HCM 2010 Analysis Procedure

Roundabout Traffic Operations Analysis
Short Course
Highway Capacity Manual 2010
Roundabouts Procedure

Largely based on research documented in NCHRP Report 572

Procedure is:
- Anchored to empirical U.S. performance
- Able to analyze multilane roundabouts
- Able to be calibrated
Comparing HCM 2010 Procedure to NCHRP Report 572

The HCM 2010 incorporates several modifications to the NCHRP Report 572 procedure, including:

- The HCM procedure provides a separate capacity calculation for the left and right lane of a two-lane entry. NCHRP Report 572 computes capacity and performance measures for only the critical lane of an approach.
- Additional guidance provided on lane use and lane utilization factors
- Calculation using either 15-minute volumes or hourly volumes modified by a PHF
- Calculation of control delay and queues using vehicles per hour instead of passenger car equivalents per hour (heavy vehicles handled differently)
- Control delay equation includes additional term for yield control
HCM 2010 Analysis Procedure

Step 1: Convert movement demand volumes to flow rates

Step 2: Adjust flow rates for heavy vehicles

Step 3: Determine circulating and exiting flow rates

Step 4: Determine entry flow rates by lane

Step 5: Determine the capacity of each entry lane and bypass lane as appropriate in passenger car equivalents

Step 6: Determine pedestrian impedance to vehicles

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
Step 1: Convert movement demand volumes to flow rates

- Use peak 15-minute volumes and multiply by 4 to directly measure an hourly flow rate for those peak 15 minutes, OR
- Use hourly volumes and a peak hour factor to get an estimated hourly flow rate for those peak 15 minutes

\[ v_i = \frac{V_i}{PHF} \]

where:

- \( v_i \) = demand flow rate on approach \( i \), veh/h
- \( V_i \) = demand volume on approach \( i \), veh/h
- \( PHF \) = Peak Hour Factor

HCM 2010, Equation 21-8
Step 2: Adjust flow rates for heavy vehicles

- Convert trucks to passenger car equivalents (pce)

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Passenger Car Equivalent, $E_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>1.0</td>
</tr>
<tr>
<td>Heavy vehicle</td>
<td>2.0</td>
</tr>
</tbody>
</table>

\[
\nu_{i,pce} = \frac{\nu_i}{f_{HV}} \quad f_{HV} = \frac{1}{1 + P_T(E_T - 1)}
\]

where

\[
\nu_{i,pce} = \text{demand flow rate for movement } i \text{ (pc/h)},
\]

\[
\nu_i = \text{demand flow rate for movement } i \text{ (veh/h)},
\]

\[
f_{HV} = \text{heavy-vehicle adjustment factor},
\]

\[
P_T = \text{proportion of demand volume that consists of heavy vehicles}, \text{ and}
\]

\[
E_T = \text{passenger car equivalent for heavy vehicles}.
\]
Step 3: Determine circulating and exiting flow rates

- Circulatory volume = sum of movements as shown
Step 3: Determine circulating and exiting flow rates (cont.)

- Exit volume = sum of movements as shown
- Deduct right-turn movement if it is using a bypass lane
Step 4: Determine entry flow rates by lane

- Check for fixed or *de facto* lane assignments

<table>
<thead>
<tr>
<th>Designated Lane Assignment</th>
<th>Assumed Lane Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT, TR</td>
<td>If $v_U + v_L &gt; v_T + v_{R,e}$: L, TR (de facto left-turn lane)</td>
</tr>
<tr>
<td></td>
<td>If $v_{R,e} &gt; v_U + v_L + v_T$: LT, R (de facto right-turn lane)</td>
</tr>
<tr>
<td></td>
<td>Else LT, TR</td>
</tr>
<tr>
<td>L, LTR</td>
<td>If $v_T + v_{R,e} &gt; v_U + v_L$: L, TR (de facto through–right lane)</td>
</tr>
<tr>
<td></td>
<td>Else L, LTR</td>
</tr>
<tr>
<td>LTR, R</td>
<td>If $v_U + v_L + v_T &gt; v_{R,e}$: LT, R (de facto left–through lane)</td>
</tr>
<tr>
<td></td>
<td>Else LTR, R</td>
</tr>
</tbody>
</table>

Notes: $v_U$, $v_L$, $v_T$, and $v_{R,e}$ are the U-turn, left-turn, through, and nonbypass right-turn flow rates using a given entry, respectively. L = left, LT = left–through, TR = through–right, LTR = left–through–right, and R = right.
Step 4: Determine entry flow rates by lane (cont.)

