16-15-1 Basic Principles February 2025

1.1 Introduction

The Highway Capacity Manual (HCM) provides several analytical or deterministic tools that can estimate roadway or intersection capacity, delay, density, and other performance measures for various elements of the street and highway system. The HCM also includes procedures for evaluating bicycle, pedestrian, and transit facilities. In most cases, the HCM is the standard for traffic analysis in the US; its methods are generally reliable and have been well-tested through significant validation efforts. The Highway Capacity Manual, 7th Edition: A Guide for Multimodal Mobility Analysis (HCM7) (1) is the most current version of the HCM. A list of the updates included with the release of HCM7 is noted in the "Forward" section of HCM7. The most significant changes include:

- A new two-lane highway methodology which incorporates new performance measures
- A new network analysis method for the evaluation of spillback between freeways and urban streets
- Addition of guidance on the application of HCM methods for determining impacts of connected and automated vehicles (CAVs)
- Enhancements to existing pedestrian analysis methods at signalized intersections and uncontrolled pedestrian crossings

All projects initiated on or after January 1, 2023 **shall** follow the HCM7 methodologies unless otherwise authorized by WisDOT regional traffic staff.

The HCM consists of the following four volumes:

- Volume 1: Concepts
- Volume 2: Uninterrupted Flow
- Volume 3: Interrupted Flow
- Volume 4: Applications Guide (a web-based document, requires a free user account)

Each chapter within Volume 2 and Volume 3 of the HCM has six or more sections covering the following topics: introduction, concepts, methodology, extensions to the methodology, applications, and references. The methodology section (typically Section 3) highlights the scope, strengths, and limitations of the applicable HCM methodology, and as such, serves as a good reference when determining whether use of the HCM methodology is appropriate. HCM, Volume 1, Chapter 7 provides additional guidance as to when an alternative (non-HCM based) analysis methodology *may* be appropriate.

The HCM procedures are good for analyzing the performance of isolated and non-congested facilities but do have limitations. For example, the HCM models *may* under-predict the extent of congestion in oversaturated conditions. Consider the strengths and limitations of the HCM methods when selecting the methodology to apply. Document the rationale for choosing the selected traffic analysis methodology (HCM-based, microsimulation, etc.) in the Traffic Analysis Tool Selection memoranda and submit to the WisDOT regional traffic staff for approval.

TEOpS 16-10 provides a brief description of when and how to apply the HCM methodologies and identifies the WisDOT-supported programs that implement the HCM methodology.

1.2 Traffic Data

Traffic data such as existing and forecasted traffic volumes (e.g., turning movement counts, directional design hour volumes, etc.) including pedestrian and bicycle volumes, heavy vehicle truck percentages, and peak-hour factor values are key inputs into the HCM-based operational analysis. In near, or over-capacity, conditions it is critical that the existing traffic counts reflect the traffic demand and not just the volume throughput.

When gathering the existing traffic data, note any special lane utilizations or imbalances, especially at roundabouts, intersections with dual or triple turn lanes, or interchange ramps with more than one lane. Intermediate design year forecasts may be beneficial for conducting sensitivity analysis to determine when capacity expansion may be necessary (i.e., when it might be necessary to expand a roundabout from a one-lane to a two-lane entry).

See TEOpS 16-5 for additional details on assembling and preparing the traffic data. FDM 11-5-2 provides additional information on gathering traffic forecasts.

16-15-5 Signalized Intersections February 2025

5.1 Introduction

WisDOT accepts the use of the HCM, Chapter 19 methods for estimating the performance of a signalized intersection from the perspective of the motor vehicle, pedestrian, and bicycle modes. These procedures are applicable for three-leg and four-leg intersections that operate in isolation from nearby signals with a pre-timed, semi-actuated or fully-actuated controller. Signalized intersections that are not isolated, that operate in an actuated-coordinated manner, or are part of a system or corridor require the use of a combination of both the signalized intersection methods of Chapter 19 and the urban street segment procedures outlined in Chapter 18. For closely spaced signals, such as those found at freeway ramp terminals, the analyst *should* follow the methodology presented in Chapter 23 for interchange ramp terminals. If the project spans multiple contiguous urban street segments, consider applying the Chapter 16 urban street facilities methodologies.

The analyst *should* recognize and account for the methodological limitations of the signalized intersection methods. There are cases that *may not* fit within the analytical framework of the HCM, including but not limited to intersections with five or more approaches, those with more than two exclusive turn lanes on any approach or those with complex geometry or controller operations. When these, or similar limitations exists, the project manager *should* specify the use of an alternative tool such as microsimulation. See TEOpS 16-20 for additional details on performing microsimulation analysis.

The WisDOT-supported tools that implement the HCM methodology for signalized intersection analysis are:

- Highway Capacity Software (HCS), McTrans
- Synchro, Cubic|Trafficware
- Vistro, PTV Group (requires prior approval from WisDOT regional traffic engineer)

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

When conducting capacity analysis for signalized intersections, apply the basic signal parameters as outlined in the following section in conjunction with the HCM-based analysis methodologies.

5.2 Basic Parameters for Capacity Analysis

The Traffic Signal Design Manual, Section 3, Chapter 2-2 (TSDM 3-2-2) provides recommended parameters to use for the general analysis of state-owned signals; including minimum and maximum green times, pedestrian phase times and cycle lengths. TEOpS 4-2-5 provides guidance on yellow and all-red clearance intervals. The following provides updated direction for the use of right-turn on red (RTOR) and saturation flow rate. Unless noted otherwise, the policy within this section supersedes the guidance provided in TSDM 3-2-2. If it is unclear which guidance to follow, contact BTO-TASU (DOTTrafficAnalysisModeling@dot.wi.gov) for clarification.

5.2.1 Right-Turn on Red (RTOR)

5.2.1.1 Background

Right-turns made while facing a red traffic signal indication, permitted under Wisconsin statute 346.37(1)(c)3, can have a beneficial effect on traffic flow and intersection capacity as they reduce the number of vehicles serviced during the green phase. The following section describes how to apply RTOR when conducting capacity analysis for signalized intersections.

5.2.1.2 Dedicated Right-Turn Lanes

Since vehicles making other movements (through or left-turns) *may* block right-turn access at shared left-through-right (LTR) or shared through-right (TR) lanes, WisDOT has only investigated RTOR volumes at locations with dedicated right-turn lanes. For the purposes of RTOR inclusion in capacity analyses, a dedicated right-turn lane is any lane that satisfies at least one of the following criteria:

- Pavement markings or signage clearly dedicate the lane for a right-turn only movement
- Field observations indicate that the lane functions as a de-facto right-turn only lane (requires approval from WisDOT regional traffic staff)
- Subject approach flares out at the intersection such that a right-turning vehicle can safely fit beside a through vehicle within the same lane and field observations show vehicles using the approach flare to make right turns (requires approval from WisDOT regional traffic staff)

Additionally, for RTOR inclusion to be applicable for capacity analysis, the following must exist:

- Right-turns on red are permissible (i.e., field signage does not prohibit this maneuver during the analysis period)
- Vehicle queuing from the adjacent lane does not prevent vehicles wishing to make a right-turn from accessing the dedicated (or de-facto) right-turn lane

For additional clarification, as to what constitutes a right-turn lane for purposes of capacity analysis at signalized intersections, contact the WisDOT regional traffic engineer or BTO-TASU.

5.2.1.3 RTOR Estimation

An estimate of the proportion of vehicles making RTOR from a dedicated right-turn lane is most accurate when derived from field counts taken at the intersection in question. As it is not always practical to gather this information, WisDOT conducted field studies throughout Wisconsin in 2009 (3), 2015 (4), and 2021 (5) to develop recommendations for estimating RTOR volumes (V_{RTOR}) in relation to total right-turn demand (V_{RT}) for both planning-level and design-level analyses.

WisDOT has not studied RTOR at any intersection configuration other than those shown in Equations 5.2 – 5.12, such as shared lanes or triple right-turn lanes, thus unless intersection-specific field data is available to indicate otherwise, the analyst *should* assume that vehicles do not make RTOR movements at these locations. Obtain approval from WisDOT regional traffic staff prior to including RTOR volumes for triple right-turn lanes or shared lanes within the capacity analysis.

The analyst **shall not** use RTOR volumes in the analysis when field signage prohibits this maneuver during the analysis period.

5.2.1.3.1 Planning-Level Assessment

For planning-level analyses, when signal timing or phasing is still in flux, analysts *should* use the following equations to calculate the RTOR volumes.

- Single Right-Turn Lanes at Intersections: $V_{RTOR} = 0.38V_{RT}$ [Equation 5.1]
- Single Right-Turn Lanes at Interchange Off Ramps: $V_{RTOR} = 0.74V_{RT}$ [Equation 5.2]
- Single Right-Turn Lanes at Interchange On Ramps: $V_{RTOR} = 0.25V_{RT}$ [Equation 5.3]
- Dual Right-Turn Lanes at Intersections: $V_{RTOR} = 0.30V_{RT}$ [Equation 5.4]
- Dual Right-Turn Lanes at Interchange Off Ramps: $V_{RTOR} = 0.53V_{RT}$ [Equation 5.5]
- Dual Right-Turn Lanes at Interchange On Ramps: $V_{RTOR} = 0.12V_{RT}$ [Equation 5.6]

Where:

$V_{RTOR} =$ Right-turn on red volumes
$V_{RT} =$ Total right-turn demand

5.2.1.3.2 Design-Level Assessment

For design-level analyses, specifically when refining the storage requirements for right turn lanes, it *may* be appropriate to consider signal timings when calculating the RTOR volumes. In such instances, the analyst *may* apply the following equations:

- Single Right-Turn Lanes at Intersections: $V_{RTOR} = 0.18V_{RT} \times e^{1.26 \times R_{\%}}$ [Equation 5.7]
- Single Right-Turn Lanes at Interchange Off Ramps: $V_{RTOR} = 0.24V_{RT} \times e^{1.35 \times R_{\%}}$ [Equation 5.8]
- Single Right-Turn Lanes at Interchange On Ramps: $V_{RTOR} = 0.07V_{RT} \times e^{2.90 \times R_{\%}}$ [Equation 5.9]
- Dual Right-Turn Lanes at Intersections: $V_{RTOR} = 0.04V_{RT} \times e^{3.34 \times R_{\%}}$ [Equation 5.10]
- Dual Right-Turn Lanes at Interchange Off Ramps: $V_{RTOR} = 0.08V_{RT} \times e^{2.59 \times R_{\%}}$ [Equation 5.11]
- Dual Right-Turn Lanes at Interchange On Ramps: $V_{RTOR} = 0.07V_{RT} \times e^{1.53 \times R_{\%}}$ [Equation 5.12]

Where:

V_{RTOR} = Right-turn on red volumes

V_{RT} = Total right-turn demand

$R_{\%} = (C - g_{RT})/C$ = Percentage of the cycle showing red for the right-turn movement (e.g., 0.25 for 25%)

C = Cycle Length

g_{RT} = Right-turn green time

Use the WisDOT *Right Turn on Red Analysis Tool* to calculate the RTOR using the above design-level assessment equations.

5.2.1.4 RTOR Application

WisDOT supports the use of HCS for traffic signal analysis and supports the use of Vistro and Synchro for both traffic signal analysis and signal optimization (see TEOpS 16-10). Use and acceptance of Vistro for signal analysis and optimization, however, is up to the discretion of the WisDOT regional office. Due to limitations of the HCS optimization methodologies, WisDOT does not support the use of HCS for signal optimization.

Vistro uses the same module for both HCM-compliant analysis and signal optimization. Synchro, however, uses two distinct modules – one which provides HCM-compliant analysis and another which provides signal optimization as well as non-HCM-compliant analysis. The later module uses a proprietary methodology to calculate intersection delay and other values. Changes made in one module do not necessarily transfer to the other module. Therefore, there are nuances in how to conduct HCM-compliant analysis and signal optimization in Synchro which are not present in Vistro.

