The Project for Urban Mobility Improvement in Kigali

The 6th Working Group 2 (4. Lecture 1: Roundabout Planning)

22nd February 2023

Contents

1. Design Standards and Manuals

- Highway Capacity Manual (HCM), Transportation Research Board of the National Academies of Science in the United States, 2000 (and 2010)
- Guide to Traffic Engineering Practice, AUSTROADS, 1993

2. Function

(1) Function

- Roundabout perform better at the intersection of roads with roughly similar traffic flows and a high proportion of right turn traffic. Round about can improve safety by simplifying conflicts, reducing vehicle speeds and providing a clearer indication of the driver’s right of way compared to other forms of channelization.

3. Capacity and Diameter

We need to know appropriate size of roundabout based on traffic volume when we make plan and design.

Roughly entry capacity for a roundabout by diameter is shown in figures below.

Entry capacity for a single lane roundabout with a 4 m wide entry lane and one circulating lane

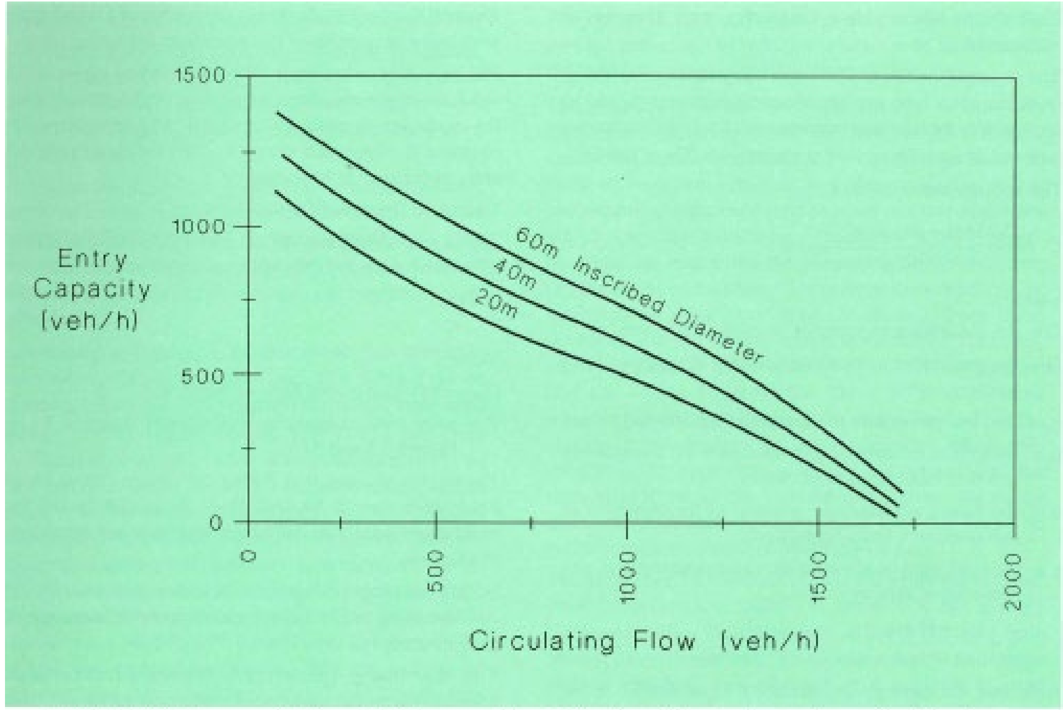


FIGURE 3.5 Entry capacity for a single lane roundabout with a 4 m wide entry lane and one circulating lane.

Entry capacity for a roundabout with two 4 m wide entry lanes and two circulating lanes

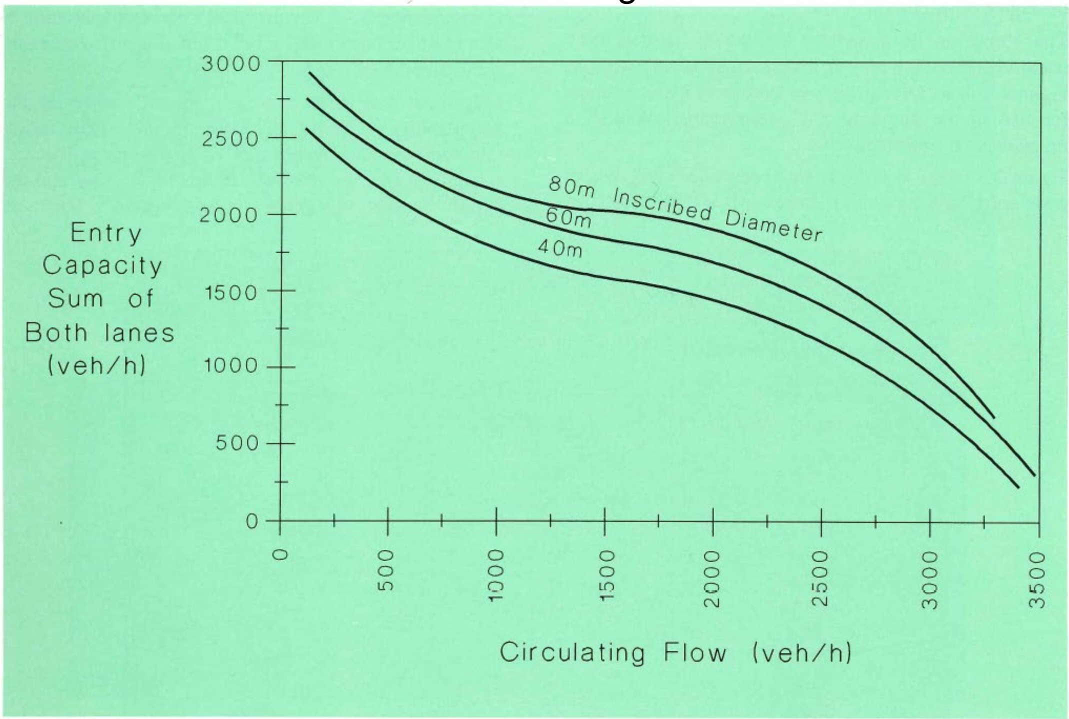


FIGURE 3.6 Entry capacity for a roundabout with two 4 m wide entry lanes and two circulating lanes

