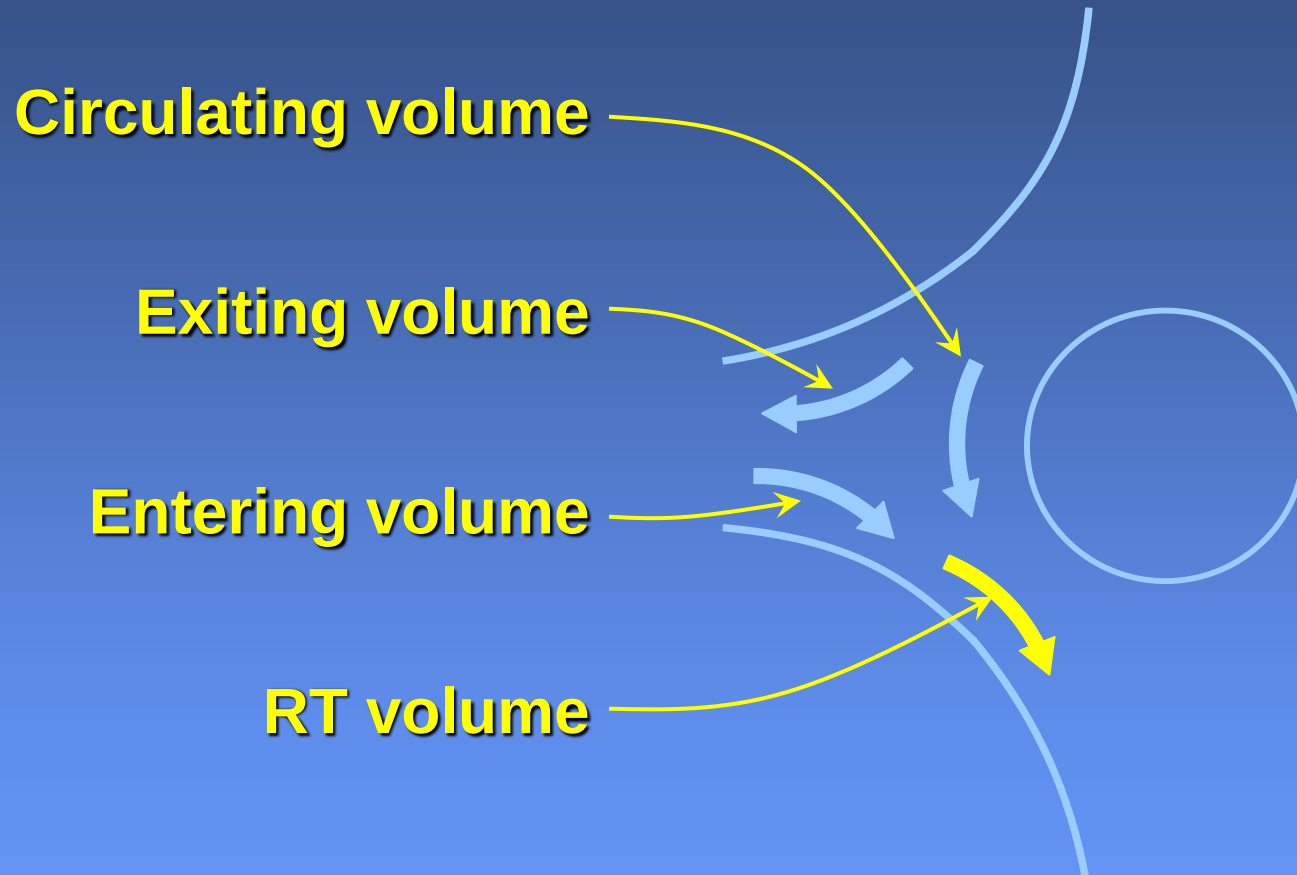
Method 1: Direct Turning Movement Count

- **Requires person to track vehicles traveling through the roundabout**
- **Only feasible at small roundabouts with low volumes**
- **Video analysis**

Method 2: Hose Counts + O-D Sample

- **Hose counts across entries, exits, and circulatory roadway**
- **Origin-destination sample by matching license plates or other method**
- **Need to check that inbound and outbound flows balance at each junction**
- **O-D survey is labor intensive**