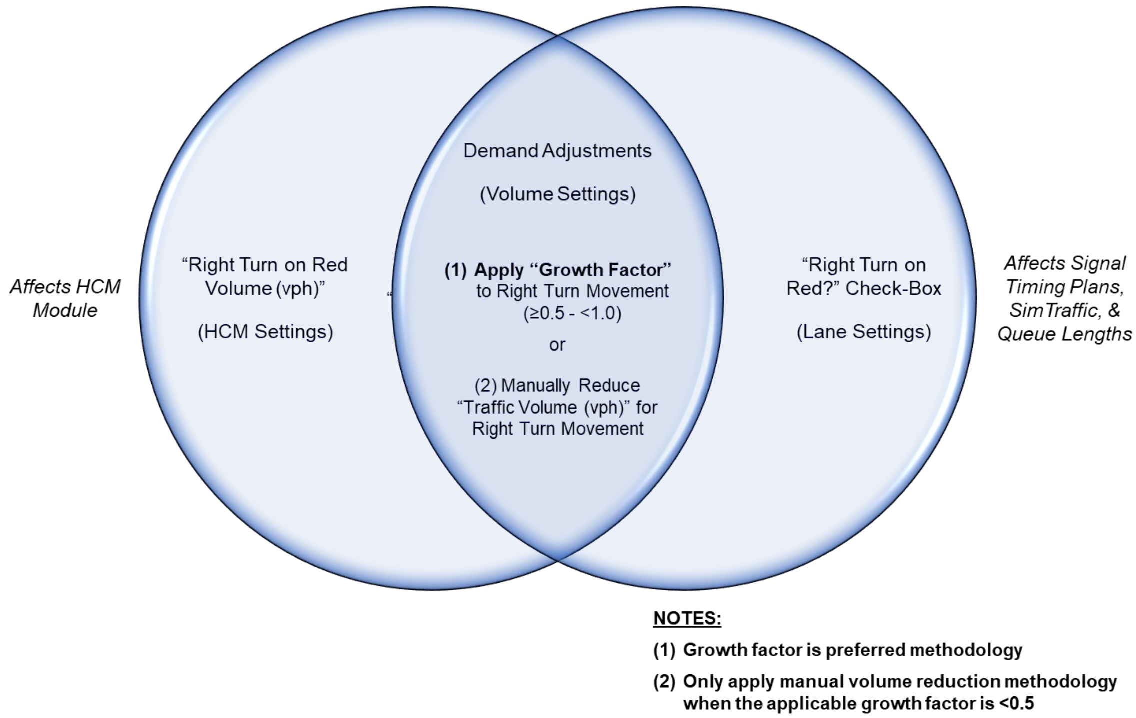
Figure 5.1 provides an overview of the various methodologies available for affecting RTOR in the two modules of Synchro. A subset of the methodologies, those which adjust demand, affect both Synchro modules. As noted in the figure, the “growth factor” method is the preferred methodology when the analyst is using Synchro to conduct HCM-compliant analysis and signal optimization. This methodology involves applying a growth factor of less than one to the right turn movements. For planning-level analyses, apply the following growth factors, derived from Equations 5.1, 5.3, 5.4 and 5.6 unless field data is available and supports otherwise:

- 0.62 for Single Right-Turn Lanes at Intersections
- 0.75 for Single Right-Turn Lanes at Interchange On Ramps
- 0.70 for Dual Right-Turn Lanes at Intersections
- 0.88 for Dual Right-Turn Lanes at Interchange On Ramps

Note that the above rates do not include a growth rate for Single or Dual Right-Turn Lanes at Interchange Off Ramps. Applying Equations 5.2 and 5.5 would yield a growth factor of 0.26 and 0.47, respectively for these scenarios; however, Synchro currently sets a floor of 0.5 for growth rates preventing the use of the 0.26 or 0.47. When dealing with Single and Dual Right-Turn Lanes at Interchanges, or when calculating the RTOR volumes using Equations 5.7 – 5.12 for design-level analysis, use the manual reduction method detailed below.

The manual reduction methodology also affects both modules in Synchro and involves manually reducing the right-turn volumes by the V_{RTOR}. This is less transparent when conducting a peer review and is more prone to typographical error. Therefore, WisDOT prefers the use of the growth factor method where possible.

Figure 5.1 Synchro RTOR Adjustments Venn Diagram



5.2.1.4.1 HCM-Compliant Analysis

WisDOT provides the following guidance on incorporating RTOR volumes when conducting HCM-compliant analysis. The RTOR volumes used *may* be based on field-collected values or the equations above (see Equations 5.1 – 5.12).

- HCS: Enter the V_{RTOR}, rounded to the nearest whole vehicle per hour (veh/h), into the "RTOR, veh/h" field for the relevant approaches. This field is at the bottom of the "Primary Input Data" within the HCS "Streets" module, which includes traffic signal analysis.
- Vistro: Go to the "Volumes" tab. Check the "Right Turn on Red" boxes for the relevant approaches and select the "Right Turn on Red Method" from the drop-down list (either Percentage or Absolute Value). If using the percentage methodology (recommended), enter the percentage of the total right turn demand (V_{RT}) that turn on the red indication (see equations 5.1 – 5.6) into the "Right Turn on Red Percentage [%]" field. The percentage methodology will calculate the V_{RTOR} which will automatically update with changes to the V_{RT}. If using the absolute value methodology, enter the V_{RTOR}, rounded to the nearest whole vehicle per hour (veh/h), into the "Right-Turn on Red Volume [veh/h]" field. Using the absolute value methodology will require a manual update to the V_{RTOR} every time there are modifications to the V_{RT}.
- Synchro: Use the growth factor method or manual volume reduction method (when the applicable growth factor is <0.5) outlined above. Uncheck the "Right Turn on Red" box in the "Lane Settings" for all approaches of a signalized intersection. Checking the "Right Turn on Red" box in the "Lane Settings" area **does not** affect the HCM-compliant analysis but **will** affect the queues in the "Timing Settings" window.

The analyst **shall not** enter a volume other than the default of 0 into the "Right Turn on Red Volume" field in combination with the growth factor method, as it will lead to incorrect results.

5.2.1.4.2 Signal Optimization

In Synchro, changes to the “Right Turn on Red Volume” field in the HCM module do not affect the signal timings or optimization calculations. If the analyst checks a box to allow RTOR within the “Lane Settings” module (automatically checked by default), Synchro uses an algorithm to determine a “Saturated Flow Rate (RTOR)”. Synchro uses the “Saturated Flow Rate (RTOR)” value within the signal optimization function. The RTOR checkbox **does not** affect the HCM results. Synchro’s proprietary RTOR methodology, enabled via the RTOR checkbox, is not straightforward and is thus not a preferred methodology for developing signal timing plans. When optimizing signals, the analyst *should* uncheck the RTOR checkbox for all approaches.

WisDOT prefers the use of the growth factor method for conducting signal optimization in Synchro. The analyst *should* only apply the manual volume reduction method when the applicable growth factor is <0.5.

5.2.1.4.3 Microsimulation Analysis

WisDOT also currently supports two microsimulation software programs for traffic signal analysis: SimTraffic (associated with Synchro, affected by demand reductions but not by changes within the HCM module) and Vissim. The analyst *should not* dictate RTOR volumes within microsimulation programs, as the models *should* determine when these turns happen based on how the right-turning vehicles interact with other vehicles in the system. Where right-turns at signals are critical movements, a good check for reasonableness could be comparing modeled RTOR volumes to field-collected ones. The analyst *should* direct any questions regarding how to model RTOR within a specific microsimulation software program to BTO-TASU (DOTTrafficAnalysisModeling@dot.wi.gov).

5.2.2 Saturation Flow Rate

5.2.2.1 Background

One of the many variables that influence the performance of traffic signals is saturation flow (sat. flow) rate. The base saturation flow rate for a lane is the theoretical number of vehicles that could travel through the intersection during one hour of green time under ideal conditions. The saturation headway, or the average time between the front bumper of one vehicle and the front bumper of the vehicle behind it under ideal conditions, determines the saturation flow rate. The HCM default values for base saturation flow rate are:

- 1900 passenger cars per hour per lane (pc/h/ln) in metropolitan areas with population ≥250,000
- 1750 pc/h/ln otherwise

The HCM provides several factors to adjust these base saturation flow rates to account for prevailing conditions at the approach, including heavy vehicle percentages, grade, lane width, etc. More information on flow rate concepts is available in HCM, Chapters 4 and Chapters 19.

This policy focuses on the saturation flow rate for left-turn lanes and through lanes.

5.2.2.2 Saturation Flow Rate Methodology

A field saturation flow study at an intersection will provide the most accurate measure of experienced flow rates on its approaches. Given the expense, it *may not* be practical to conduct these studies, especially at locations that are operating significantly under capacity.

Since it is impractical to conduct field studies for every intersection and in an effort to gain a better understanding of the range of saturation flow rates, WisDOT conducted field studies in 2015 (4) and 2021 (5) to evaluate saturation flow rates at various signalized intersections across the state. The study aimed to identify the variables, beyond those already accounted for by the HCM, which influenced the field saturation flow rates. The study followed the methodology laid out in the HCM and only collected data on the saturation flow rate for left-turn lanes (5) and through lanes (4).

The 2015 WisDOT sat. flow study (4) found that the following three factors affect the base saturation flow rate of a through lane at a signalized intersection: the urbanized area or cluster population, the total number of approach lanes (left, through and right), and the posted speed limit of the approach. Accordingly, the base saturation flow rate *may* differ from one approach to the next at a given signalized intersection. The field conditions or traffic signal design dictate the total number of approach lanes and the posted speed limit of the approach. The urbanized area or cluster population information is available from either the table or map provided by the 2010 Census Bureau.

WisDOT used the results of the 2015 (4) study to develop a methodology to estimate the base saturation flow rate for exclusive through lanes and shared through-right lanes at signalized intersections in Wisconsin. The 2021 WisDOT sat. flow study (5) found that the observed left-turn movement saturation flow rate is approximately 95.26% of the estimated through movement saturation flow rate, which is consistent with the 95.24% that the HCM suggests. Since the percentages are nearly identical, to calculate the left-turn saturation flow rate, WisDOT recommends first calculating the base saturation flow rate for through lanes using the WisDOT methodology described in section 5.2.2.3 below, and then applying the HCM default left-turn adjustment factor.

Since the methodology accounts for more variables and reflects Wisconsin-specific data, analysts *should* use the WisDOT sat. flow methodology as described below to estimate the base saturation flow rate for exclusive through lanes and shared through-right lanes at signalized intersections. If the WisDOT estimation methodology results in a sat. flow rate less than the relevant HCM default value, specifically if it is less than 1750 pc/h/ln, the analyst *should* consider completing a field study or using the HCM default values.

Coordinate with WisDOT regional traffic staff to determine the most appropriate methodology for calculating the base saturation flow rate for exclusive left, exclusive through, and shared through-right lanes. At ramp terminals, since there is typically a negligible number of through vehicles on the exit ramp, treat the shared left-through lane as an exclusive left-turn lane. WisDOT did not study the shared left-through-right lane configuration, however, if the through movement is the dominant movement, the analyst *may*, with caution, treat this lane configuration the same as an exclusive through lane. Use the HCM default base saturation flow rates for all other lane groups (i.e., shared left-through, shared left-right, and exclusive right turn lanes) unless there is field data or other documentation supporting an alternative value or WisDOT instructs otherwise.

5.2.2.3 Saturation Flow Rate Estimation

Use the WisDOT sat. flow spreadsheet (a Microsoft Excel based spreadsheet) or the adjustment factors shown in Table 5.1 to implement the WisDOT sat. flow methodology. The WisDOT sat. flow spreadsheet implements equations to apply the various site-specific adjustments in the same general form as the HCM and calculates the base sat. flow rate for each lane group

In lieu of the WisDOT sat. flow spreadsheet, the analyst *may* use the adjustment factors shown in Table 5.1 in conjunction with a starting saturation flow rate value of 1980 pc/h/ln (derived from the 2015 WisDOT sat. flow study (4)) and the following equation:

- $s_0 = 1980 \times f_{Pop} \times f_N \times f_{SL}$ [Equation 5.13]

Where:

$s_0 = Base\ saturation\ flow\ rate\ for\ exclusive\ left, exclusive\ through, and\ shared\ through - right\ lanes$

$f_{Pop} = Adjustment\ factor\ for\ population$

$f_N = Adjustment\ factor\ for\ number\ of\ approach\ lanes$

$f_{SL} = Adjustment\ factor\ for\ speed\ limit\ of\ approach$

As with the WisDOT sat. flow spreadsheet, apply the adjustment factors by approach to determine the base sat. flow rate for each lane group. The lane adjustment factor (f_N) is dependent on the total number of lanes on the approach (i.e., includes all left, through, right, and shared lanes)[1] and the speed adjustment factor (f_{SL}) is based on the speed limit of the approach. Accordingly, the base saturation flow rate *may* differ from one approach to the next at a given signalized intersection (e.g., the base saturation flow rate for the eastbound through movement *may* be 1950 pc/h/ln while the base saturation flow rate for the northbound through lane *may* be 1825 pc/h/ln).

Due to rounding, use of the adjustment factors from Table 5.1 *may* result in a slightly different sat. flow rate than that calculated using the WisDOT sat. flow spreadsheet. The WisDOT sat. flow spreadsheet uses formulas to calculate the adjustment factors and does not round until after it computes the sat. flow rate, where the adjustment factor methodology utilizes rounded values from Table 5.1 to compute the sat. flow rate.

An example of how to apply the adjustment factors for saturation flow rate follows:

Example 1: *A signalized intersection is within an urbanized area that has a population of 29,000 (f_{Pop} = 0.95). Looking at an approach with a left-turn lane, two through lanes, and two right-turn lanes (five total approach lanes, f_N = 0.97) and a posted speed limit of 40 MPH (f_{SL} = 1.00), the resulting base saturation flow rate would be:*

$s_0 = 1980 \times 0.95 \times 0.97 \times 1.00$ $s_0 = 1825$ *pc/h/ln*

Use the resulting base saturation flow rate ($s_o = 1825$ pc/h/ln) for operational analysis of the left-turn lane and two through lanes on this approach. Use the HCM default values for the two right turn

[1] Free-flow-right turn lanes do not count toward the number of lanes at an approach

lanes unless there is field data or other documentation supporting an alternative value or WisDOT instructs otherwise. Calculate the base saturation flow rate for the left-turn and through lane groups on all other approaches in a similar manner.