Source: AUSTROADS

4. Flow for Calculation of Capacity (by HCM)

Step 1: Convert movement demand volume to flow rates

Step 2: Adjust flow rates for heavy vehicles

Step 3: Determine circulating and existing flow rates

Step 4: Determine entry flow rates by lane

Step 5: Determine the capacity of each entry lane in passenger car equivalents

Step 6: Determine pedestrian impedance to vehicle

Step 7: Convert lane flow rates and capacities into vehicles per hour

Step 8: Compute the volume-to-capacity ratio for each lane

Step 9: Compute the average control delay for each lane

Step 10: Determine LOS for each lane on each approach

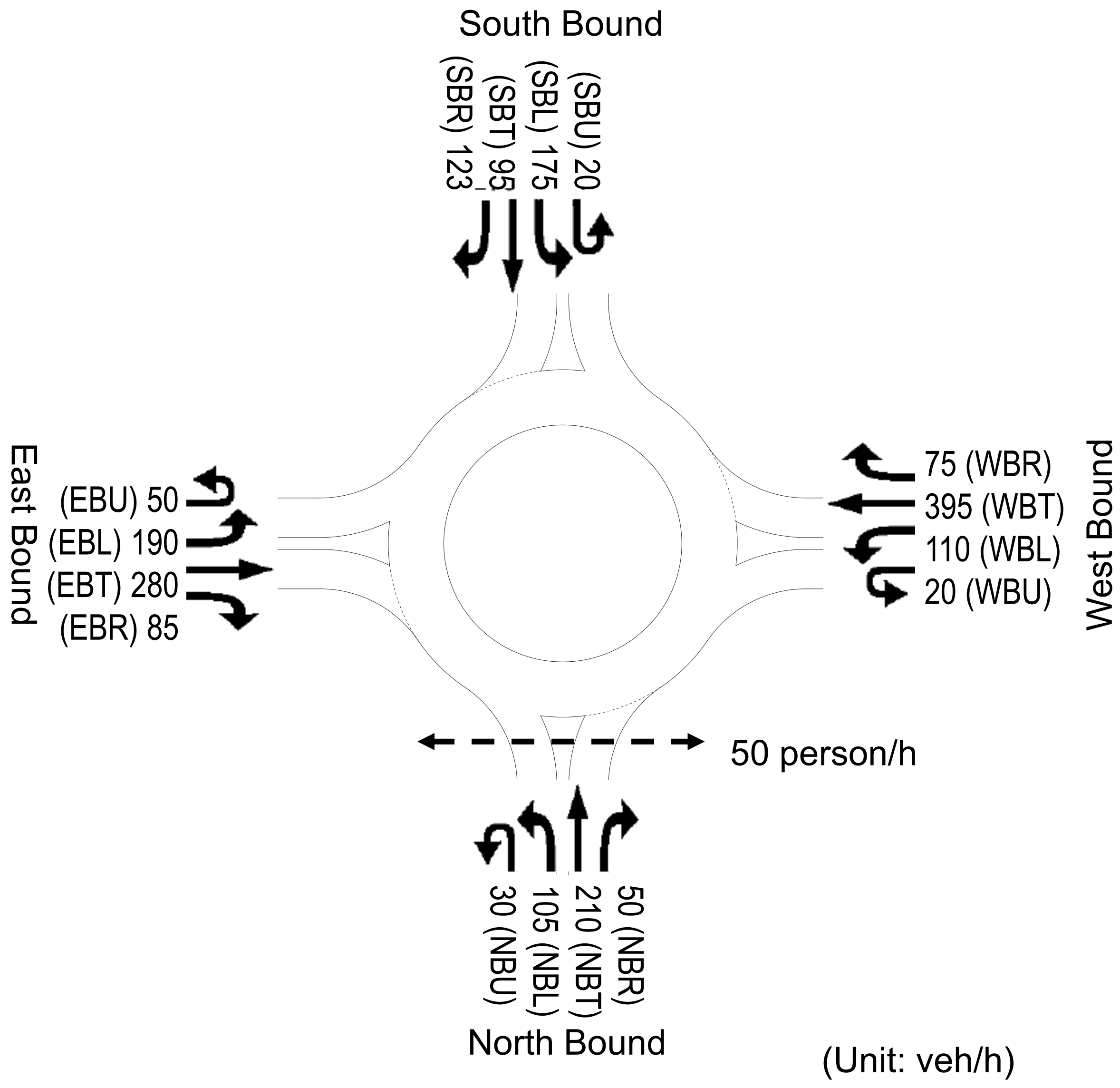
Step 11: Compute the average control delay and determine LOS for each approach and the roundabout as a whole

Step 12: Compute 95th percentile queues for each lane

5. Calculation of Capacity (by HCM)

(0) Condition of Example

- Four legs,
- One-lane entries on each leg,
- One-lane circulating way,
- Percent heavy vehicles for all movements = 2 %,
- Peak hour factor = 0.94,
- Demand volume and lane configurations as shown figures on right and,
- 50 p/h across on the north bound and negligible pedestrian activity across the other three legs.



5. Calculation of Capacity (by HCM)

(1) Step 1: Convert movement demand volume to flow rates

- The flow rate for each movement is prepared for the analysis.
- The peak 15-min traffic volume is measured. The peak 15-min flow rate is calculated by multiplying the peak 15-min traffic volume by 4.
- If 15-min data are not available, hourly demand volume for each movement are converted to peak 15-min demand flow rates in vehicle per hour.

$$v_i = \frac{V_i}{PHF}$$

where

v_i = demand flow rate for movement i (veh/h),

V_i = demand volume for movement i (veh/h), and

PHF = peak hour factor.

$$v_{SBL} = \frac{V_{SBL}}{PHF} = \frac{175}{0.94} = 186$$

Entry	Direction	V_i	PHF	v_i
South Bound	U turn	20	0.94	21
	Left turn	175		186
	Straight	95		101
	Right turn	123		131
West Bound	U turn	20		21
	Left turn	110		117
	Straight	395		420
	Right turn	75		80
North Bound	U turn	30		32
	Left turn	105		112
	Straight	210		223
	Right turn	50		53
East Bound	U turn	50		53
	Left turn	190		202
	Straight	280		298
	Right turn	85		90

5. Calculation of Capacity (by HCM)

(2) Step 2: Adjust flow rates for heavy vehicles

- The flow rate for each movement may be adjusted to account for vehicle stream characteristics by using factors.
- If we have the flow rate by PCU, it is not need to this adjustment.

$$v_{i,pce} = \frac{v_i}{f_{HV}}$$

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

where

$v_{i,pce}$ = demand flow rate for movement i (pc/h),

v_i = demand flow rate for movement i (veh/h),

f_{HV} = heavy-vehicle adjustment factor,

P_T = proportion of demand volume that consists of heavy vehicles, and

E_T = passenger car equivalent for heavy vehicles.