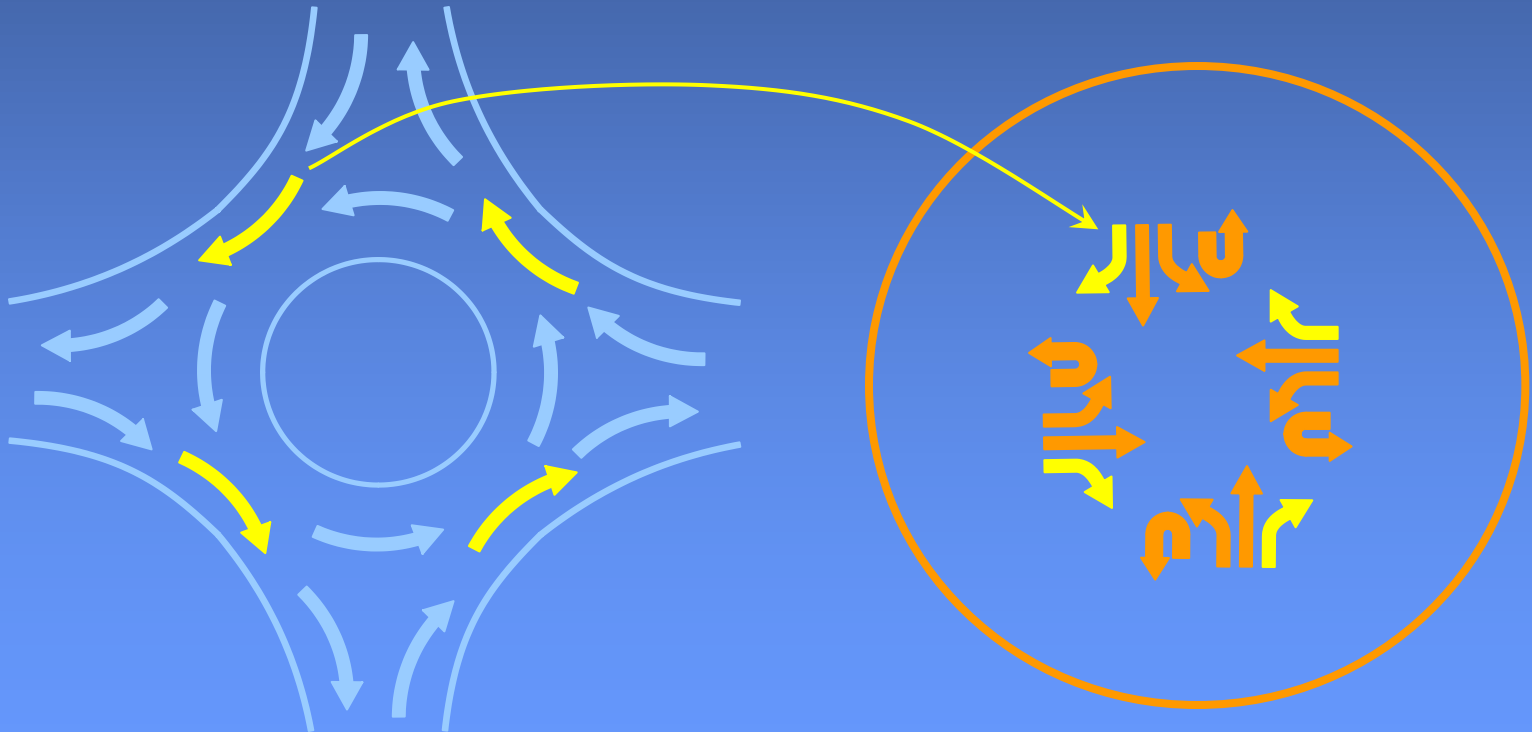
Method 3: Hose Counts + Right Turns



- **Method assumes negligible U-turns**

Step 1: Measure Right Turns