If only one lane is available for a given movement, 100% of that movement is assigned to that lane.
Step 4: Determine entry flow rates by lane (cont.)

Check to see if a turning movement creates a *de facto* lane assignment.

LTs dominate left lane, create *de facto* LT lane. THs are assumed to use only the right lane.

\[ 610 \quad 515 \quad 515 \quad 420 \quad (= 290 + 130) \]
Step 4: Determine entry flow rates by lane (cont.)

Lane flow by lane assignment case:

<table>
<thead>
<tr>
<th>Case</th>
<th>Assumed Lane Assignment</th>
<th>Left Lane</th>
<th>Right Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L, TR</td>
<td>$v_u + v_l$</td>
<td>$v_T + v_{RE}$</td>
</tr>
<tr>
<td>2</td>
<td>LT, R</td>
<td>$v_u + v_L + v_T$</td>
<td>$v_{RE}$</td>
</tr>
<tr>
<td>3</td>
<td>LT, TR</td>
<td>$(%LL)v_s$</td>
<td>$(%RL)v_s$</td>
</tr>
<tr>
<td>4</td>
<td>L, LTR</td>
<td>$(%LL)v_s$</td>
<td>$(%RL)v_s$</td>
</tr>
<tr>
<td>5</td>
<td>LTR, R</td>
<td>$(%LL)v_s$</td>
<td>$(%RL)v_s$</td>
</tr>
</tbody>
</table>

Notes: $v_u$, $v_L$, $v_T$, and $v_{RE}$ are the U-turn, left-turn, through, and nonbypass right-turn flow rates using a given entry, respectively. L = left, LT = left-through, TR = through-right, LTR = left-through-right, and R = right.

<table>
<thead>
<tr>
<th>Lane Configuration</th>
<th>% Traffic in Left Lane</th>
<th>% Traffic in Right Lane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left-through + through-right</td>
<td>0.47</td>
<td>0.53</td>
</tr>
<tr>
<td>Left-through-right + right</td>
<td>0.47</td>
<td>0.53</td>
</tr>
<tr>
<td>Left + left-through-right</td>
<td>0.53</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Notes: *These values are generally consistent with observed values for through movements at signalized intersections. These values should be applied with care, particularly under conditions estimated to be near capacity.*

HCM 2010, Exhibits 21-14, 21-21
Step 4: Determine entry flow rates by lane (cont.)

Adjustments can be made to account for downstream destinations, geometric effects, etc.

450 of the 590 are turning right onto a freeway on-ramp immediately beyond this intersection.

The downstream on-ramp creates a lane imbalance at this intersection that should be accounted for in the analysis.

\[
\begin{align*}
210 & \rightarrow 590 \\
130 & \leftarrow
\end{align*}
\]

\[
\begin{align*}
350 &= 210 + 140 \\
465 &= 465 \\
580 &= 130 + 450
\end{align*}
\]
Step 5: Determine capacity of each entry lane and bypass lane

HCM 2010, Exhibit 21-7
Capacity: 1 lane

- Capacity of one-lane entry or either lane of two-lane entry against one conflicting lane
- Capacity of one-lane entry or two-lane entry against two conflicting lanes

Dashed regression extrapolated beyond the data
Capacity: 2x1 lane

Conflicting Flow Rate (pc/h)

Capacity (pc/h)