$$f_{HV} = \frac{1}{1+P_T(E_T-1)} = \frac{1}{1+0.02\,(2-1)} = 0.98$$

$$v_{SBL,pce} = \frac{v_{SBL}}{f_{HV}} = \frac{186}{0.98} = 190 \text{ pcu/h}$$

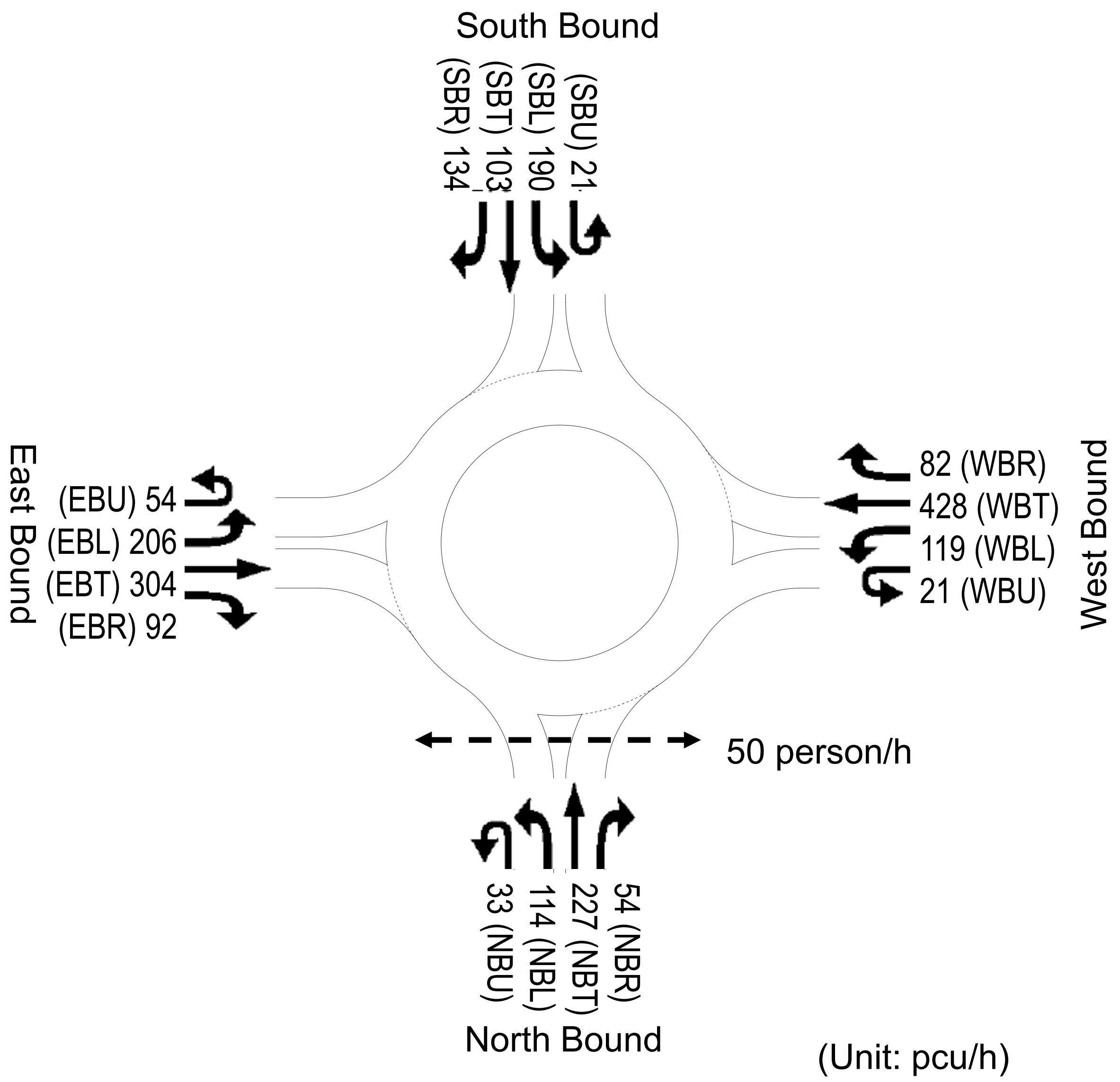
Entry	Direction	v_i	P_T	E_T	f_{HV}
South Bound	U turn	21	0.02	2	21
	Left turn	186			190
	Straight	101			103
	Right turn	131			134
West Bound	U turn	21			21
	Left turn	117			119
	Straight	420			428
	Right turn	80			82
North Bound	U turn	32			33
	Left turn	112			114
	Straight	223			227
	Right turn	53			54
East Bound	U turn	53			54
	Left turn	202			206
	Straight	298			304
	Right turn	90			92

5. Calculation of Capacity (by HCM)

Step 0: Demand volume and lane configurations

Step 1: Convert movement demand volume to flow rates

Step 2: Adjust flow rates for heavy vehicles



5. Calculation of Capacity (by HCM)

(3) Step 3: Determine circulating and existing flow rates

- Circulating and existing flow rates are calculated for each roundabout leg.
- The circulating flow opposing a given entry is defined as the flow conflicting with the entry flow. (i.e, the flow passing in front of the splitter island next to the subject entry)

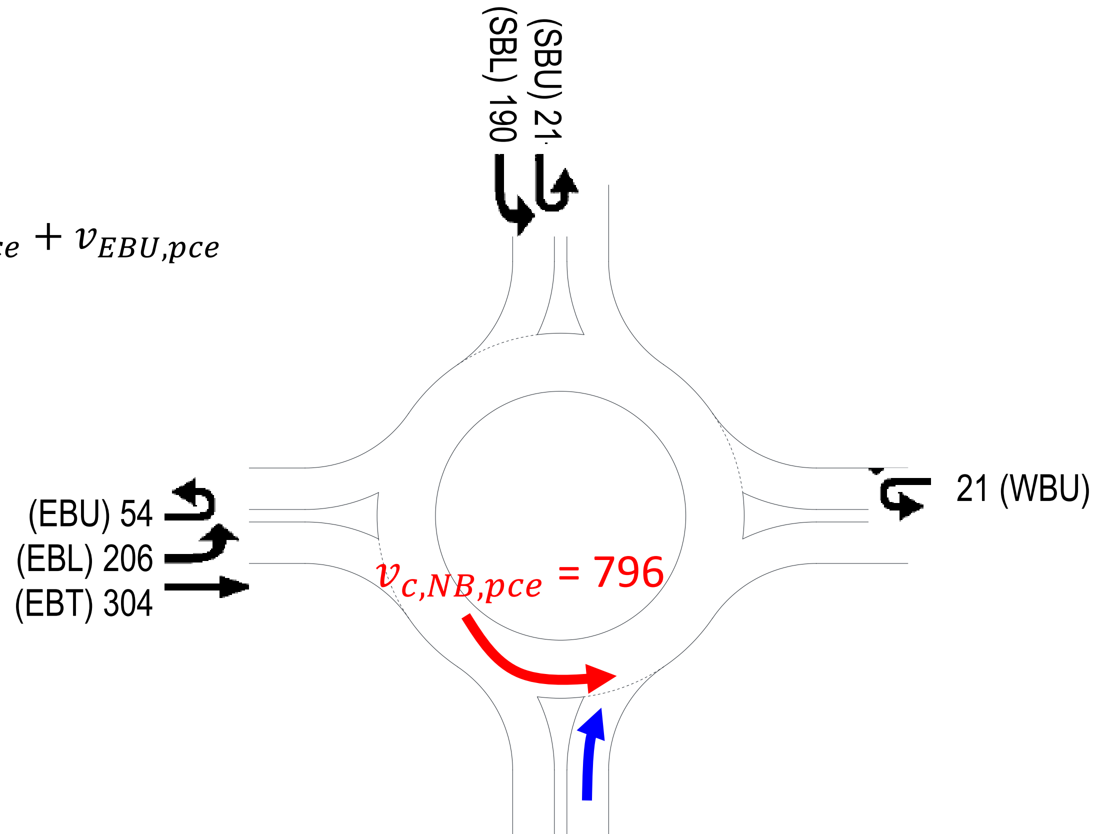
The circulating flow rate calculation for the northbound circulating flow rate is illustrated in below.