Table 5.1 WisDOT Saturation Flow Adjustment Factors

Population Adjustment Factor	
Urbanized Area/ Cluster Population	Adjustment Factor
< 2,000	0.91
2,000 - 4,499	0.92
4,500 - 8,999	0.93
9,000 - 18,999	0.94
19,000 - 39,999	0.95
40,000 - 82,999	0.96
83,000 - 170,499	0.97
170,500 - 347,499	0.98
347,500 - 704,499	0.99
≥ 704,500	1.00

Lane Adjustment Factor	
Total # Approach Lanes	Adjustment Factor
1	0.88
2	0.94
3	0.96
4	0.97
5	0.97
6	0.98
≥7	0.98

Speed Adjustment Factor	
Posted Speed Limit of Approach (mph)	Adjustment Factor
25	0.94
30	0.96
35	0.98
40	1.00
45	1.02
50	1.04
55	1.07

Since the WisDOT sat. flow methodology calculates a Wisconsin, site-specific base saturation flow rate, the analyst should apply all other HCM adjustment factors (e.g., heavy vehicles, grade, lane width, Central Business District (CBD), left or right-turn vehicle presence, etc.) as appropriate to calculate the final adjusted sat. flow rate. These adjustments are typically applied within the individual software program (HCS, Synchro, Vistro).

It is important to note that the WisDOT sat. flow estimation methodology applies only to exclusive left, exclusive through, and shared through-right lanes. At ramp terminals, since there is typically a negligible number of through vehicles on the exit ramp, treat the shared left-through lane as an exclusive left-turn lane. WisDOT did not study the shared left-through-right lane configuration, however, if the through movement is the dominant movement, the analyst may, with caution, treat this lane configuration the same as an exclusive through lane.

5.2.2.4 Saturation Flow Rate Application

5.2.2.4.1 HCM-Compliant Analysis and Signal Timing Plan Development

As detailed in TEOpS 16-10, WisDOT currently supports three HCM-based software programs for traffic signal analysis, HCS, Vistro, and Synchro, although use of Vistro requires prior approval from the WisDOT regional traffic engineer. WisDOT provides the following guidance on entering base saturation flow rates generated from the WisDOT sat. flow methodology.

- HCS: Enter the base saturation flow rate, rounded to the nearest 5 pc/h/ln, into the “Base Saturation, pc/h/ln” field for the relevant movements. This field is in the “Traffic and Geometry” section within the HCS “Streets” module, which includes traffic signal analysis.
- Vistro: Check the “Override Base Saturation Flow Rate per Lane” box for the relevant lane groups in the “Saturation Flow” area of the “Traffic Control” tab. Enter the base saturation flow rate, rounded to the nearest 5 pc/h/ln, into the “User Defined Base Saturation Flow Rate per Lane (pc/h/ln)” field.
- Synchro: In the HCM module, used to generate fully HCM-compliant results, enter the base saturation flow rate, rounded to the nearest 5 pc/h/ln into the “Ideal Satd. Flow (vphpl)” field for the relevant movements. Alternately, edit this field through the “Lane Settings” module – changes made there carry through to the HCM module.

Note that the resulting base saturation flow rate calculated for a lane group containing a shared through-right lane would also be applied to the right turn movement unless there is an exclusive right turn lane on the approach.

Although the terminology within Synchro indicates that the base saturation flow rate is in vehicles per hour per lane (vphpl), further investigations found that this value is actually representative of passenger cars per hour per lane (pc/h/ln). Therefore, the analyst *should* enter the base saturation flow rate as calculated above in pc/h/ln without further adjustment.

As noted above (TEOpS 16-15-5.2.2.2), the field data used to develop the WisDOT sat. flow methodology purposely minimized the impact from heavy vehicles to lessen the impact of using pc/h/ln versus using veh/h/ln. Further, any of the adjustment factors beyond those included in the 2015 WisDOT sat. flow study (4) that are incorporated into the HCM base saturation flow rate calculations (heavy vehicles, grade, lane width, CBD, left or right-turn vehicle presence, etc.) will be applied on top of the WisDOT sat. flow rates within the software package used to calculate the final adjusted sat. flow rate in pc/h/ln.

5.2.2.4.2 Microsimulation Analysis

Capacity is not typically an explicit input within microsimulation programs, as it will vary based on vehicle interactions and various parameters. Since headway dictates saturation flow rate and because each microsimulation program has one or more adjustable parameters characterizing the concept of headway, adjustments to these settings will increase or decrease potential and realized capacities. The analyst *should* calibrate each signalized intersection, ensuring that the model meets the applicable validation thresholds and adequately replicates field behavior. Direct any questions regarding how to apply saturation flow rate within a specific microsimulation software program to BTO-TASU (DOTTrafficAnalysisModeling@dot.wi.gov).

16-15-10 Two-Way Stop-Controlled (TWSC) Intersections — February 2025

WisDOT accepts the use of the HCM, Chapter 20 methods for analyzing the performance of a two-way stop-controlled (TWSC) intersection from the perspective of the motor vehicle mode and the pedestrian modes. Currently, no specific methodology exists to assess the performance of bicycles at TWSC intersections. These methods are applicable to three-leg and four-leg intersections with stop-control only on the side street(s).

Analysts *should* recognize and account for the limitations of the TWSC methodology in Chapter 20. Some of the limitations of the TWSC methodology include, but are not limited to, the following:

- Only applicable for TWSC intersections with up to three through lanes (either shared or exclusive) on each major-street approach and up to three lanes on each minor-street approach (max of one exclusive lane per movement)
- Limited to no more than four approaches
- Limited to one stop-controlled approach on each side of the major street

Additionally, apart from a TWSC intersection located between two signalized intersections, the HCM methodology typically does not account for the effects from other intersections. For TWSC intersections located on an urban street segment between two coordinated signalized intersections, to account for the interaction of the adjacent signalized intersections, the analyst *should* follow the methodologies presented in Chapter 18 for urban street segments. When these, or similar limitations exists, the project manager *should* specify the use of an alternative tool such as microsimulation. See TEOpS 16-20 for additional details on performing microsimulation analysis.

The WisDOT-supported traffic engineering software programs for HCM-based TWSC intersection analysis are:

- *HCS, McTrans*
- *Synchro, Cubic|Trafficware (version 12 or newer)*
- Vistro, PTV Group (requires prior approval from WisDOT regional traffic engineer)

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

16-15-15 All-Way Stop-Controlled (AWSC) Intersections — February 2025

WisDOT accepts the use of the HCM, Chapter 21 methods for analyzing the performance of unsignalized intersections with stop control at all approaches (i.e., requires every vehicle to stop before entering the intersection). HCM, Chapter 21 methodologies focus on the motor vehicle mode but do offer some guidance for how to assess the performance of pedestrian and bicycles. The procedure is applicable for typical AWSC configurations of three-leg and four-leg intersections with no more than four approaches and no more than three lanes on any given approach.

Analysts *should* recognize and account for the limitations of the AWSC methodology in Chapter 21. There are cases that *may* not fit within the analytical framework of the HCM, including but not limited to queue interactions from adjacent intersections, or the impact of pedestrians. When these, or similar limitations exists, the project manager *should* specify the use of an alternative tool such as microsimulation. See TEOpS 16-20 for additional details on performing microsimulation analysis.

The WisDOT-supported traffic engineering software programs for HCM-based AWSC intersection analysis are:

- *HCS, McTrans*
- *Synchro, Cubic|Trafficware*
- Vistro, PTV Group (requires prior approval from WisDOT regional traffic engineer)

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

16-15-20 Roundabouts February 2025

20.1 Roundabout Operations

20.1.1 Introduction

WisDOT accepts the use of the HCM, Chapter 22 methods for the analysis of isolated roundabouts with one-lane and two-lane entries, up to one yielding or non-yielding bypass lane per approach, and up to two circulating lanes. HCM, Chapter 22 methodologies focus on the motor vehicle mode but do offer some guidance for how to assess the performance of pedestrian and bicycles.

Section 3 of HCM, Chapter 22 provides detailed descriptions and equations for each step of the roundabout analysis, while Chapter 33, Roundabouts Supplemental of the HCM (Section 3) goes through each of the computational steps for two example problems: one for a single-lane roundabout with bypass lanes and one for a multi-lane roundabout. These steps describe how to calculate the capacity, LOS, and queue for a roundabout by hand. The use of software makes analyzing the operations of a roundabout more efficient.

Analysts *should* recognize and account for the limitations of the roundabout methodology in Chapter 22. For roundabouts that are not isolated, are part of a system or corridor of roundabouts, or are located within the influence area of an adjacent signal, the analyst *should* use a combination of the roundabout methods of Chapter 22 and the urban street segment procedures outlined in Chapter 18. For closely spaced roundabouts (roundabouts spaced less than 1,000 feet from center-to-center), specifically those found at freeway ramp terminals, the analyst *should* follow the methodology presented in Chapter 23 for interchange ramp terminals.

See TEOpS 16-15-20.5 for additional information on the use of supplemental tools for operational analyses and design.

20.1.2 Roundabout Capacity

The capacity of each entry to a roundabout is the maximum rate at which vehicles can reasonably enter the roundabout during a given time period under prevailing traffic and geometric conditions. An operational analysis considers entering and circulating traffic flow rates defined for the morning and evening peak periods for each lane at a roundabout. Analysis of the peak hour period is critical to assess the level of performance at each approach and the roundabout as a whole.

The maximum flow rate that a roundabout entry can accommodate depends on two factors: (1) the circulating flow in the roundabout that conflicts with the entry flow, and (2) the number of entering lanes on the approach to the circulatory roadway. When the circulating flow is low, drivers at the entry can enter the roundabout without significant delay. The larger gaps associated with low circulating flows make it easier for drivers to enter the roundabout and provide the opportunity for more than one vehicle to enter each gap. As the circulating flow increases, the size of the gaps in the circulating flow decreases, thus the rate at which vehicles can enter also decreases.

Evaluate the conflicting flow rates at each approach leg of the roundabout individually to determine the number of entering lanes required. Base the number of lanes within the circulatory roadway on the number of lanes needed to provide lane continuity. More detailed lane assignments and refinements to the lane configurations must be determined through a more formal operational analysis as described in TEOpS 16-15-20.2.

On multi-lane roundabouts, it is important to balance the traffic use of each lane to avoid overloading one or more lanes while underutilizing other lanes. In addition, poorly designed exits may influence driver behavior and cause lane imbalance and congestion on the opposite leg.

20.1.3 Pedestrian Effects on Entry and Exit Capacity

Pedestrians crossing at a marked crosswalk have priority over entering motor vehicles. As such, pedestrian traffic can have a significant effect on the capacity of a roundabout entry, especially if there are high pedestrian volumes.

To approximate the effect of pedestrian traffic, multiply the vehicular capacity by the entry capacity adjustment factor for pedestrians (fped) according to the relationship shown in Exhibit 22-18 and 22-20 of HCM7, Chapter 22 for single-lane and two-lane entry roundabouts, respectively.

Note that the effects of conflicting pedestrians on the approach capacity decrease as conflicting vehicular volumes increase, as entering vehicles become more likely to have to stop regardless of whether pedestrians are present. Consult the HCM for additional guidance on the capacity of pedestrian crossings if the capacity of the crosswalk itself is an issue. A similar effect in capacity may occur at the pedestrian crossing on the roundabout exit.

20.2 Wisconsin-Calibrated Models

20.2.1 Driver Behavior

Critical headway (also referred to as 'critical gap') and follow-up headway are the driver behavior parameters that influence the capacity of a roundabout approach and intersection. Critical headway is the smallest gap in circulating traffic that an entering driver would accept to enter the roundabout. Follow-up headway is the time between two successive entering vehicles accepting the same gap in circulating traffic. Figure 20.1 diagrams the concept of critical headway and Figure 20.2 diagrams the concept of follow-up headway.