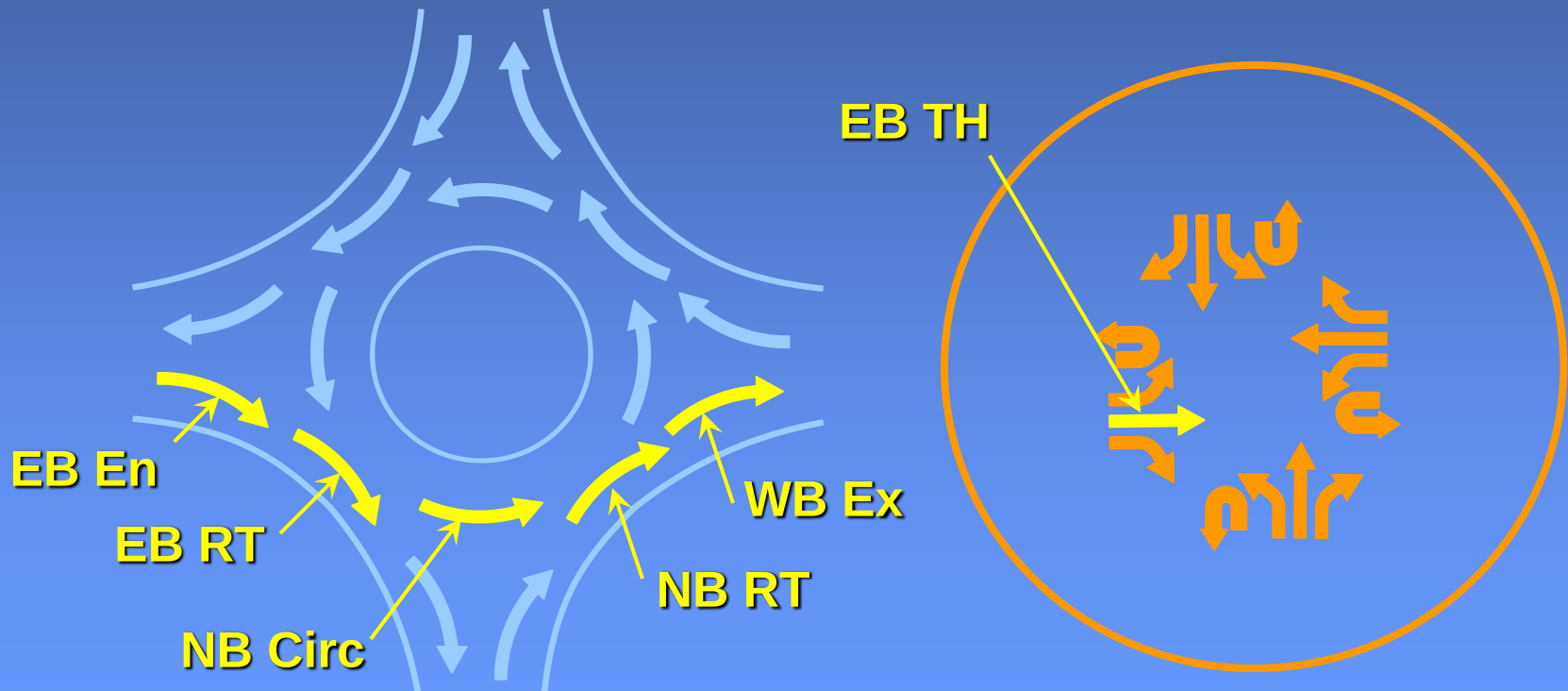
Right turns: Need to be collected in field



Step 2: Calculate Through Movements

Through movements:

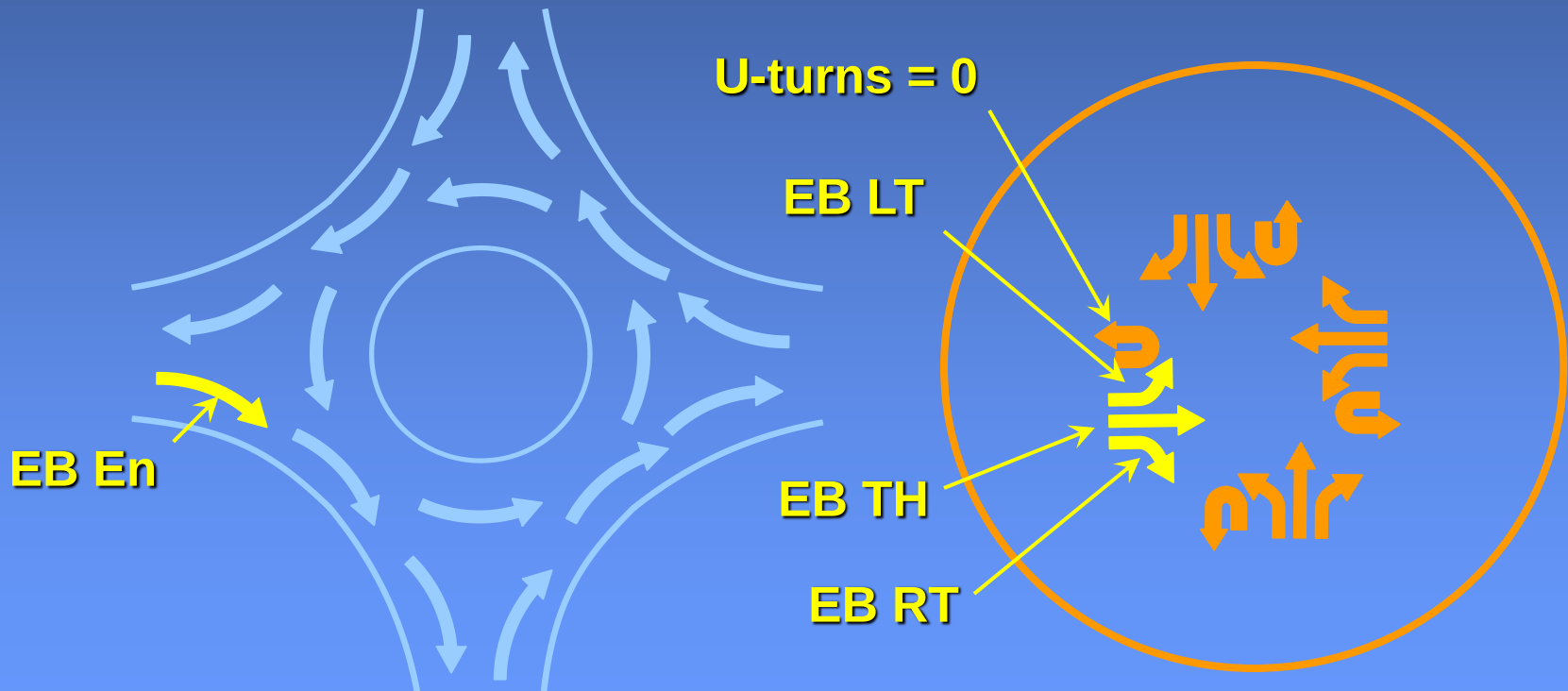
$$EB\ TH = EB\ En + WB\ Ex - (EB\ RT + NB\ Circ + NB\ RT)$$