$$v_{c,NB,pce} = v_{WBU,pce} + v_{SBL,pce} + v_{SBU,pce} + v_{EBT,pce} + v_{EBL,pce} + v_{EBU,pce}$$

$$v_{c,NB,pce} = v_{WBU,pce} + v_{SBL,pce} + v_{SBU,pce} + v_{EBT,pce} + v_{EBL,pce} + v_{EBU,pce}$$

$$= 21 + 190 + 21 + 304 + 206 + 54$$

$$= 796 \text{ pcu/h}$$



5. Calculation of Capacity (by HCM)

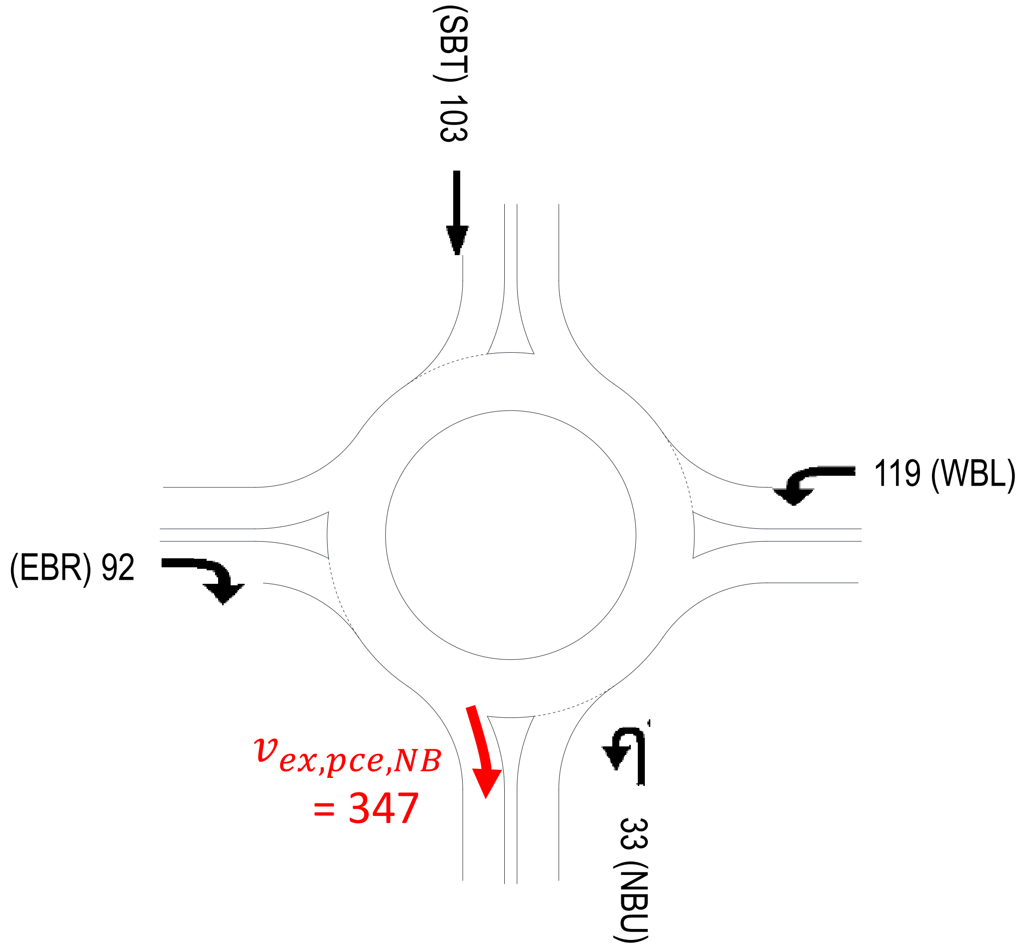
(3) Step 3: Determine circulating and existing flow rates

- The existing flow rate for a given leg is used primarily in the calculation of conflicting flow for right-turn bypass lanes.

The exiting flow rate circulation for the southbound exit is shown in below.

$$v_{ex,pce} = v_{NBU,pce} + v_{WBL,pce} + v_{SBT,pce} + v_{EBR,pce} - v_{EBR,pce,bypass}$$

$$v_{ex,pce,NB} = v_{NBU,pce} + v_{WBL,pce} + v_{SBT,pce} + v_{EBR,oce}$$
$$v_{ex,pce,NB} = 33 + 119 + 103 + 92$$
$$= 347$$



5. Calculation of Capacity (by HCM)

(4) Step 4: Determine entry flow rates by lane

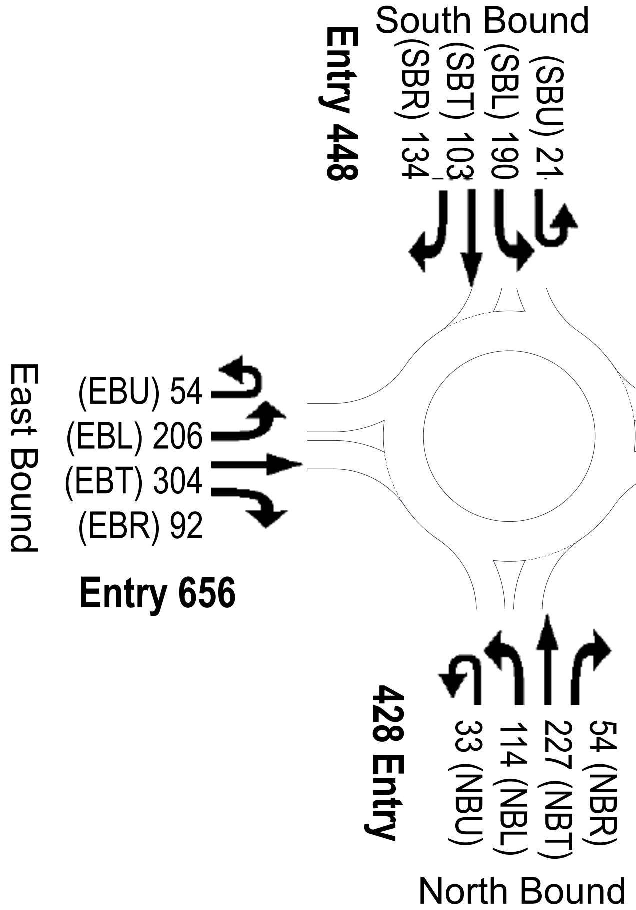
- For single-lane entries, the entry flow rate is the sum of all movement flow rate using that entry.
- For multilane entries or entries with bypass lanes, or both, some procedure may be used to assign flows to each lane. (shown in HCM)