Capacity of one-lane entry or right two-lane entry against two conflicting lanes

Capacity of left lane of two-lane entry against two conflicting lanes

Capacity of one-lane or either lane of two-lane entry against one conflicting lane

Dashed regression extrapolated beyond the data
Capacity: 1x2 lane

Conflicting Flow Rate (pc/h)

Capacity (pc/h)

Capacity of one-lane or either lane of two-lane entry against one conflicting lane

Capacity of one-lane or two-lane entry against two conflicting lanes

Dashed regression extrapolated beyond the data
Capacity: 2x2 lane

- Capacity of one-lane entry or either lane of two-lane entry against one conflicting lane
- Capacity of one-lane entry or two-lane entry against two conflicting lanes
- Dashed regression extrapolated beyond the data
Right Turn Bypass Lanes

- Right turn volume excluded from roundabout entry volume for roundabout capacity calculations.
- Separate capacity calculation may be required for bypass lane.
- Two types:
  - Yielding bypass lane (Type 1)
  - Non-yielding bypass lane (Type 2)
Yielding Bypass Lane (Type 1)

- Terminates at a high angle - yielding to exiting traffic
- Capacity approximated using the appropriate single-lane (1x1) or multilane (1x2) capacity formula
- Treat the exiting flow from the roundabout as the conflicting flow
Non-Yielding Bypass Lane (Type 2)

- Merges at a low angle with exiting traffic or forms a new lane adjacent to exiting traffic.
- Capacity is expected to be relatively high due to a merging operation between two traffic streams at similar speeds.
Step 6: Determine pedestrian impedance to vehicles

- Single-lane case
Step 6: Determine pedestrian impedance to vehicles (cont.)

- Double-lane case

![Graph showing pedestrian impedance to vehicles with conflicting circulating flow.](image)
Step 7: Convert lane flow rates and capacities into veh/h

\[ v_i = v_{i,PCE} f_{HV,e} \quad \text{and} \quad c_i = c_{i,PCE} f_{HV,e} f_{ped} \]

\[ f_{HV,e} = \frac{f_{HV,U} v_{U,PCE} + f_{HV,L} v_{L,PCE} + f_{HV,T} v_{T,PCE} + f_{HV,R,e} v_{R,e,PCE}}{v_{U,PCE} + v_{L,PCE} + v_{T,PCE} + v_{R,e,PCE}} \]

where:

- \( v_i \) = flow rate for lane \( i \) (veh/h),
- \( v_{i,PCE} \) = flow rate for lane \( i \) (pc/h),
- \( f_{HV,e} \) = heavy-vehicle adjustment factor for the entry lane,
- \( c_i \) = capacity for lane \( i \) (veh/h),
- \( c_{i,PCE} \) = capacity for lane \( i \) (pc/h),
- \( f_{ped} \) = pedestrian impedance factor,
- \( f_{HV,i} \) = heavy-vehicle adjustment factor for movement \( i \).
Step 8: Compute volume-to-capacity ratio for each lane

- Calculated as follows:

\[ x_i = \frac{v_i}{c_i} \]

- HCM 2010 does not set target values for \( x \)
- For design purposes, often desirable to design for value of 0.85, or a different value under appropriate circumstances
Step 9: Compute average control delay for each lane

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

where:

\( D = \text{control delay, s/veh} \)
\( x = \text{volume-to-capacity ratio} \)
\( c = \text{capacity, veh/h} \)
\( T = \text{time period} = 0.25 \text{ h} \)
Graphical Depiction of HCM 2010 Control Delay Equation

Note: Assumes T=0.25 h
Step 10: Determine LOS for each lane

- Same as for other unsignalized intersections

<table>
<thead>
<tr>
<th>LOS</th>
<th>Control Delay (s/veh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 – 10</td>
</tr>
<tr>
<td>B</td>
<td>&gt; 10 – 15</td>
</tr>
<tr>
<td>C</td>
<td>&gt; 15 – 25</td>
</tr>
<tr>
<td>D</td>
<td>&gt; 25 – 35</td>
</tr>
<tr>
<td>E</td>
<td>&gt; 35 – 50</td>
</tr>
<tr>
<td>F</td>
<td>&gt; 50</td>
</tr>
</tbody>
</table>
Step 11: Compute control delay and LOS for approaches and roundabout as a whole