Step 3: Calculate Left Turns

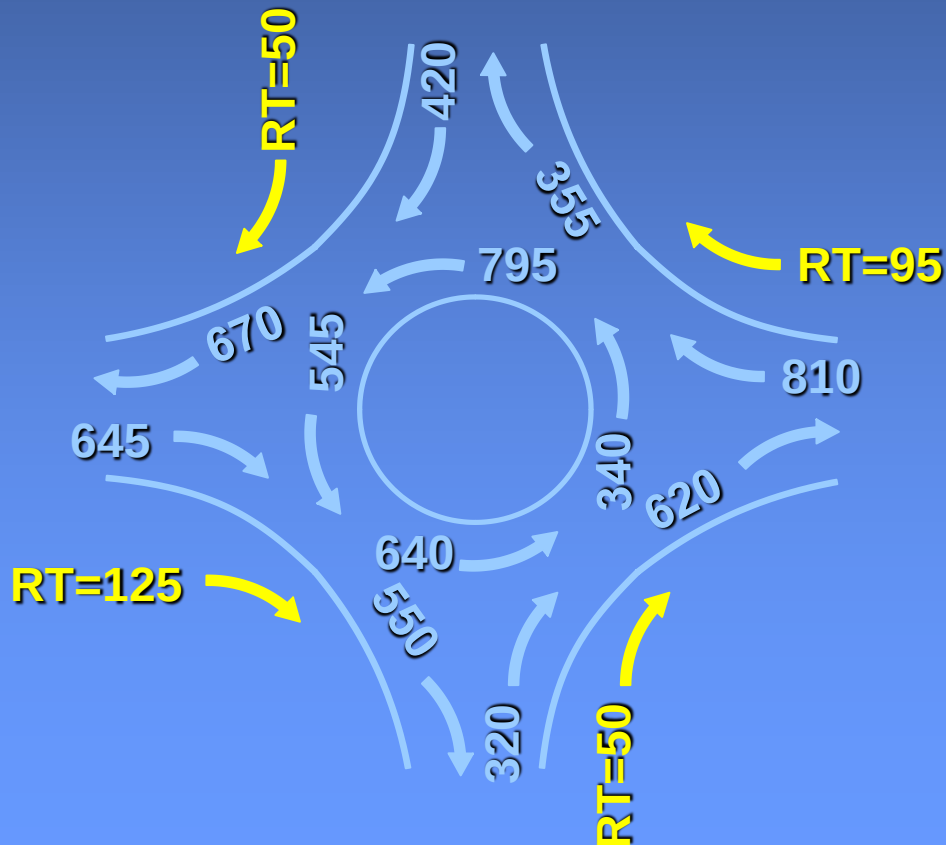
Left turns:

$$EB\ LT = EB\ En - (EB\ TH + EB\ RT)$$



Step 1: Measure Right Turns

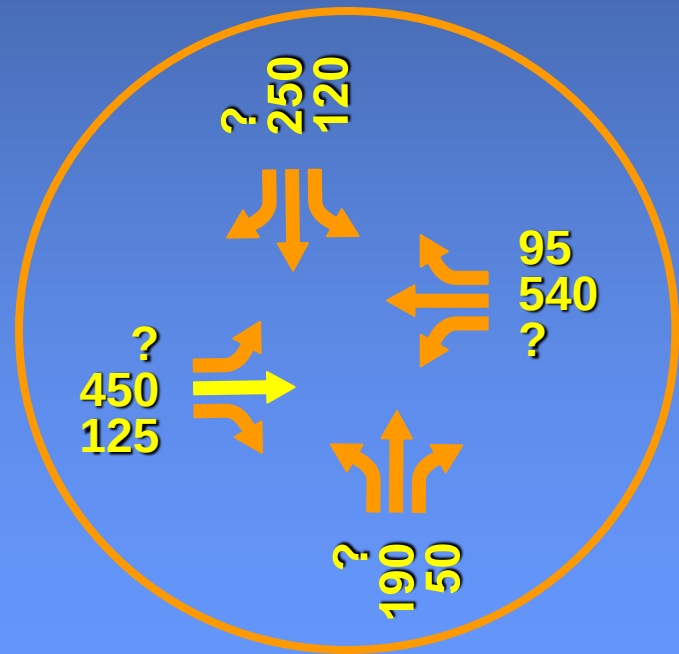
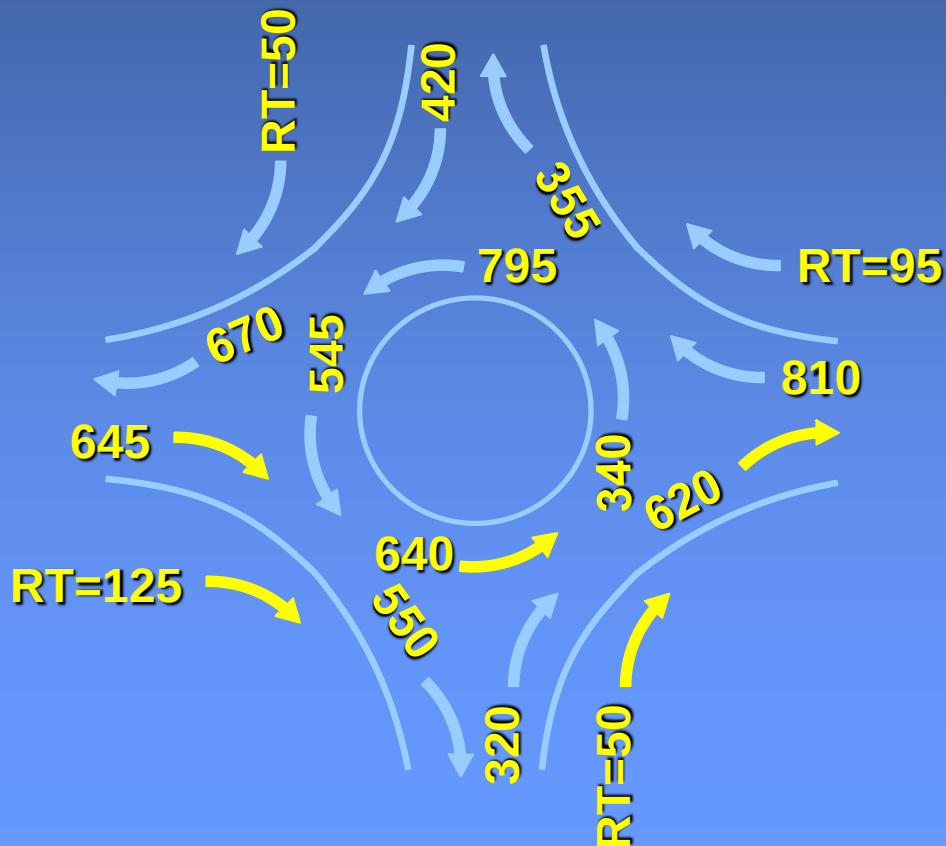
Right turns: Need to be collected in field