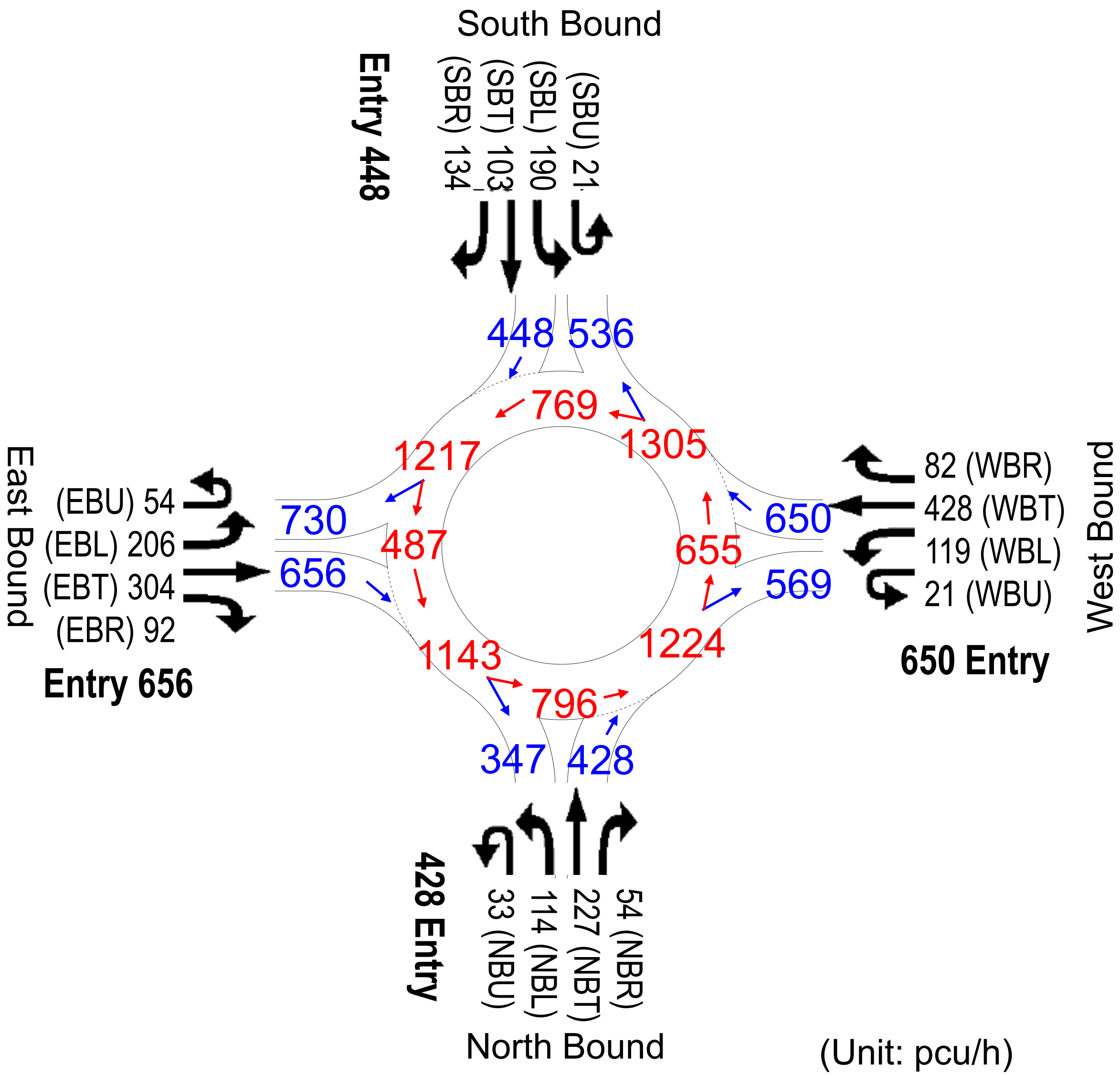
$$v_{e,SB,pce} = v_{SBU,pce} + v_{SBL,pce} + v_{SBT,pce} + v_{SBR,pce}$$
= 21 +190 +103 + 134 = 448

$$v_{e,WB,pce} = v_{WBU,pce} + v_{WBL,pce} + v_{WBT,pce} + v_{WBR,pce}$$
= 21 + 119 + 428 + 82 = 650

$$v_{e,NB,pce} = v_{NBU,pce} + v_{NBL,pce} + v_{NBT,pce} + v_{NBR,pce}$$
= 33+ 114 + 227 + 54 = 428

$$v_{e,EB,pce} = v_{EBU,pce} + v_{EBL,pce} + v_{EBT,pce} + v_{EBR,pce}$$
= 154 + 206 + 304 + 92 = 656




South Bound
Entry 448
(SBR) 134
(SBT) 103
(SBL) 190
(SBU) 21
448
536
769
1305
1217
730
487
656
1143
796
347
428
655
650
569
1224
East Bound
(EBU) 54
(EBL) 206
(EBT) 304
(EBR) 92
Entry 656
82 (WBR)
428 (WBT)
119 (WBL)
21 (WBU)
West Bound
650 Entry
428 Entry
33 (NBU)
114 (NBL)
227 (NBT)
54 (NBR)
North Bound

(Unit: pcu/h)

5. Calculation of Capacity (by HCM)

(5) Step 5: Determine the capacity of each entry lane in passenger car equivalents

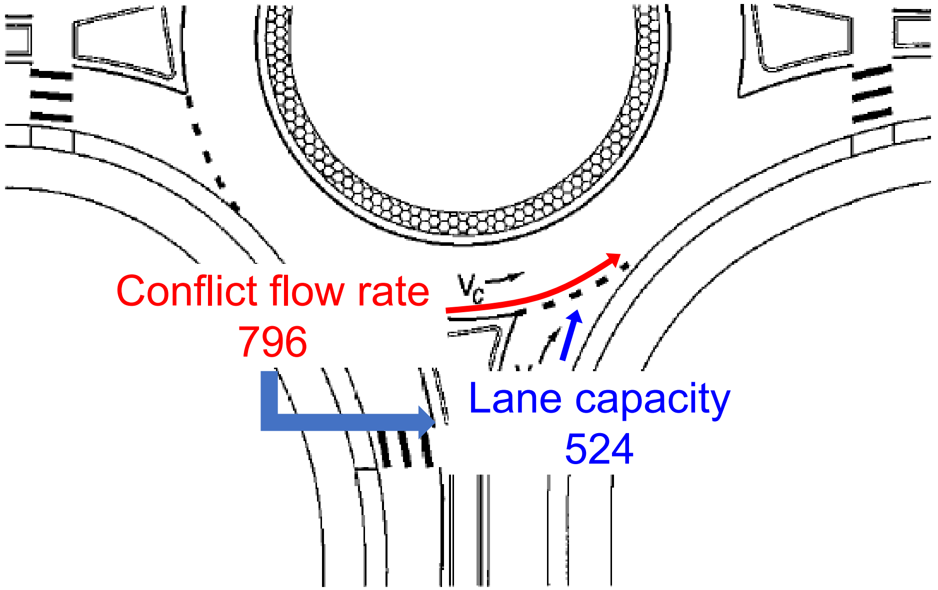
- The capacity of single entry lane conflicted by one circulating lane is based on the conflicting flow

$$c_{e,pce} = 1{,}130e^{(-1.0\times10^{-3})v_{c,pce}}$$

where

$c_{e,pce}$ = lane capacity, adjusted for heavy vehicles (pc/h), and

$v_{c,pce}$ = conflicting flow rate (pc/h).



$$v_{pce,SB} = 1130e^{(-1.0\times10^{-3})v_{c,pce,SB}}$$
$$= 1130e^{(-1.0\times10^{-3})(769)} = 524$$

$$v_{pce,WB} = 1130e^{(-1.0\times10^{-3})v_{c,pce,WB}}$$
$$= 1130e^{(-1.0\times10^{-3})(655)} = 587$$

$$v_{pce,NB} = 1130e^{(-1.0\times10^{-3})v_{c,pce,NB}}$$
$$= 1130e^{(-1.0\times10^{-3})(796)} = 510$$

$$v_{pce,EB} = 1130e^{(-1.0\times10^{-3})v_{c,pce,EB}}$$
$$= 1130e^{(-1.0\times10^{-3})(487)} = 694$$

5. Calculation of Capacity (by HCM)

(6) Step 6 : Determine pedestrian impedance to vehicle

- Pedestrian traffic can reduce the vehicle capacity of a roundabout entry if sufficient pedestrians are present and they assert the right of way typically granted pedestrians in most jurisdictions.
- Under high vehicular conflicting flows, pedestrians typically pass between queued vehicles on entry, thus negligible additional impact on vehicular entry capacity