Figure 20.1 Critical Headway

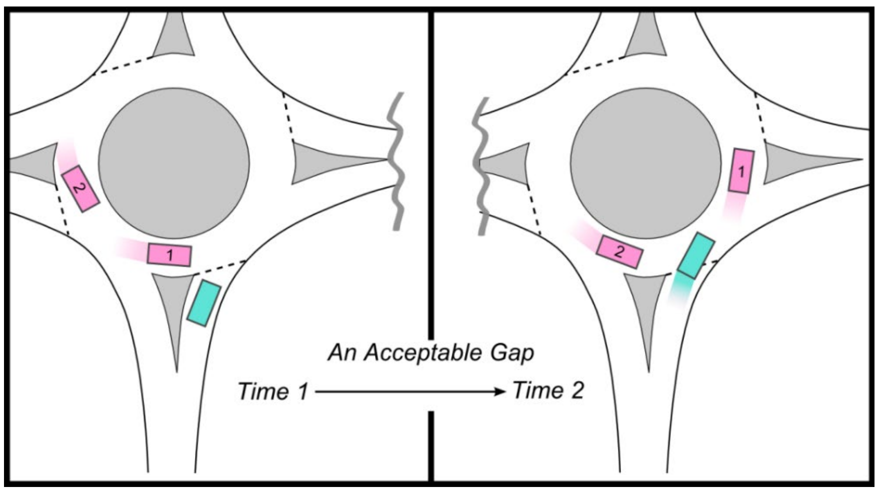
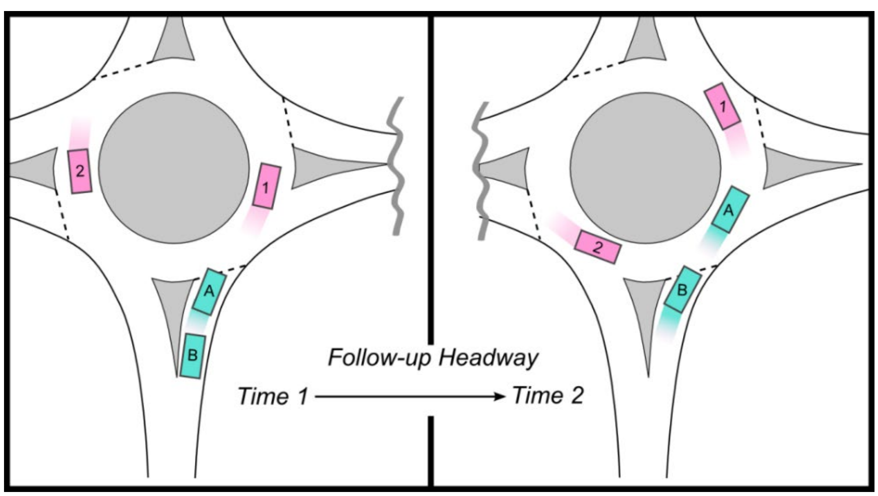


Figure 20.2 Follow-up Headway



The HCM (Chapters 22 and 33) provides an empirical capacity equation for estimating the operations of a U.S. roundabout which is based on an exponential gap-acceptance theory combined with field determined headway values. This method of analyzing roundabouts is the basis for Wisconsin's driver behavior-based approach to analyzing roundabout operations.

The general form of the capacity equation for a roundabout follows below in Equation 20.1 - Equation 20.3:

$$c_{pce} = Ae^{(-Bv_c)}$$ [Equation 20.1]

$$A = \frac{3,600}{t_f}$$ [Equation 20.2]

$$B = \frac{t_c - (t_f/2)}{3,600}$$ [Equation 20.3]

where:

c_{pce} = entry lane capacity, adjusted for heavy vehicles (pc/hr/ln)

v_c = lane capacity, adjusted for heavy vehicles (pc/hr)

t_c = critical headway (s), and

t_f = follow − up headway (s)

Adjusting the critical and follow-up headways allow the capacity equation in Equation 20.1 to be calibrated to reflect local site conditions. The HCM provides default capacity equations based on observations of critical and follow-up headways made at US roundabouts in 2012 (7)

In an effort to calibrate the HCM capacity equations to reflect conditions in Wisconsin, in 2020, WisDOT completed a research project to observe headways at Wisconsin roundabouts (8). Table 20.1 lists the recommended headway values and the corresponding parameters A and B that were developed based on the findings of the study. The analyst **shall** use the values listed in Table 20.1 for roundabout capacity analyses statewide. Refer to Attachment 20.1 for an illustration of the roundabout lane configurations associated with the headway values in Table 20.1.

Table 20.1 Recommended Headway Values[1]

	Critical Headway, t_c	Follow-up Headway, t_f	Parameter A	Parameter B
Single Circulating (Conflicting) Lane				
Single Lane Entry (1 - 1)	4.7	2.6	1385	0.000944
Two Lane Entry				
Left Lane (L2 - 1)	4.7	2.5	1440	0.000958
Right Lane (R2 - 1)	4.4	2.5	1440	0.000875
Three Lane Entry				
Left Lane (L3 - 1)	4.6	2.3	1565	0.000958
Center Lane (C3 - 1)	4.4	2.6	1385	0.000861
Right Lane (R3 - 1)	4.4	2.4	1500	0.000889
Yielding Slip/Bypass Lane (R-bypass - 1)	4.0	2.3	1565	0.000792
Multi-Circulating (Conflicting) Lanes[2]				
Single Lane Entry (1 - 2)	4.8	2.6	1385	0.000972
Two Lane Entry				
Left Lane (L2 - 2)	4.6	2.6	1385	0.000917
Right Lane (R2 - 2)	4.3	2.6	1385	0.000833
Three Lane Entry				
Left Lane (L3 - 2)	4.6	2.5	1440	0.000931
Center Lane (C3 - 2)	4.4	2.4	1500	0.000889
Right Lane (R3 - 2)	4.6	2.5	1440	0.000931
Yielding Slip/Bypass Lane (R-bypass - 2)[3]	4.8	2.8	1286	0.000944

[1] Refer to the TADI 2020 research study for details on how the recommended headway values were calculated (8).
[2] Values are based on observations of roundabouts with two circulating (conflicting) lanes but are assumed to be similar for roundabouts with three circulating (conflicting) lanes. For roundabouts with more than two circulating (conflicting) lanes, consider conducting field investigations to verify values.
[3] The TADI 2020 research study (8) did not evaluate bypass lanes for multi-circulating lane roundabouts with more than one entry lane.

20.2.2 HCM Analysis

The WisDOT-supported traffic engineering software programs for HCM-based roundabout analysis are:

- HCS, McTrans
- SIDRA (HCM mode only), Akcelik & Associates

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. Use of the WisDOT-supported software requires calibration with the recommended Wisconsin headway values listed in Table 20.1.

20.2.2.1 HCS

Consistent with the confines of the HCM methodology, HCS restricts analysis to no more than four approaches, a maximum of two entry lanes, and up to one yielding or nonyielding bypass lane per approach. For other roundabout lane configurations, use of SIDRA or a supplemental tool (see TEOpS 16-15-20.5) is required.

20.2.2.2 SIDRA

SIDRA can analyze roundabouts with multiple models, including SIDRA Standard and HCM6 capacity models. ; SIDRA does not yet reference HCM7; however, the roundabout capacity models are the same for HCM6 and HCM7, so the US HCM 6 model is reflective of both HCM6 and HCM7 methodologies. When analyzing Wisconsin roundabouts, the analyst **shall** use the US HCM 6 (HCM7) capacity and delay models and **shall** treat the level of service the same as sign control (located under the Roundabouts window, Options tab). Check the “Apply Extended Model” under the US HCM 6 roundabout capacity model to expand the available roundabout capacity model parameters to reflect the roundabout lane configurations illustrated in Table 20.1.

SIDRA (U.S. mode) expands upon the lane configuration limitations of the HCM methodology such that SIDRA (U.S. mode) is applicable for all roundabouts but is specifically required for the evaluation of roundabouts with three entry lanes, two right-turn bypass lanes, or five or more approaches. SIDRA applies the basic HCM procedures and provides essentially the same results as HCS. Verify the SIDRA results for three-lane entries and dual bypass lanes with one of the supplemental design-aid tools discussed in TEOpS 16-15-20.5.

Within SIDRA, there is the option to apply an HCM Roundabout Capacity Model Extension to address unbalanced flow conditions. Additionally, SIDRA has an Extra Bunching parameter (located under the Intersection window, Intersection tab, Approach Data field), that when applied, adjusts the proportion of platooned vehicles in the traffic stream according to the proximity of and level of queuing at an upstream signalized intersection. Prior to utilizing either the unbalanced flow model extension or the extra bunching parameter for operational analysis, the analyst *should* verify the appropriateness of their use with the WisDOT regional traffic engineer or BTO-TASU.

In addition to the HCM mode, SIDRA has its own roundabout capacity model (i.e., SIDRA Standard) which is based on Australian and international research. The analyst *may* use the SIDRA Standard model as a design-checking tool, but this mode is not acceptable for demonstrating that the roundabout provides sufficient capacity. See TEOpS 16-15-20.5 for additional information on the use of supplemental design-aid tools.

20.2.2.3 Selecting the Appropriate Analysis Tool

Use Table 20.2 as guidance in choosing the most appropriate WisDOT supported analysis tool for the specific roundabout lane configuration under consideration. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

Table 20.2 Choosing the Appropriate Analysis Tool

Analysis Tool	Appropriate Situations
HCS	One or two-lane entries, single-lane right-turn bypass lanes, no more than four approach legs
SIDRA Intersection	One, two or three-lane entries, one or two-lane right-turn bypass lanes, up to 8 approach legs
Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version of HCS and SIDRA Intersection that WisDOT currently supports.	

20.2.3 Calibrating the HCM Model

20.2.3.1 HCS

In order to calibrate the HCM model within HCS, the analyst will need to enter the headway values (both critical and follow-up) for each travel lane under the Roundabout “Traffic” tab. Critical and follow-up headway values **shall** match the accepted Wisconsin headways listed in Table 20.1. The headway values entered depend on the number of entry lanes and the number of lanes circulating (conflicting) past a given entry, see Attachment 20.1. Refer to the HCS Users Guide for additional details on how to modify the critical and follow-up headway values.

20.2.3.2 SIDRA

After entering the intersection geometry, the analyst has two options to calibrate the model within SIDRA to reflect the Wisconsin-specific values shown in Table 20.1.

With the first option, the analyst will need to revise the default Parameter A and Parameter B values (located under the Roundabouts window, HCM 6 Extended Data tab). In order to view the parameters for all combinations of entering and circulating lanes as shown in Table 20.1, the analyst will need to check “Apply Extended Model” under the US HCM 6 roundabout capacity model options (see Figure 20.3). In most cases, on dual or triple-lane entry roundabouts, the right lane acts as the dominant lane while the left and middle lane act as the subdominant lane(s).

Alternatively, the analyst can enter the headway values (both critical and follow-up) for each travel lane (located under the Gap Acceptance window, Data tab, Vehicle Movements Opposing field) making sure to specify the use of “Input” values rather than the default “Program” values (see Figure 20.4).

See the SIDRA User Guide for additional details on how to modify the Parameter A and Parameter B values and Gap Acceptance Data.

Figure 20.3 SIDRA HCM 6 Extended Data Roundabout Capacity Model Parameters

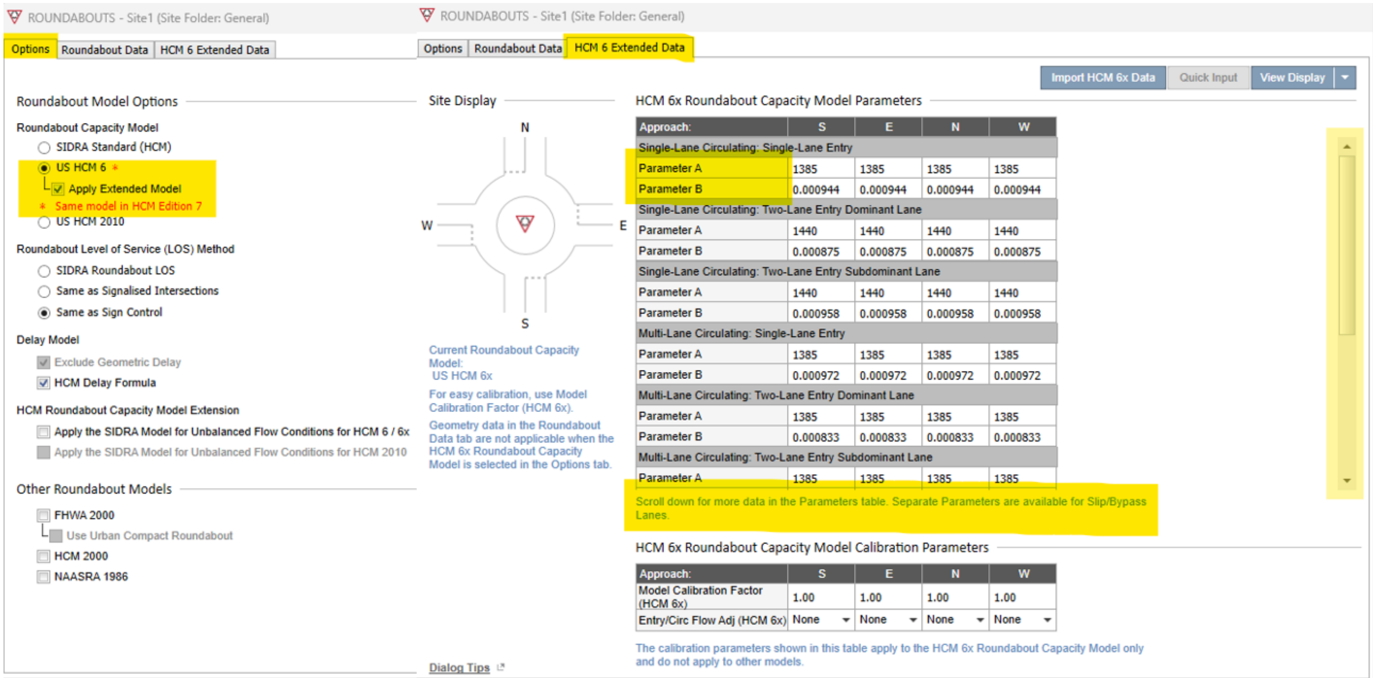
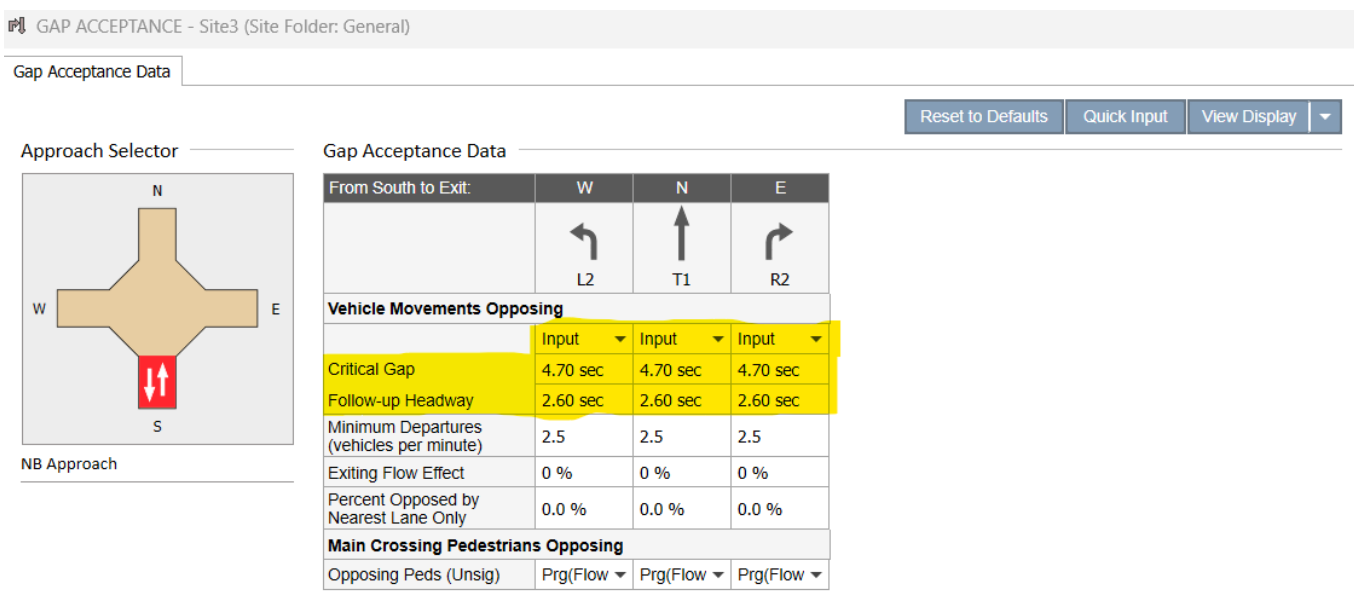