Step 2: Calculate Through Movements

Through movements:

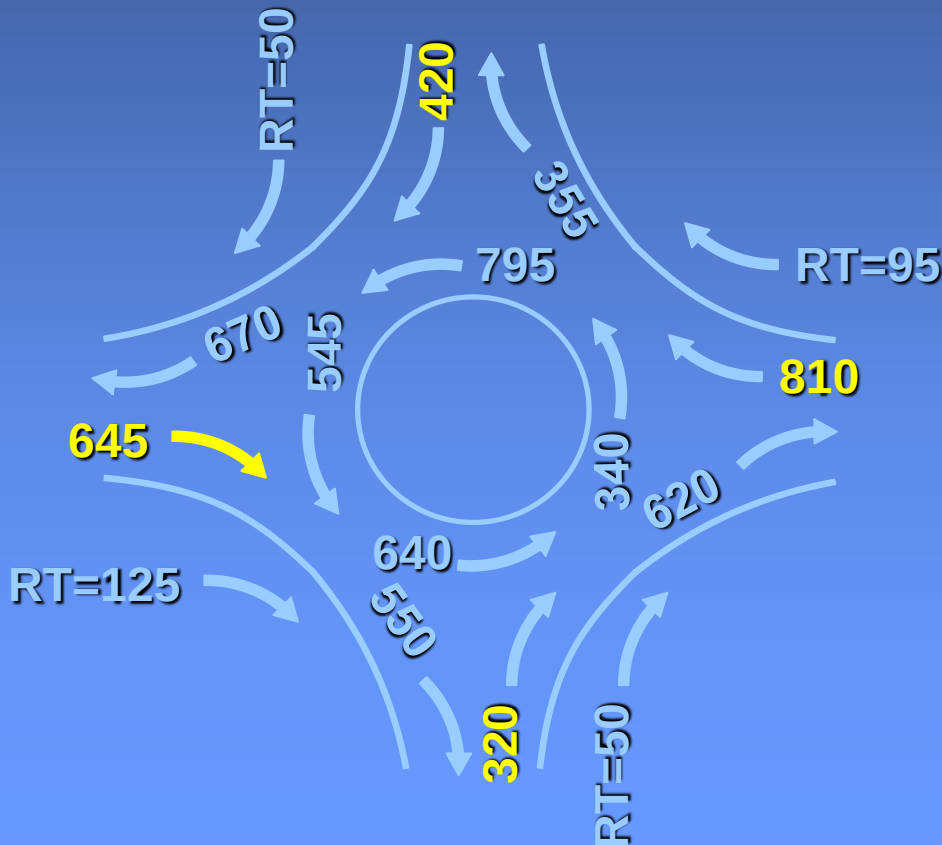
$$\begin{aligned} \text{EB TH} &= \text{EB En} + \text{WB Ex} - (\text{EB RT} + \text{NB Circ} + \text{NB RT}) \\ &= 645 + 620 - (125 + 640 + 50) = 450 \end{aligned}$$