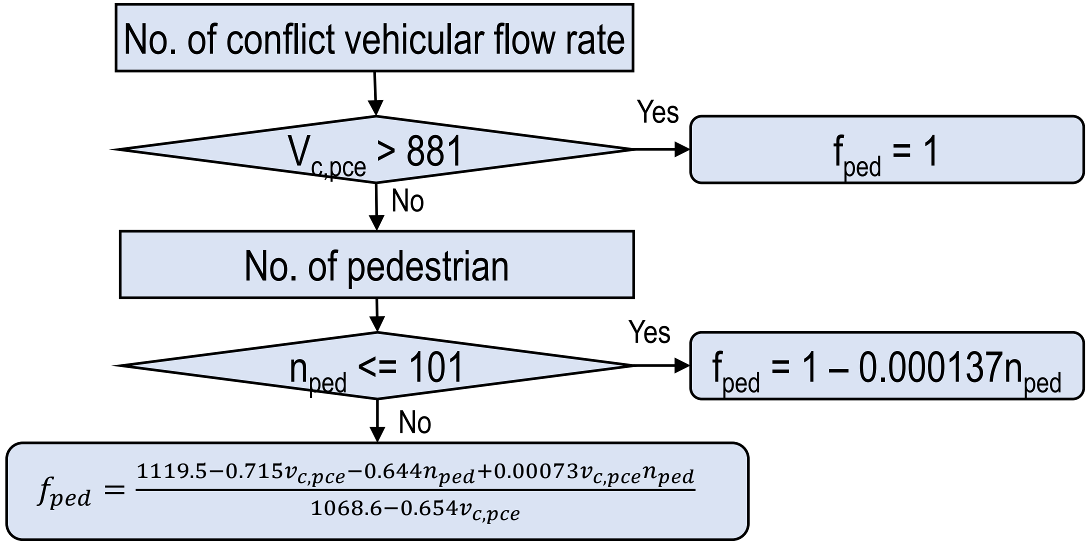
Case	One-Lane Entry Capacity Adjustment Factor for Pedestrians
If $v_{c,pce} > 881$	$f_{ped} = 1$
Else if $n_{ped} \le 101$	$f_{ped} = 1 - 0.000137 n_{ped}$
Else	$f_{ped} = \dfrac{1{,}119.5 - 0.715 v_{c,pce} - 0.644 n_{ped} + 0.00073 v_{c,pce} n_{ped}}{1{,}068.6 - 0.654 v_{c,pce}}$

where

f_{ped} = entry capacity adjustment factor for pedestrians,

n_{ped} = number of conflicting pedestrians per hour (p/h), and

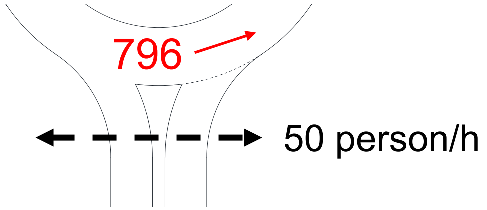
$v_{c,pce}$ = conflicting vehicular flow rate in the circulatory roadway, pc/h.



$V_{c.pce} = 796$

$N_{ped} = 50$

$F_{ped} = 1 – 0.000137 \times (50) = 0.993$



5. Calculation of Capacity (by HCM)

(7) Step 7 : Convert lane flow rates and capacities into vehicles per hour

- The flow rate for a given lane is converted back to vehicle per hour by multiplying the passenger-car-equivalent flow rate computed in the previous step by heavy vehicle factor for the lane.

$$v_i = v_{i,PCE} f_{HV,e}$$

where

v_i = flow rate for lane i (veh/h),

$v_{i,PCE}$ = flow rate for lane i (pc/h), and

$f_{HV,e}$ = heavy-vehicle adjustment factor for the lane (see below).

$v_{SB} = v_{pce,SB} f_{HV,e,SB}$ = 448 × 0.980 = 439

$v_{WB} = v_{pce,WB} f_{HV,e,WB}$ = 650 × 0.980 = 638

$v_{NB} = v_{pce,NB} f_{HV,e,NB}$ = 428 × 0.980 = 420

$v_{EB} = v_{pce,EB} f_{HV,e,EB}$ = 656 × 0.980 = 643

$$c_i = c_{i,PCE} f_{HV,e} f_{ped}$$

where

c_i = capacity for lane i (veh/h),

$c_{i,PCE}$ = capacity for lane i (pc/h),

$f_{HV,e}$ = heavy-vehicle adjustment factor for the lane (see below), and

f_{ped} = pedestrian impedance factor.

$C_{SB} = C_{pce,SB} f_{HV,e,SB} f_{ped}$ = 524 × 0.980 × 1 = 514

$C_{WB} = C_{pce,WB} f_{HV,e,WB} f_{ped}$ = 587 × 0.980 × 1 = 575

$C_{NB} = C_{pce,NB} f_{HV,e,NB} f_{ped}$ = 510 × 0.980 × 0.993 = 497

$C_{EB} = C_{pce,EB} f_{HV,e,EB} f_{ped}$ = 694 × 0.980 × 1 = 680

5. Calculation of Capacity (by HCM)

(8) Step 8 : Compute the volume-to-capacity ratio for each lane

- For a given lane, the volume-to-capacity ratio is calculated by dividing the lane's calculated capacity into its demand flow rate.

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

where

x_i = volume-to-capacity ratio of the subject lane i,

v_i = demand flow rate of the subject lane i (veh/h), and

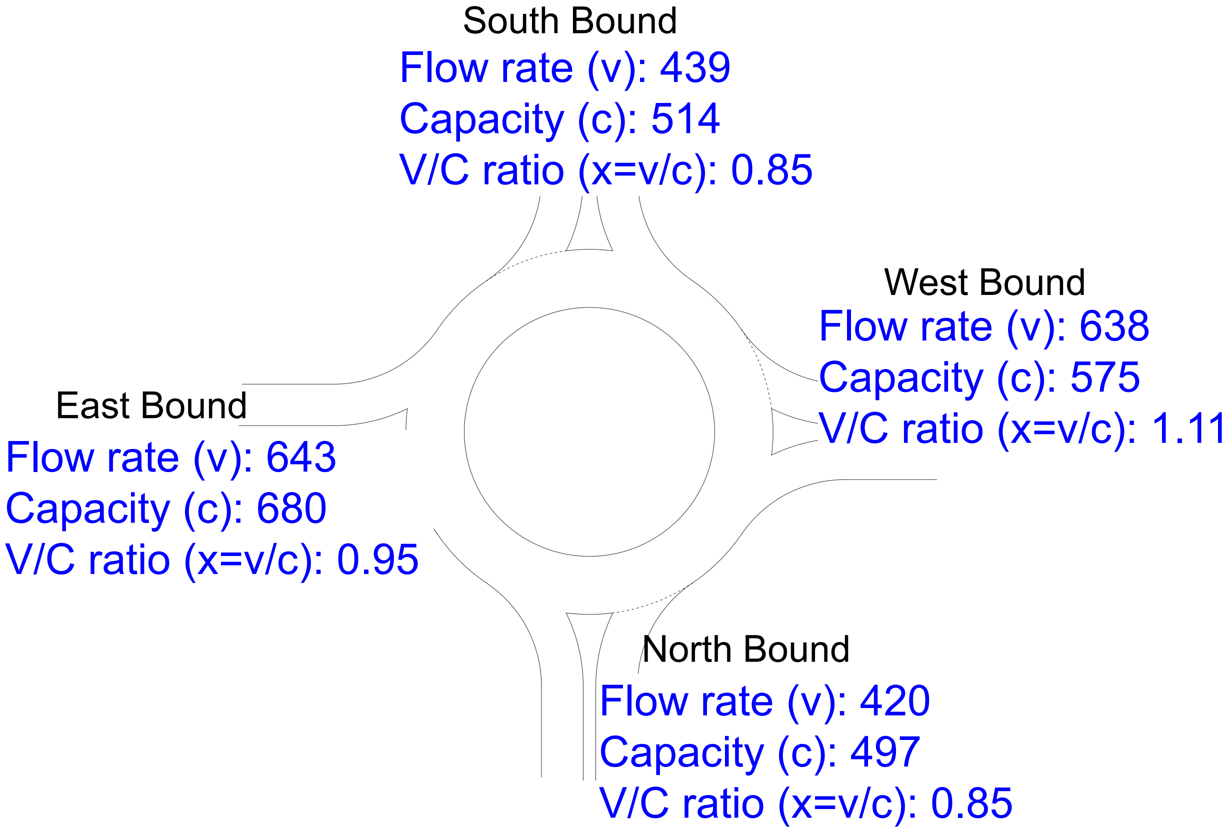
c_i = capacity of the subject lane i (veh/h).