Figure 20.4 SIDRA Gap Acceptance Data



20.3 Compact Roundabout Analysis

The HCM methodology does not account for geometric parameters, such as the inscribed circle diameter (ICD), as factors in determining the operations of a roundabout. As international research has shown, changing the size of the ICD has an impact on overall operations. Therefore, without additional calibration, the current HCM single-lane roundabout methodologies will not correctly estimate the operations of a compact roundabout, generally overestimating the capacity.

Currently, both the presence of compact roundabouts and subsequently the research on compact roundabouts is minimal in the US. As such, as an interim approach until more research becomes available on in-service compact roundabouts operating at or near capacity, WisDOT studied the effects of known volume-based operational parameters of larger sized roundabouts (ICDs greater than 120 ft) on the varying ICDs and volume flow rates of compact roundabouts.

The analyses, completed with WisDOT-supported software (HCS and SIDRA), resulted in the development of volume calibration factors (VCFs) for two size ranges of compact roundabouts, those between 80-99 feet and those between 100-119 feet.

20.3.1 Volume Calibration Factor (VCF) Selection

Select a scaling factor based on the entering AADT and the proposed ICD size, as shown in Table 20.3.

Table 20.3 Volume Calibration Factor

Entering AADT	ICD	
	80 – 99 ft	**100-119 ft**
< 15,000	30%	20%
15,000 – 15,999	29%	19%
16,000 – 16,999	28%	18%
17,000 – 17,999	27%	17%
18,000 – 18,999	26%	16%
≥19,000	25%	15%

20.3.2 Application of VCFs using HCS

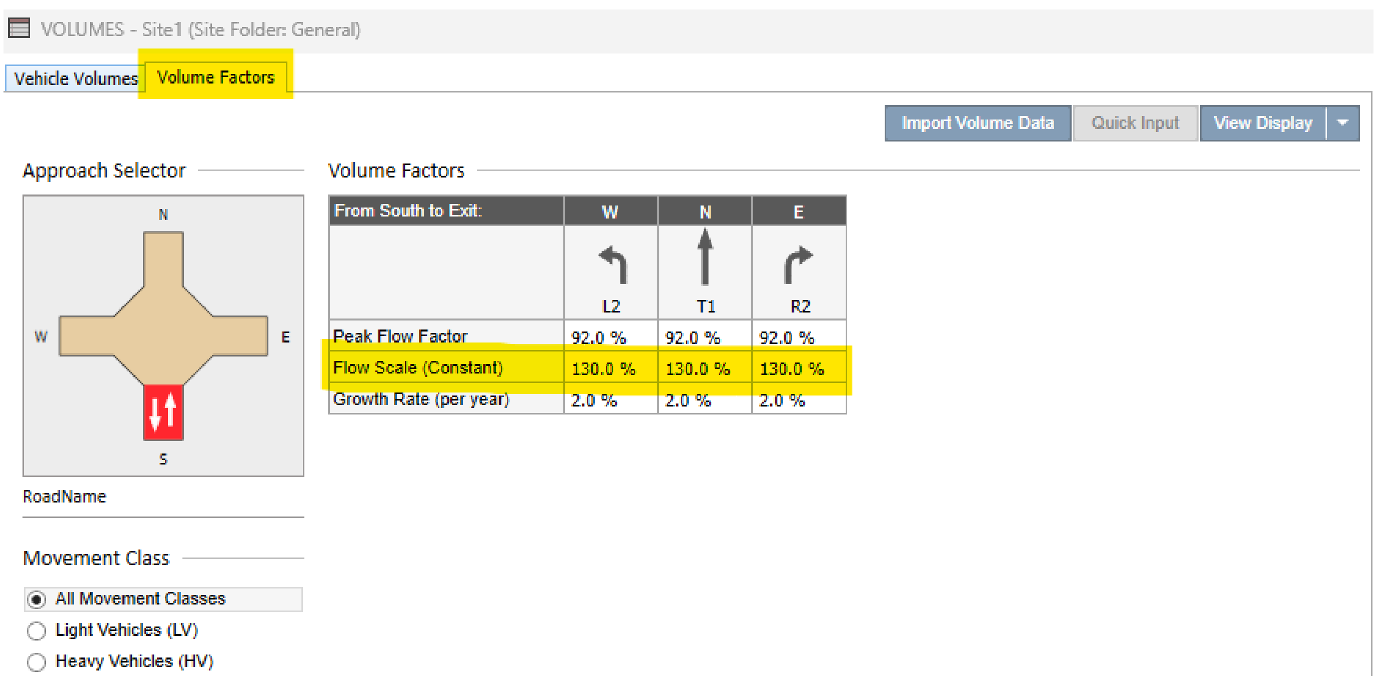
Manually increase the design year turn movement volumes by the appropriate VCF and enter the resulting volume into the Traffic tab. The new volume will be the (VCF + 100) * the field turning movement count. Enter the PHF and Percent Heavy Vehicles as determined by the field count data and use the appropriate Wisconsin calibrated headway values as shown in Table 20.1.

20.3.3 Application of VCFs using SIDRA

The following outlines the four-step process for applying the VCFs within SIDRA.

1. Start by setting up a site in SIDRA based on the instructions in TEOpS 16-15-20.2.2.2 and TEOpS 16-15-20.2.3.2. Enter the volumes, PHF, and Percent Heavy Vehicles as determined by the field count data and use the appropriate Wisconsin calibrated headway values as shown in Table 20.1.
2. Set the Roundabouts Site Input to use the US HCM 6 Roundabout Capacity Model.
3. To apply the VCF, open the Volumes window and activate the Volume Factors tab. Enter the VCF into the Flow Scale (Constant) cells under each movement, for every leg of the site. The new Flow Scale will be the VCF + 100, as shown in Figure 20.5.
4. Process the site as normal.

Figure 20.5 VCF Input as the Flow Scale



20.4 Operational Analysis and Design

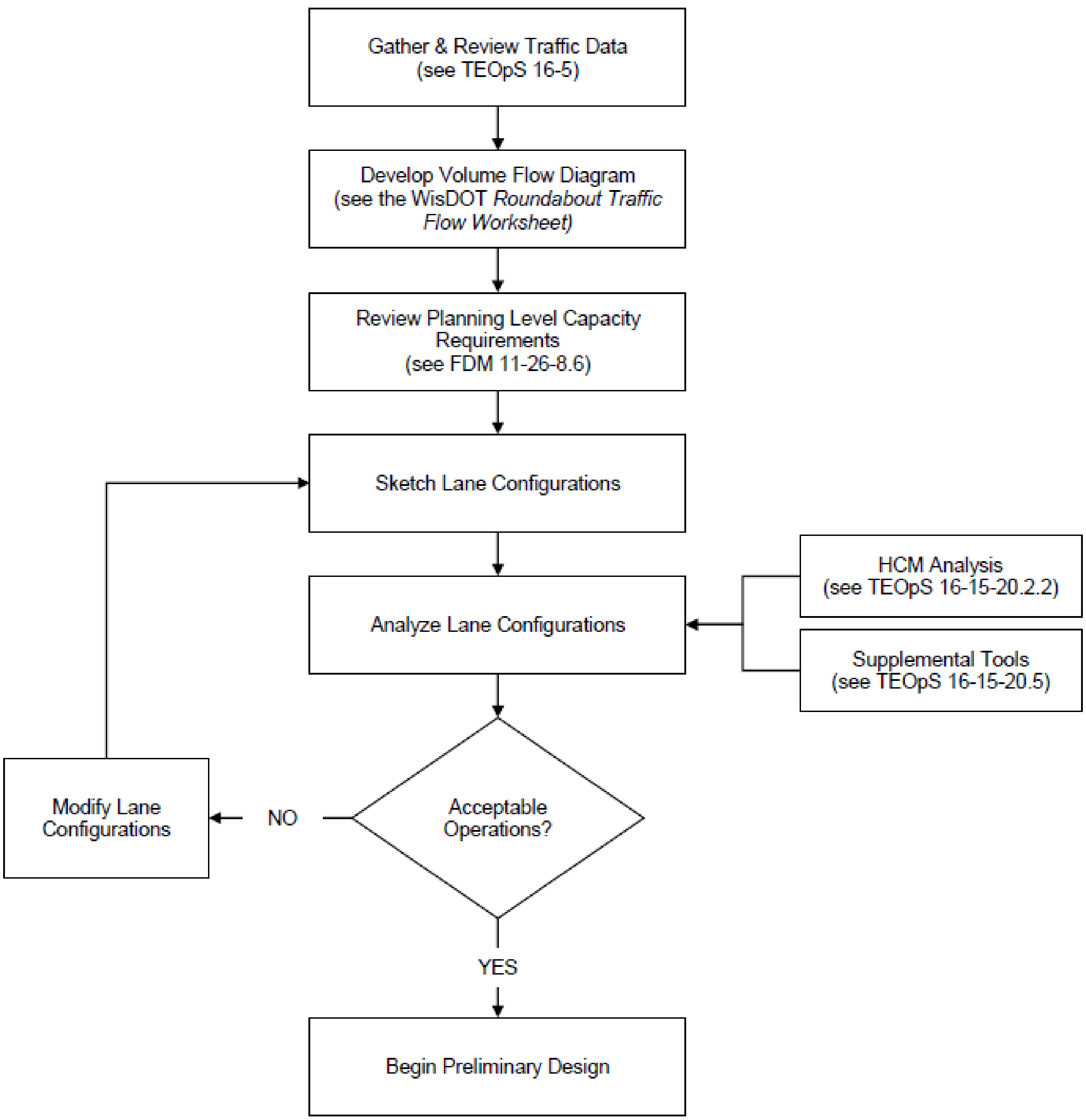
The lane configuration selected for typical operations with design year traffic conditions should be the basis of the roundabout design. Typically, a lane configuration for typical operations means that all or most movements operate at LOS D or better with a volume -to-capacity ratio less than one. See FDM 11-5-3.2 for further discussion on intersection LOS and see FDM 11-5-3.5 for further discussion on the typical level of service evaluation.

Figure 20.6 provides a diagram illustrating WisDOT's approved method for analyzing roundabouts using HCM guidance. As shown in Figure 20.6, only once the analysis is complete and the preferred lane configuration has been determined, *should* the preliminary design of the roundabout begin.