Step 3: Calculate Left Turns

Left turns:

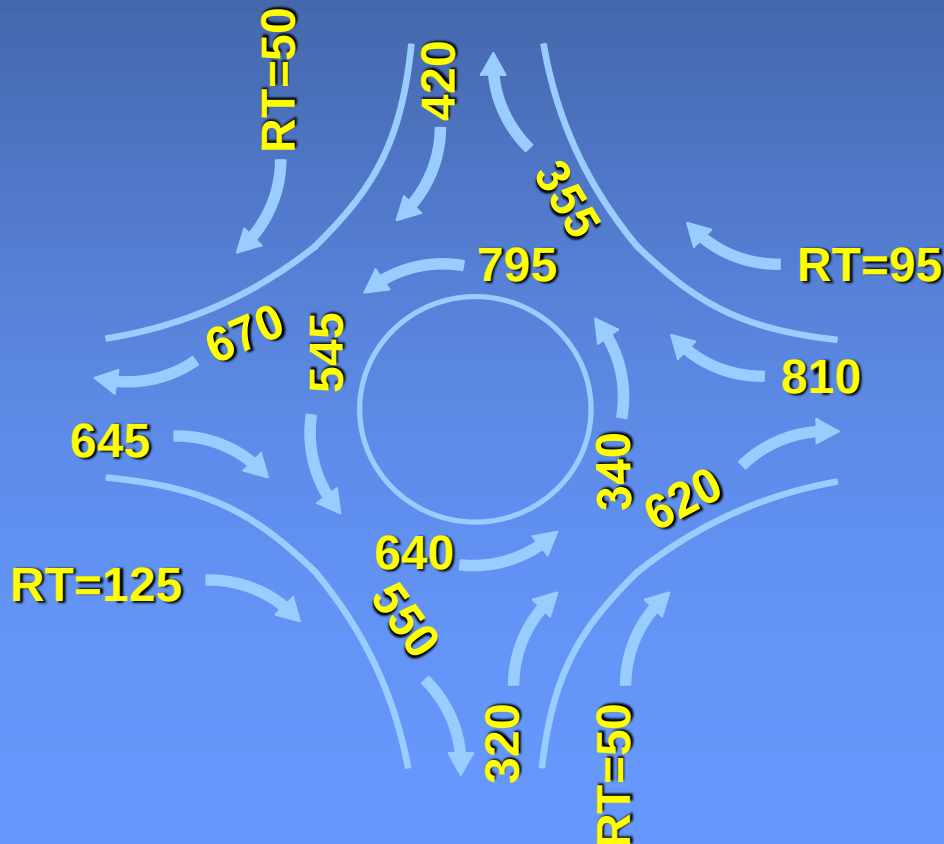
$$\begin{aligned} \text{EB LT} &= \text{EB En} - (\text{EB TH} + \text{EB RT}) \\ &= 645 - (450 + 125) = 70 \end{aligned}$$



Solution: Existing Roundabout

Roundabout
volumes

Turning
movements



Other Field Evaluation

- **Delays and queues can be measured directly using standard techniques**
- **Good for before-after studies**

Conclusion

- **Operational analysis**
 - **Capacity**
 - **Delay**
 - **Queuing**
- **Conversion of turning movements to roundabout volumes and vice versa**
- **Field evaluation of completed roundabouts good for before-after studies**