$$x_{SB} = \frac{439}{514} = 0.85$$

$$x_{WB} = \frac{638}{575} = 1.11$$

$$x_{NB} = \frac{420}{497} = 0.85$$

$$x_{EB} = \frac{643}{680} = 0.95$$



5. Calculation of Capacity (by HCM)

(9) Step 9 : Compute the average control delay for each lane

- Control delays can be predicted in a manner generally similar to that used for other unsignalized intersections
- Equation below shows the model that should be used to estimate average control delay for each lane of a roundabout approach

$$d = \frac{3{,}600}{c} + 900T\left[x - 1 + \sqrt{(x-1)^2 + \frac{\left(\frac{3{,}600}{c}\right)x}{450T}}\right] + 5 \times \min[x, 1]$$

where

d = average control delay (s/veh),

x = volume-to-capacity ratio of the subject lane,

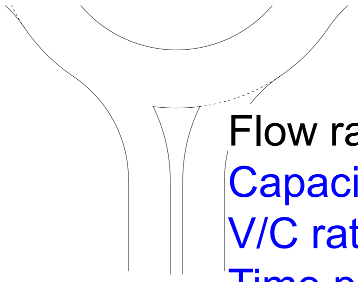
c = capacity of the subject lane (veh/h), and

T = time period (h) ($T = 0.25$ h for a 15-min analysis).

$$d_{NB} = \frac{3600}{497} + 900(0.25) + \sqrt{(0.85-1)^2 + \frac{\left(\frac{3600}{497}\right)0.85}{450\,(0.25)}} + 5 \times \min(0.85, 1)$$

= 39.6 s/veh

Similarly: d_{SB} = 39.8 s/veh, d_{WB} = 97.0 s/veh, d_{EB} = 46.8 s/veh



Flow rate (v): 420

Capacity (c): 497

V/C ratio (x = v/c): 0.85

Time period (T): 0.25 (15-min)

5. Calculation of Capacity (by HCM)

(10) Step 10 : Determine LOS for each lane on each approach

- The LOS for each lane on each approach is determined by using table below and the computed for measured values for control delay

Control Delay (s/veh)	LOS by Volume-to-Capacity Ratio[a]	
	v/c ≤ 1.0	v/c >1.0
0–10	A	F
>10–15	B	F
>15–25	C	F
>25–35	D	F
>35–50	E	F
>50	F	F

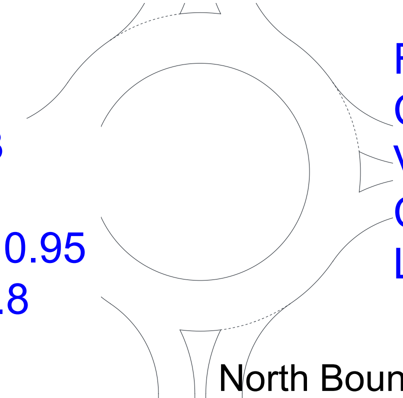
Note: [a] For approaches and intersectionwide assessment, LOS is defined solely by control delay.

Entry	Control Delay (s/veh)	LOS
SB	39.8	E
WB	97.0	F
NB	39.6	E
EB	46.8	E

South Bound
Flow rate (v): 439
Capacity (c): 514
V/C ratio (x=v/c): 0.85
Control delay: 39.8
LOS: E

West Bound
Flow rate (v): 638
Capacity (c): 575
V/C ratio (x=v/c): 1.11
Control delay: 97.0
LOS: F

East Bound
Flow rate (v): 643
Capacity (c): 680
V/C ratio (x=v/c): 0.95
Control delay: 46.8
LOS: E



North Bound
Flow rate (v): 420
Capacity (c): 497
V/C ratio (x=v/c): 0.85
Control delay: 39.6
LOS: E

5. Calculation of Capacity (by HCM)

(11) Step 11 : Compute the average control delay and determine LOS for each approach and the roundabout as a whole

- The control delay for an approach is calculated by computing a weighted average of the delay for each lane on the approach, weighted by the volume in each lane.

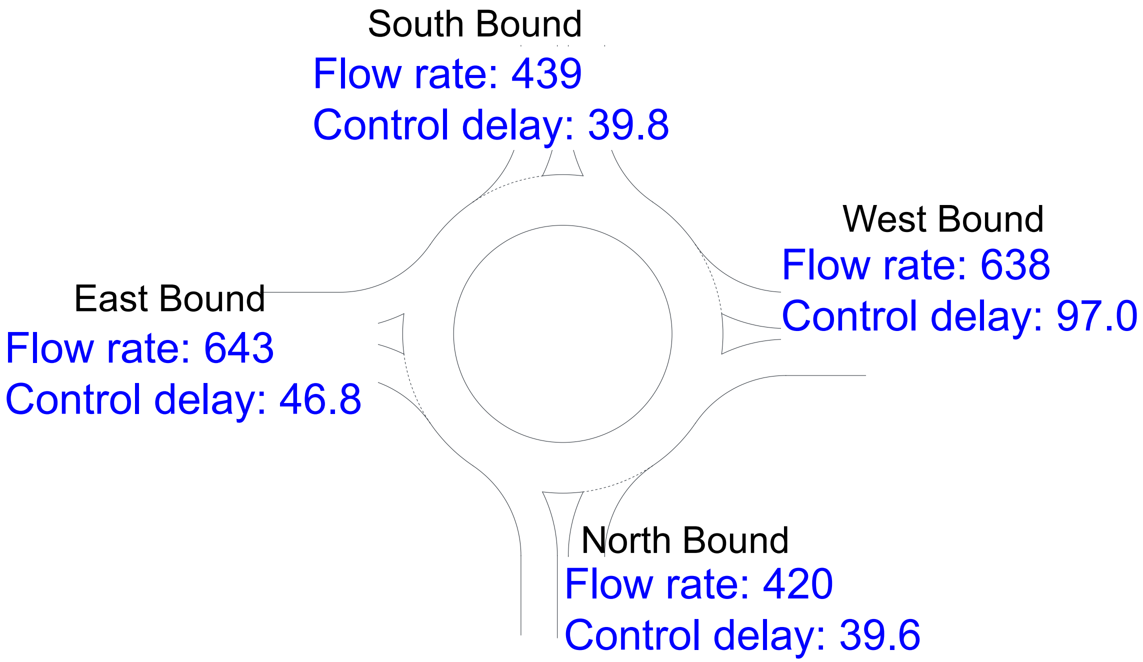
$$d_{\text{intersection}} = \frac{\sum d_i v_i}{\sum v_i}$$

where

$d_{\text{intersection}}$ = control delay for the entire intersection (s/veh),

d_i = control delay for approach i (s/veh), and

v_i = flow rate for approach i (veh/h).