20.4.1 Develop Volume Flow Diagram

After gathering and reviewing the existing and forecasted traffic volumes for reasonableness (see TEOpS 16-5), develop a volume flow diagram that illustrates the entering and circulating volumes for each roundabout approach. Forecasts developed by the WisDOT Traffic Forecasting section include a volume flow diagram. Alternatively, the WisDOT Roundabout Traffic Flow Worksheet provides a format for summarizing the AM and PM peak hour traffic volumes and truck percentages for a 3-leg or 4-leg roundabout.

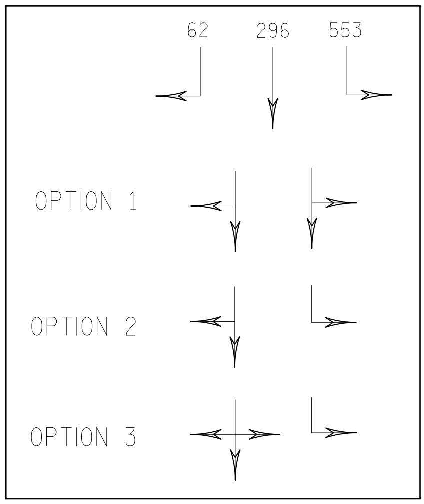
Figure 20.6 WisDOT Approved Method for Analyzing Roundabouts



20.4.2 Review Planning Level Capacity Requirements

Refer to FDM 11-26-8.6, Figure 8.2 to establish a planning-level estimate of the number of entry lanes a roundabout would require to serve the traffic demands illustrated in the volume flow diagram. Using the planning-level lane requirement estimates, determine the entry volumes for each lane of the roundabout approach. Adjust the lane volumes based on observed or estimated lane utilization patterns or imbalances. If no lane utilization patterns are observed, the HCM default values are 47% of entry flow in the left lane and 53% of entry flow in the right lane for left-through plus through-right (Option 1 in Figure 20.7) and left-through-right plus right lane configurations, and 53% in the left lane and 47% in the right lane for left plus left-through-right (Option 3 in Figure 20.7) lane configurations.

Figure 20.7 Roundabout Lane Configuration Options



20.4.3 Sketch Lane Configurations

A lane configuration sketch of the roundabout *should* accompany the traffic volumes to facilitate the selection of the number of lanes and the lane assignments. The layout process is critical because it affects the geometry. This step precedes the detailed roundabout capacity analysis. In Figure 20.7, the assessment of lane assignments for the example traffic flows could include three different options. Unless traffic demand for a given approach is indicative of the potential need for an exclusive left turn lane, the preferred configuration is Option 1 for its simplicity of design and because the configuration should accommodate both peak and off-peak traffic demand. In the example, Options 2 and 3 would require spiral geometry and marking treatment for the upstream entry left turn. Additionally, Options 2 and 3 imply a single-lane exit for lane continuity of the through movement. These alternatives complicate the design and may influence driver behavior by causing confusion when navigating the circulatory roadway. Figure 20.8 is an example of the roundabout lane configuration sketch employing Option 1.

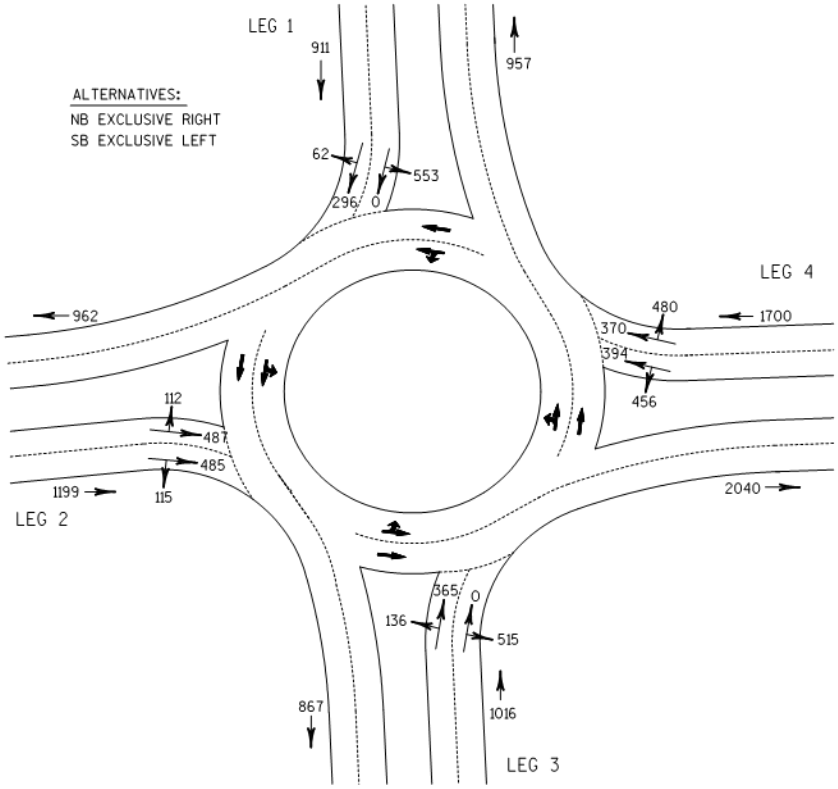
20.4.4 Analyze Lane Configurations

Evaluate the preliminary lane configurations following the HCM analysis methodology outlined in TEOpS 16-15-20.2. Start by using one of the two WisDOT supported HCM-based analysis tools (HCS or SIDRA) and conduct sensitivity testing with supplemental design-aid tools as appropriate (see TEOpS 16-15-20.5).

Following FDM guidance and HCM methodologies, check for acceptable levels of operation. If levels of operation are not acceptable, modify the preliminary lane configurations and reevaluate until a lane configuration for acceptable operations is determined, after which the detailed design can be completed.

Existing roundabouts may need to be field adjusted to improve capacity; use of supplemental tools may be appropriate to help determine potential improvements for an existing roundabout.

Figure 20.8 Lane Configuration Sketch



20.4.5 Special Considerations

Lane designation or lane assignments are critical to the success of the roundabout lane configuration and design. Conditions can be very complex with subtle problems that can reduce capacity and cause severe lane imbalance. Great care and sensitivity are required to achieve lane utilization balance. Supplementary software is especially suited to these situations.

- Unbalanced Conflicting Flows:

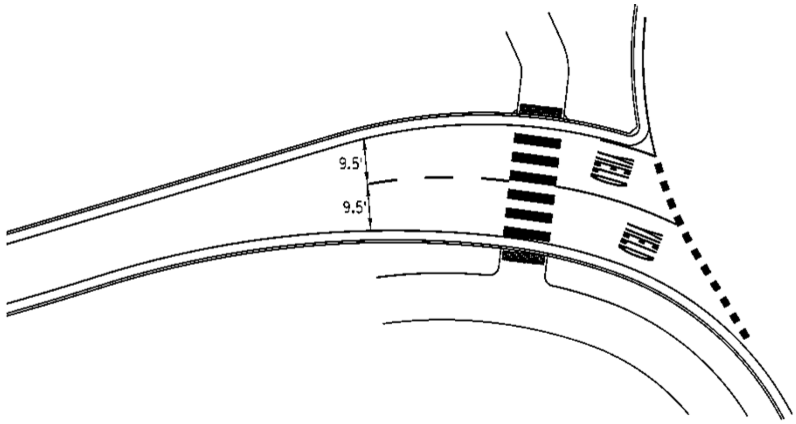
  At a roundabout with unbalanced conflicting flow patterns, a traffic stream with a low flow rate enters the roundabout having to yield to a circulating stream with a high flow or visa-versa.

  Unbalanced circulating flows highlight an operational condition that traffic engineers and designers *should* understand and interpret by taking into consideration all aspects including but not limited to the results of the analysis, the existing and future field conditions, and the traffic patterns to better inform the findings on the analysis. The SIDRA Standard capacity model is sensitive to the ratio of entering to circulating flow, and therefore may be able to reflect expectations of capacity when unbalanced flow conditions are expected. A microsimulation model can also supplement the analysis, but the level of data and effort to calibrate this model can be significant and may not be appropriate for an isolated roundabout analysis.

- Capacity Considerations of Flared Entries:

  In some situations, the use of appropriate lane arrows can encourage balanced lane use, thus improving capacity. Traffic often has a bias towards the right-most lane. Lane arrows either can encourage this bias or can encourage lane balance. Figure 20.9 shows the preferred pavement marking scheme to encourage balanced lane demand. It is important for the analyst not to assume that flared entries at roundabouts will always provide for balanced lane use and therefore add capacity to that entry as HCS and SIDRA will predict. This scenario *may* occur on the approach to a roundabout that has little to no conflicting circulating traffic (e.g., a roundabout at an interchange ramp or any roundabout with a one-way street). The suitable marking for an approach will depend on the turning volume proportions. A methodology similar to that described in TEOpS 16-15-20.4.2 is used to assess lane designation alternatives.

Figure 20.9 Capacity Considerations of Flared Entries



In addition, assessment of the potential for one lane to fill and block the flared lane is necessary to achieve the predicted levels of service (i.e., the geometry must be effective to match the capacity prediction). Lane starvation is a primary failure mechanism for flared entries. Microsimulation models have various forms of lane-by-lane simulation features, which allow the analyst to test alternative lane configurations with visualization of the simulated flows accumulating and filling the flared lanes.

20.5 Supplemental Tools for Operational Analysis and Design

When performing roundabout operational evaluations, analysts *should* recognize and account for the methodological limitations of the HCM. There are cases that *may not* fit within the analytical framework of the HCM, including, but not limited to: volume-to-capacity ratio exceeding 0.80, high-level of pedestrian or bicycle activity, priority reversal under extremely high flows, and flared entry lanes. When the volume-to-capacity ratio exceeds 0.80, the analyst *should* carefully consider predicted queues and delays and perform additional sensitivity analysis. Further analysis with microsimulation or design-aid tools such as SIDRA Standard, Rodel, or ARCADY can supplement the study if the effort is justifiable based on the site conditions.

Use of supplemental software tools may also be appropriate for evaluating operations for in-service roundabouts whereby collection of data under at or over capacity conditions are available to calibrate the roundabout capacity equations. FDM 11-26-8.10 provides additional details on the assessment of existing roundabouts.

Microsimulation is capable of system level analysis and allows the analyst to adjust roundabout designs indirectly. Additionally, microsimulation that provides for animation and visualization of operating predictions is useful for assessing lane utilization and capacity, especially when considering closely spaced roundabouts (roundabouts spaced less than 1,000 feet from center-to-center). Analysis with microsimulation may help identify lane imbalances or lane use problems within a series of intersections allowing for a more robust design of any single roundabout. Microsimulation may also prove beneficial for public outreach. Since microsimulation requires significantly more time, resources, and effort than HCM-based analysis, it is not appropriate to use for all roundabout analysis or design. Refer to TEOpS 16-10 for additional guidance on determining whether the use of a microsimulation tool would be appropriate. See TEOpS 16-20 for additional details on performing microsimulation analysis.

SIDRA Standard, Rodel, ARCADY and any other tool that designers have available to assist them in the design process can prove beneficial for the final geometric design of the roundabout. These programs provide for geometric sensitivity testing, allowing the user to test the effects of size and key geometric parameters (e.g., inscribed circle diameter, entry radius, phi angle, lane width, and flared entry) along with varied flows on an existing or proposed roundabout design. Prior to using supplemental design-aid tools, the analyst *should* first determine the basic lane configuration using the HCM-based operational analysis and any other pertinent considerations. When the results of the HCM analysis show that a multi-lane roundabout is necessary on an existing single-lane roadway, the designer *should* confirm the HCM results using supplemental design-aid tools.

Rodel and ARCADY apply UK research producing a model that relates geometry to capacity, for roundabout capacity calculations. SIDRA Intersection, when used in Standard mode, implements a capacity estimation method that assumes a dependence of gap acceptance parameters on multiple factors. Roundabout geometry, circulating flows, entry lane flows, and model designation of dominant or subdominant lanes all influence gap acceptance parameters to account for lane-by-lane capacity variation. SIDRA Standard utilizes what they call the Environment Factor as one of the main parameters to calibrate the capacity model. The recommended Environment Factor for U.S. roundabouts is 1.05 for one-lane roundabouts (approach road or circulating road has one lane) and 1.2 for multi-lane roundabouts (both approach road and circulating road have two or more lanes). See the SIDRA Intersection User Guide Calibration Parameters for Roundabout Capacity Models for details on how to apply the Environment Factor in the SIDRA capacity model.

LIST OF ATTACHMENTS

Attachment 20.1	Roundabout Lane Configurations

16-15-25 Alternative Intersections — February 2025

Alternative intersections separate out one or more of the turning movement conflicts (typically left-turns) by rerouting them away from the center of the intersection to a secondary junction. Alternative intersections *may* be signalized or stop-controlled on the minor street movements. Examples of alternative intersections include, but are not limited to, the following:

- Restricted Crossing U-Turn (RCUT), also known as the J-Turn or superstreet (a signalized RCUT),
- Median U-Turn (MUT), also known as the Michigan left turn or modified RCUT, and
- Displaced Left Turn (DLT), also known as the continuous-flow intersection

Refer to FDM 11-25 Attachment 3.3 for a brief description, summary of the key elements to consider, and some of the potential benefits/concerns associated with these alternative intersections. For additional information on RCUTs, see the WisDOT *Restricted Crossing U-Turn* webpage.