- Can be used 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 control delay, s/veh
- \(D_{\text{approach } i}\) = control delay on approach \(i\), s/veh
- \(V_{\text{approach } i}\) = volume on approach \(i\), veh/h
Step 12: Compute 95\textsuperscript{th} percentile queue for each lane

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

where:

- \(Q_{95}\) = queue length, veh
- \(x\) = volume-to-capacity ratio
- \(c\) = capacity, veh/h
- \(T\) = time period = 0.25 h
Graphical Depiction of HCM 2010 95th Percentile Queue Equation

Expected Maximum Number of Vehicles in Queue, $Q_{95}$ [veh]

FHWA Exhibit 4-10, p. 95
Example Problem

[Diagram of Adjusted Roundabout volumes with volumes indicated on each path: 271, 246, 847, 718, 693, 376, 344, 602, 249, 721, 599]
Example Problem: Capacity Calculation

Capacity of one-lane entry or right lane of two-lane entry against two conflicting lanes

Capacity of left lane of two-lane entry against two conflicting lanes

Example Problem: Capacity Calculation

NB = ~880
SB = ~900
WB = ~620
EB = ~560

Capacity of one-lane entry or right lane of two-lane entry against two conflicting lanes

Capacity of left lane of two-lane entry against two conflicting lanes

Conflicting Flow Rate (pc/h)

Capacity of one-lane or either lane of two-lane entry against one conflicting lane

Capacity extrapolated beyond the data

Example Problem: Capacity Calculation

Capacity of one-lane entry or right lane of two-lane entry against two conflicting lanes

Capacity of left lane of two-lane entry against two conflicting lanes

Conflicting Flow Rate (pc/h)
Example Problem: V/C Calculation

- Northbound Approach:
  - Entering volume = 602 veh/h
  - Capacity = 880 veh/h
  - V/C Ratio = 602 / 880 = 0.68

- Repeat calculation for other approaches
## Example Problem: V/C Results

<table>
<thead>
<tr>
<th></th>
<th>NB</th>
<th>SB</th>
<th>EB</th>
<th>WB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Entering volume (pce)</strong></td>
<td>602</td>
<td>847</td>
<td>271</td>
<td>344</td>
</tr>
<tr>
<td><strong>Conflicting volume (pce)</strong></td>
<td>246</td>
<td>222</td>
<td>693</td>
<td>599</td>
</tr>
<tr>
<td><strong>Entry capacity (pce)</strong></td>
<td>884</td>
<td>905</td>
<td>565</td>
<td>621</td>
</tr>
<tr>
<td><strong>V/C Ratio</strong></td>
<td>0.68</td>
<td>0.94</td>
<td>0.48</td>
<td>0.55</td>
</tr>
<tr>
<td><strong>Approach Control Delay (s/veh)</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Intersection Control Delay (s/veh)</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>95th %ile Queue (veh)</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Example Problem: Control Delay Calculation (Northbound Approach)

Note: Assumes T=0.25 h
Example Problem: Delay Results

<table>
<thead>
<tr>
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<td>0.94</td>
<td>0.48</td>
<td>0.55</td>
</tr>
<tr>
<td>Approach Control Delay</td>
<td>12</td>
<td>33</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Intersection Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay (s/veh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95th %ile Queue (veh)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Example Problem: 95th Percentile Queue (Northbound Approach)

- Expected Maximum Number of Vehicles in Queue, $Q_{95}$ [veh]

- $v/c$ Ratio [-]

- $884 \times 0.25 = 221$
### Example Problem: Delay Results

<table>
<thead>
<tr>
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<td>33</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Intersection Control</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay (s/veh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95th %ile Queue (veh)</td>
<td>6</td>
<td>15</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>