$$d_{intersection} = \frac{(39.8)(439)+(97.0)(638)+(39.6)(420)+(46.8)(643)}{439+638+420+643} = 58.9 \text{ s/veh}$$

5. Calculation of Capacity (by HCM)

(12) Step 12 : Compute 95th percentile queues for each lane

- The 95th percentile queue for a given lane on an approach is calculated by using following equation.

$$Q_{95} = 900T\left[x - 1 + \sqrt{(1-x)^2 + \frac{\left(\frac{3,600}{c}\right)x}{150T}}\right]\left(\frac{c}{3,600}\right)$$

where

Q_{95} = 95th percentile queue (veh),

x = volume-to-capacity ratio of the subject lane,

c = capacity of the subject lane (veh/h), and

T = time period (h) ($T = 1$ for a 1-h analysis, $T = 0.25$ for a 15-min analysis).

$$Q_{95,NB} = 900(0.25) + (0.85 - 1 + \sqrt{(0.85-1)^2 + \frac{\left(\frac{3600}{497}\right)0.85}{150\ (0.25)}}) \times \frac{497}{3600}$$

= 8.6 veh

Similarly: $Q_{95,SB}$ = 9.2 veh, $Q_{95,WB}$ = 21.0 veh, $Q_{95,EB}$ = 16.0 veh

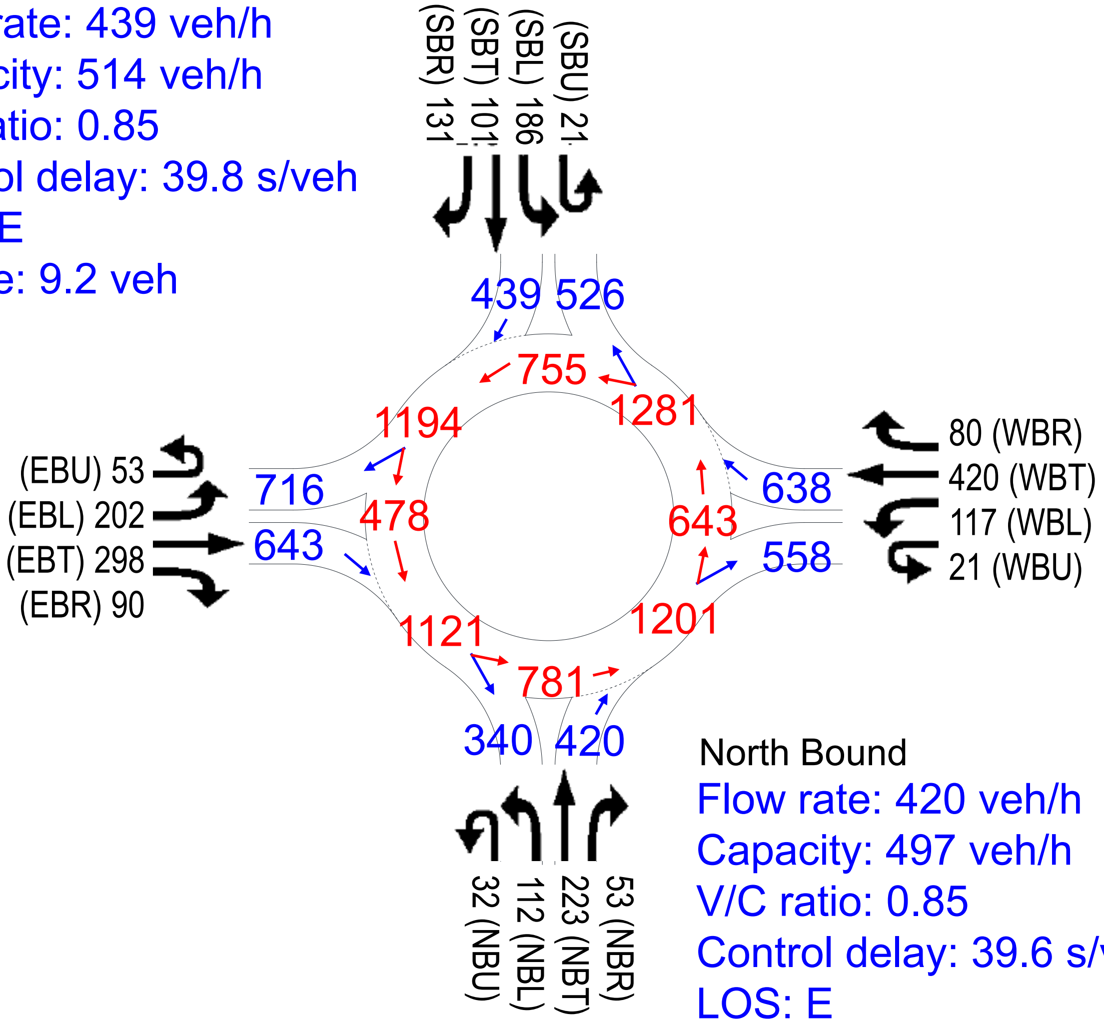
5. Calculation of Capacity (by HCM)

South Bound

Flow rate: 439 veh/h
Capacity: 514 veh/h
V/C ratio: 0.85
Control delay: 39.8 s/veh
LOS: E
Queue: 9.2 veh

East Bound

Flow rate: 643 veh/h
Capacity: 680 veh/h
V/C ratio: 0.95
Control delay: 46.8 s/veh
LOS: E
Queue: 16.0 veh



West Bound

Flow rate: 638 veh/h
Capacity: 575 veh/h
V/C ratio: 1.11
Control delay: 97.0 s/veh
LOS: F
Queue: 21.0 veh

North Bound

Flow rate: 420 veh/h
Capacity: 497 veh/h
V/C ratio: 0.85
Control delay: 39.6 s/veh
LOS: E
Queue: 8.6 veh

6. Exercise

Please calculate the LOS and the average delay of the roundabout based on following condition.

- Four legs,
- 2-lane entries on each leg,
- 2-lane circulating way,
- Peak hour factor = 0.95,
- Percent heavy vehicles for all movements = 5 %,
- Passenger car equivalent for heavy vehicle = 2.0
- Demand volume and lane configurations as shown figures on right and,
- 50 p/h across on the north bound and east bound.