By rerouting one or more of the turn movements away for the center of the primary intersection, alternative intersections result in two or more closely spaced intersections that are operationally dependent on one another. Thus, the analyst *should* treat these intersections as a single unit.

WisDOT accepts the use of the HCM, Chapter 23 to assess the performance of the RCUT, MUT, and DLT from the perspective of the motor vehicle, pedestrian, and bicycle modes. Note that the Chapter 19 signalized methodology for pedestrians and bicycles is typically applicable for the minor street crossings at a signalized RCUT (superstreet) and for all crossings at the signalized MUT. The HCM, Chapter 23 methodology provides a means to measure experienced travel time and considers the control delay experienced at each intersection plus the additional travel time needed to travel from the primary/center intersection to the secondary junction and back to the primary/center intersection.

Analysts *should* recognize and account for the limitations of the HCM methodology. Specifically, the analyst *should* bear in mind that the HCM Chapter 23 methodology is only applicable to the RCUT, MUT, and DLT. Consider using microsimulation analysis tools for those alternative intersections that do not fit within the methodological limitations of the HCM. See TEOpS 16-20 for additional details on performing microsimulation analysis.

The WisDOT-supported traffic engineering software for HCM-based analysis of alternative intersections is:

- HCS, McTrans

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

Trafficware has not yet implemented the HCM methodology for alternative intersections within Synchro; however, the analyst *may* be able to manipulate the coding within Synchro to analyze these intersections in accordance with the HCM methods. Confirm with the WisDOT regional traffic engineer whether it is appropriate to utilize Synchro for the analysis of alternative intersections.

16-15-30 Interchange Ramp Terminals — February 2025

The close spacing and interdependency of most ramp terminals requires that the operational analysis consider all ramp terminals within the interchange as a single unit. WisDOT accepts the use of the HCM, Chapter 23 for the analysis of interchange ramp terminals. As no specific methodologies for pedestrian and bicycle operations at interchange ramp terminals currently exist, the HCM, Chapter 23 methodologies for interchange ramps focus on the motor vehicle mode. Chapter 23, however, does provide some guidance for addressing bicycles and pedestrians at interchanges.

The HCM, Chapter 23 methodology addresses the following conventional interchange designs:

- Diamond interchanges,
- Partial cloverleaf (parclo) interchanges, and
- Interchanges with roundabouts.

Additionally, the HCM, Chapter 23 methodology addresses the following alternative interchange designs:

- Diverging diamond interchanges (DDIs) and
- Single-point interchanges (SPI).

Refer to FDM 11-25 Attachment 3.3 for a brief description, summary of the key elements to consider, and some of the potential benefits/concerns associated with each of these interchange designs. For additional information on DDIs and SPIs, see the WisDOT *Innovative interchange design* webpage.

The HCM, Chapter 23 methodology calculates the control delay experienced at each ramp terminal plus any additional travel time associated with driving between ramp terminals within the interchange. This allows for an equal comparison of the various interchange designs.

The analysts *should* recognize and account for the methodological limitations of the HCM, Chapter 23 methods. Specifically, the analyst *should* bear in mind that the analysis methodology is not applicable for freeway-to-freeway or system interchanges. Additionally, the methodology does not cover interchanges with TWSC intersections or interchanges consisting of both a signalized and roundabout intersection. Consider using microsimulation analysis tools for those interchanges that do not fit within the methodological limitations of the HCM. See TEOpS 16-20 for additional details on performing microsimulation analysis.

The WisDOT-supported traffic engineering software programs for HCM-based analysis of interchange ramp terminals are:

- HCS, McTrans
- Synchro, Cubic|Trafficware (conventional ramp terminals only)

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

Trafficware has not yet implemented the HCM methodology for the alternative interchange ramp terminals (e.g., DDI, SPI) within Synchro; however, the analyst *may* be able to modify the coding within Synchro to analyze these types of interchange ramp terminals in accordance with the HCM methods. Confirm with the WisDOT regional traffic engineer whether it is appropriate to utilize Synchro for the analysis of the alternative interchange ramp terminals. In most cases, the analyst *should* only utilize Synchro for planning-level applications. For design considerations, the analyst should utilize a WisDOT-supported microsimulation tool. Refer to the *Best Practice – Vissim Analysis of Diverging Diamond Interchanges* for the recommended approach for analyzing DDIs, especially for design considerations.

16-15-35 Urban Street Facilities — February 2025

WisDOT accepts the use of the HCM, Chapters 16 and 18 for an integrated multimodal analysis of an urban street facility, including the intersections and segments that make up the facility. The methodology provides the analytical framework to assess the automobile, pedestrian, bicycle, and transit modes by calculating delay and other performance measures by mode for each direction of travel along each segment of the given urban street facility, in addition to mid-block access points and other study intersections. The analyst *should* also consider the methods for TWSC, AWSC, roundabouts, and signalized intersections to the extent that those facilities exist along the subject roadway.

For intersections along an urban arterial or collector street that do not operate in isolation (i.e., the operation of one intersection influences the operation of the adjacent intersection), follow the Chapter 18 Urban Street Segment methodology. If the project spans multiple contiguous urban street segments, consider applying the Chapter 16 Urban Street Facilities methodologies. The Chapter 16 Urban Street Facilities methods allow the analysis of corridors of coordinated signalized intersections to capture average-phase-duration and other analytical components related to progression and vehicular platooning. If travel time reliability performance measures are of interest, consider using the urban street reliability methodologies in HCM, Chapter 17. For additional information on incorporating travel-time reliability into the analysis, contact BTO-TASU (DOTTrafficAnalysisModeling@dot.wi.gov).

Analysts *should* recognize and account for the limitations of the HCM urban streets methodology. Accordingly, limitations of the individual intersection methods are also limitations of the urban street methods. For urban street facilities that do not fit within the analytical framework of the HCM, including but not limited to cases involving turn-lane spillover, mid-block parking maneuvers, or capacity constraints between intersections, the project manager *should* specify the use of an alternative tool such as microsimulation. See TEOpS 16-20 for additional details on performing microsimulation analysis.

The WisDOT-supported traffic engineering software programs for HCM-based urban streets analysis are:

- HCS, McTrans
- Synchro, Cubic|Trafficware

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

16-15-40 Freeway Facilities — February 2025

WisDOT accepts the use of the HCM analysis methods in Chapter 10 for a combined freeway facility, Chapter 11 for freeway reliability analysis, Chapter 12 for basic freeway segments, Chapter 13 for freeway weaving segments and Chapter 14 for freeway merge and diverge segments. Analysts *should* use these methods to assess uninterrupted flow facilities that typically have restricted access and consist of higher-speed roadways through rural, suburban, and urban areas. Since there is no pedestrian/bicycle traffic on freeways, the HCM methodology focuses on the vehicular mode of travel. For additional information on incorporating travel-time reliability into the analysis, contact BTO-TASU (DOTTrafficAnalysisModeling@dot.wi.gov).

Analysts *should* recognize and account for the limitations of the HCM methodology for freeway analysis. For freeway facilities that do not fit within the analytical framework of the HCM, the project manager *should* specify the use of an alternative tool such as microsimulation. See TEOpS 16-20 for additional details on performing microsimulation analysis.

The WisDOT-supported traffic engineering software for HCM-based freeway analysis is:

- HCS, McTrans

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

16-15-45 Multilane Highways — February 2025

WisDOT accepts the use of the HCM, Chapter 12 methods for the analysis of an expressway or multilane highway. The methodology provides the analytical framework to assess the automobile and bicycle modes of travel. The analyst *should* use these methods to assess uninterrupted flow on multilane highway facilities with free-flow speeds between 45 and 70 mph, and two miles or more between traffic signals. These facilities *may* be divided, undivided, or have a two-way left-turn lane (TWLTL).

Many multilane highways will have periodic signalized intersections that are more than two miles apart. In these cases, the analyst *should* evaluate the highway segment portion using the Chapter 12 method and evaluate the isolated intersection using the signalized intersection analysis tools outlined in TEOpS 16-10-5.

Analysts *should* recognize and account for the methodological limitations of the multilane highway methods. For multilane highway conditions that do not fit within the analytical framework of the HCM, including but not limited to; effect of lane drops and lane additions at the beginning or end of the multilane highway segment, queuing impacts at transition areas (e.g., transitions from a multilane to two-lane highway), significant presence of on-street parking, or significant pedestrian activity, the analyst *should* use an alternative tool such as microsimulation. See TEOpS 16-20 for additional details on performing microsimulation analysis.

The WisDOT-supported traffic engineering software for HCM-based multilane highway analysis is:

- HCS, McTrans

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

16-15-50 Two-Lane Highways February 2025

WisDOT accepts the use of the HCM, Chapter 15 methods for the analysis of a two-lane highway. The methodology provides the analytical framework to assess the automobile and bicycle modes of travel. Use these methods to assess uninterrupted flow (i.e., there are no traffic control devices that interrupt traffic) on two-lane highways that have one lane in each direction. Passing takes place on these facilities in the opposing lane of traffic when there is adequate sight distance and safe gaps in the opposing traffic. The two-lane highway methodology also includes a procedure for predicting the effect of passing and truck climbing lanes on two-lane highways.

In general, this analysis includes any segments that have signalized intersections spaced two or more miles apart. Classify two-lane highways with signalized intersections spaced closer than two miles apart as an urban street or arterial and apply the methodologies of HCM, Chapter 16 as appropriate. Further, analyze any major signalized or unsignalized intersections within the two-lane highway corridor using the appropriate tools as outlined in TEOpS 16-10-5.

HCM7 (1) introduced a new methodological framework to analyze two-lane highways that is vastly different from the methodology in previous versions of the HCM. HCM7 uses follower density as the performance measure, with thresholds for LOS based on posted speed limit. The HCM7 methodology uses three different segment types (passing zone, passing constrained, and passing/climing lane), which can be combined into a faciity-level analysis, and incorporates impacts from horizontal and vertical curves. Previous versions of the HCM broke out two-lane corridors into three classifications (Class I, Class II, and Class III) and used percent-time-spent-following (PTSF), average travel speed (ATS), or a combination of the two as the performance measures for determining LOS. The previous HCM methodology handled the impact of counter-directional passing on two-lane segment LOS through a “Percent no-passing zone (%)” rather than explicity requiring the identification of passing zones and passing constrained segments.

All projects **shall** follow the HCM7 methodologies unless otherwise authorized by WisDOT regional traffic staff.

Analysts *should* recognize and account for the methodological limitations of the two-lane highway methods. For two-lane highways that do not fit within the analytical framework of the HCM, the project manager *should* specify the use of an alternative tool such as microsimulation. See TEOpS 16-20 for additional details on performing microsimulation analysis.

The WisDOT-supported traffic engineering software for HCM-based two-lane highway analysis is:

- HCS, McTrans

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

16-15-55 Network Analysis February 2025

HCM7, Chapter 38 introduces a new methodology for evaluating the interactions between freeways and urban streets. The methodology expands upon the analysis methods of individual intersections and segments to consider the spillback effects from the downstream facility. Since spillback affects each lane differently, the analysis is conducted on a lane-by-lane basis and provides performance measures at both the network and origin-destination level. The analysis methodology applies capacity adjustment factors dependent on the queue flow regime. There are five different flow regimes, regimes 0 – regime 4, where Regime 0 has no queues and Regime 4 has queues which block the adjacent lane.

WisDOT has not currently identified a specific HCM-based analysis tool for analyzing the interactions between freeways and urban streets. Direct any specific questions regarding the network analysis and spillback effects from the downstream facility to the WisDOT regional traffic engineer or BTO-TASU.

16-15-60 Pedestrian and Bicycle Facilities February 2025

60.1 Mid-Block Pedestrian Crossings

WisDOT accepts the use of the methods outlined by the HCM, Chapter 20-5 for one-stage and two-stage unsignalized mid-block pedestrian crossings, with or without a median refuge area, which are not located at an intersection. Assess the operations of mid-block pedestrian crossings by calculating seconds of delay per pedestrian or pedestrian-group.

Wisconsin-state law requires motorists to yield to pedestrians at designated mid-block pedestrian crossings. Motorist compliance, however, can vary. Implementation of pedestrian crossing treatments that are proven safety countermeasures (e.g., high visibility crosswalk markings, median refuges, and rectangular rapid flashing beacons [RRFBs] or pedestrian hybrid signals) have shown to increase motorist compliance rates and reduce pedestrian crashes. In the absence of local data, and subject to professional judgment, use the default motorist-yield-rates as recommended in the HCM7, Chapter 20 (Exhibit 20-28) for the analysis of mid-block pedestrian crossings.

Analysts *should* recognize and account for the limitations of the mid-block pedestrian crossing methodology (i.e., TWSC pedestrian mode method). For mid-block pedestrian crossings that do not fit within the analytical framework of the HCM, including but not limited to, signalized mid-block crossings or cases where the impact on the major street vehicular traffic is relevant, the project manager *should* specify the use of an alternative tool such as microsimulation. See TEOpS 16-20 for additional details on performing microsimulation analysis.

The WisDOT-supported traffic engineering software for HCM based mid-block pedestrian crossing analysis are:

- HCS, McTrans
- Synchro, Cubic|Trafficware

Refer to the *WisDOT Supported Traffic Analysis Tools* document for the version and build of the above software that WisDOT currently supports. See TEOpS 16-10-5 for additional guidance on how to select the most appropriate traffic analysis tool for a specific project.

60.2 Off-Street Pedestrian and Bicycle Facilities

WisDOT accepts the use of the HCM, Chapter 24 methods for the analysis of off-street pedestrian and bicycle facilities (i.e., non-motorized vehicle usage only). The methodology provides the analytical framework to assess the capacity and LOS for the following types of facilities:

- Walkways: pedestrian-only paved facilities (paths, ramps, and plazas) typically located more than 35 feet from an urban street
- Shared-use paths: paths, separated by a physical barrier from highway traffic, dedicated for the shared-use of all forms of non-motorized (pedestrian, bicyclists, runners, inline skaters, etc.)
- Exclusive off-street bicycle paths: separated by a physical barrier from highway traffic, dedicated for bicycle-only traffic

Analysts *should* recognize and account for the methodological limitations of the HCM. For off-street pedestrian and bicycle facilities that do not fit within the analytical framework of the HCM, the project manager *should* specify the use of an alternative tool.

WisDOT has not currently identified a specific analysis tool for analyzing off-street pedestrian and bicycle facilities. Direct any specific questions regarding the analysis of off-street pedestrian and bicycle facilities to the WisDOT regional and statewide bicycle and pedestrian coordinators.

16-15-70 References — February 2025

1. **Transportation Research Board.** *Highway Capacity Manual 7th Edition: A Guide For Multimodal Mobility Analysis.* Washington, D.C. : National Academy of Sciences, 2022. ISBN 978-0-309-08766-7.

2. **Transportation Research Board**. *Highway Capacity Manual, 6th Edition: A Guide For Multimodal Mobility Analysis.* Washington, D.C. : National Academy of Sciences, 2016. ISBN 978-0-309-36997-8.

3. **R.A. Smith National.** *Right Turn on Red Methodology Evaluation.* 2009.

4. **TranSmart Technologies, Inc.** *Signalized Intersection Capacity Data Collection: A Statewide Evaluation of Saturation Flow Rate and Right Turn on Red.* November 2015.

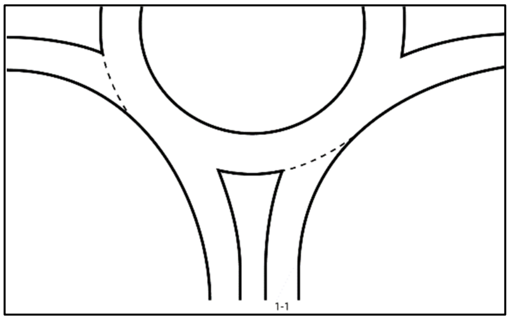
5. **Traffic Analysis and Design, Inc. (TADI).** *Signalized Intersection Data Collection - Phase III.* October 2021.

6. ***NCHRP 572.*** *Roundabouts in the United States.* 2007.

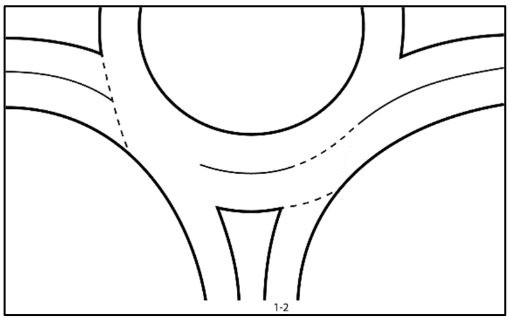
7. Rodegerdts, L.A., A. Malinge, P.S., Marnell, S.G. Beaird, M.J. Kittelson, and Y.S. Mereszcak. *Assessment of Roundabout Capacity Models for the Highway Capacity Manual: Volume 2 of Accelerating Roundabout Implementation in the Unites States.* Washington, D.C. : Federal Highway Administration, Sept. 2015. Report FHWA-SA-15-070.

8. Traffic Analysis and Design, Inc. (TADI). *Statewide Roundabout Traffic Operations Analysis.* March 2020.

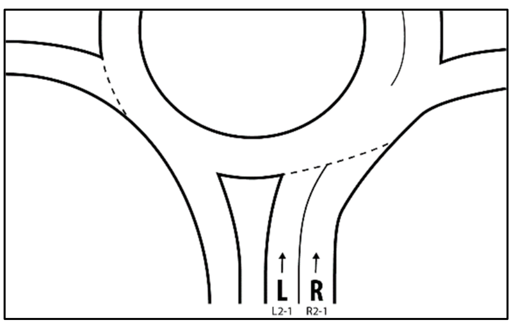
One-Lane Entry Conflicted by One Circulating Lane (1-1)



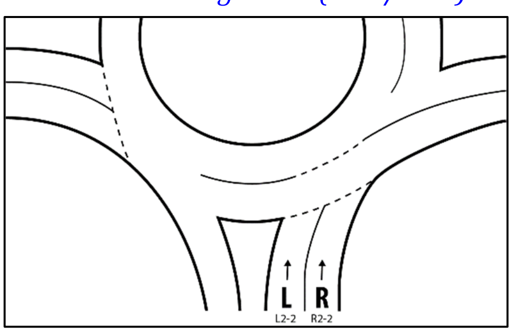
One-Lane Entry Conflicted by Two Circulating Lanes (1-2).



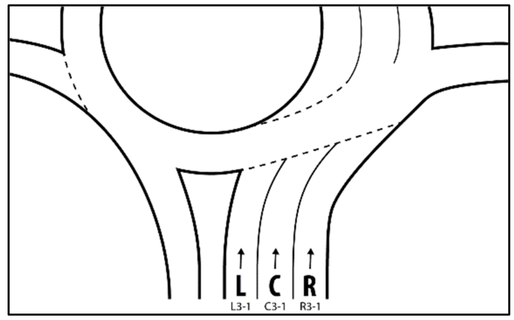
Two-Lane Entry Conflicted by One Circulating Lane (L2-1/R2-1)



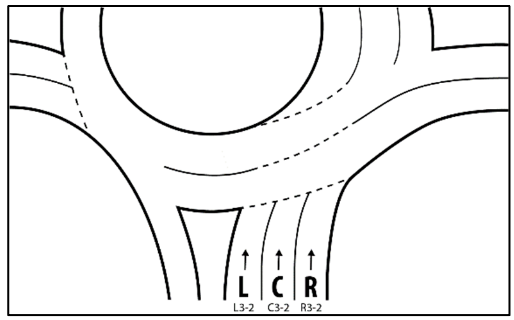
Two-Lane Entry Conflicted by Two Circulating Lanes (L2-2/R2-2).



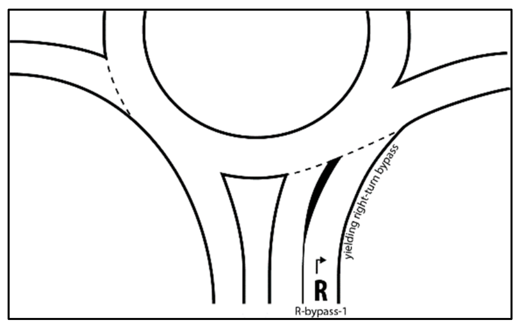
Three-Lane Entry Conflicted by One Circulating Lane (L3-1/C3-1/R3-1)



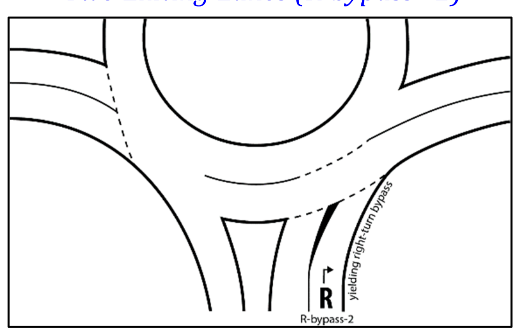
Three-Lane Entry Conflicted by Two Circulating Lanes (L3-2/C3-2/R3-2)



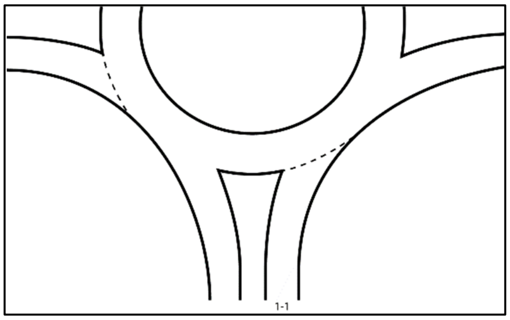
Right Yielding Bypass Lane Conflicted by One Exiting Lane (R-bypass - 1)



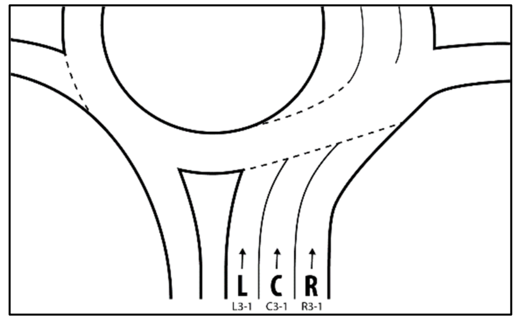
Right Yielding Bypass Lane Conflicted by Two Exiting Lanes (R-bypass - 2)



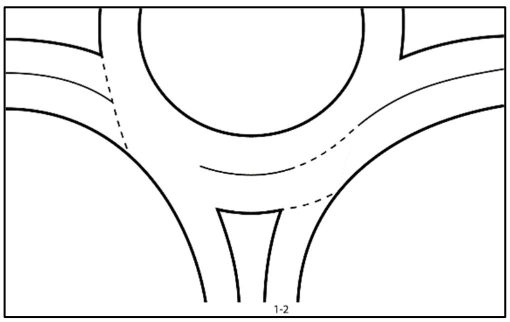
One-Lane Entry Conflicted by One Circulating Lane (1-1)



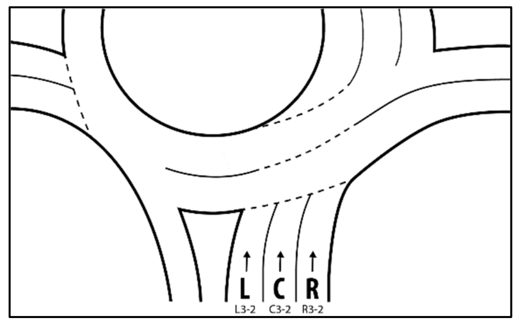
Three-Lane Entry Conflicted by One Circulating Lane (L3-1/C3-1/R3-1)



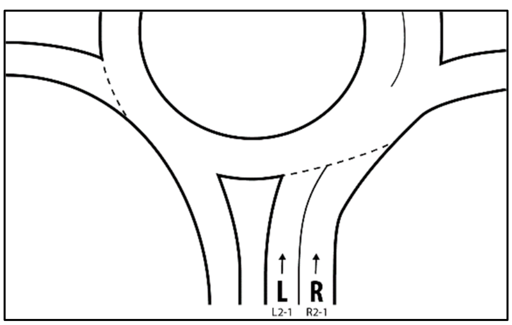
One-Lane Entry Conflicted by Two Circulating Lanes (1-2).



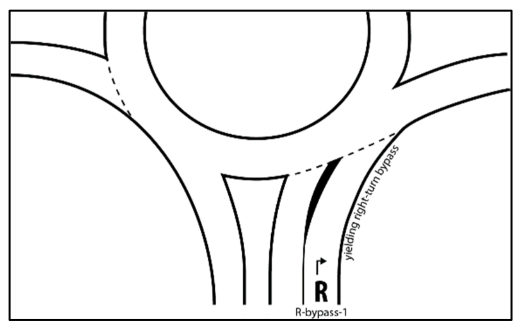
Three-Lane Entry Conflicted by Two Circulating Lanes (L3-2/C3-2/R3-2)



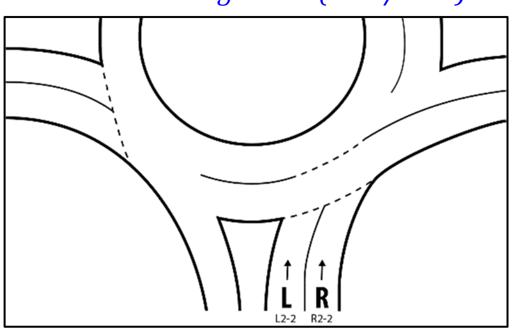
Two-Lane Entry Conflicted by One Circulating Lane (L2-1/R2-1)



Right Yielding Bypass Lane Conflicted by One Exiting Lane (R-bypass - 1)



Two-Lane Entry Conflicted by Two Circulating Lanes (L2-2/R2-2).



Right Yielding Bypass Lane Conflicted by Two Exiting Lanes (R-bypass - 2)