An assessment of the Highway Capacity Manual 2010 roundabout capacity model

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Disclaimer

The author is the developer of the SIDRA INTERSECTION model used in the study presented in this paper.

Relevance

- Operational analysis models
- Roundabout practice and knowledge in the USA: great development since early days ...
- Importance given by the traffic engineering profession to the use of operational analysis based on scientific approach, hence leading research and development work (UK, Australia, USA) – debates about models are useful ...

Research and development for operational analysis models

Combined empirical and theoretical work - costly but cost-effective !

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Paper Content

- An assessment of the new Highway Capacity Manual 2010 (HCM 2010), Chapter 21 roundabout capacity model
- Study carried out using SIDRA INTERSECTION software which now offers HCM 2010 and SIDRA Standard models as alternative roundabout capacity models
- In this study, the SIDRA Standard model option uses Environment Factor of 1.2 used for US conditions

Paper Content

- General importance of some fundamental aspects of the HCM 2010 model
- Various shortcomings of the HCM 2010 model and some related model extensions provided by the SIDRA INTERSECTION software (as an alternative model) with a view to future HCM development
- Issues related to delay and queue models and Level of Service thresholds

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Paper Content

- **Multilane roundabout example** given in HCM 2010: Compare capacity, degree of saturation (v/c ratio), delay, level of service and queue length estimates from the HCM 2010 and SIDRA Standard capacity models
- Discussions on **lower capacity of US roundabouts** (compared with Australian and UK roundabouts) and the issue of possible increases in roundabout capacities in the USA over time
- **Calibration of the HCM 2010** model

HCM 2010 ROUNDABOUT CAPACITY MODEL

- **HCM 2010 model is a non-linear empirical (regression) model with a theoretical basis in gap-acceptance methodology**

$$Q_g = f_{HVe}\, f_p\, f_A\, A\, exp[-(B / f_B)\, q_m]$$

(details in the paper)

- **f_{HVe} and f_p are heavy vehicle and pedestrian factors**
- **f_A and f_B are SIDRA INTERSECTION calibration factors for parameters A and B: method explained in the paper**

General importance the HCM 2010 model

Driver Behavior and Roundabout Geometry

HCM 2010 confirmed that:

- although important, roundabout geometry alone (as in the UK TRL model) is not sufficient for modeling capacity of roundabouts, and
- the model must also include driver behavior parameters (as in the Australian method).

... the fine details of geometric design appear to be secondary and less significant than variations in driver behavior at a given site and between sites.

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General importance the HCM 2010 model

HCM 2010 model form as "Siegloch M1" gap-acceptance model

The HCM 2010 model is based on gap-acceptance theory: it uses the form of Siegloch M1 gap-acceptance model where M1 model refers to the assumption of random arrivals of vehicles with no bunching.

(HCM 2010 and NCHRP 572 accept that the exponential regression model has a gap-acceptance basis but they do not identify it as the Siegloch M1 model.)

Refer to a paper by the author:

AKÇELIK, R. A Review of Gap-Acceptance Capacity Models. Paper presented at the 29th Conference of Australian Institutes of Transport Research (CAITR), Univ. of South Australia.

Available for download from www.sidrasolutions.com/software_downloads_articles.aspx

General importance the HCM 2010 model

Regression (empirical) and gap-acceptance models

HCM 2010 research showed that modeling capacity by:

- gap-acceptance method (using critical gap and follow-up headway parameters determined in the field in a "theoretical" gap-acceptance equation), and
- direct regression using field capacities

give very close results.

This confirms the validity of gap-acceptance methodology for roundabout capacity modeling.

Gap-acceptance parameters: fixed or variable?

HCM 2010 uses a gap-acceptance model with fixed critical-gap and follow-up headways (varies with the number of lanes only).

In contrast, the SIDRA Standard model uses variable critical gap and follow-up headway values which depend on:

Roundabout geometry

- inscribed diameter
- number of entry lanes
- average entry lane width
- number of circulating lanes
- entry radius
- entry angle
- Approach short lanes
- Exit short lanes

Traffic conditions

- circulating flow rate
- heavy vehicles in entry stream
- dominant and subdominant lanes
- Environment Factor (general calibration parameter)

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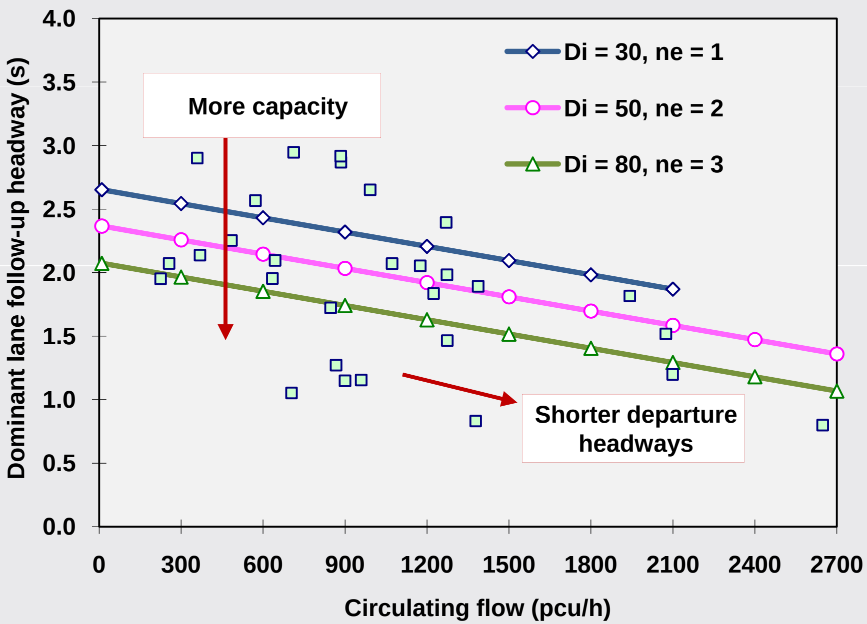
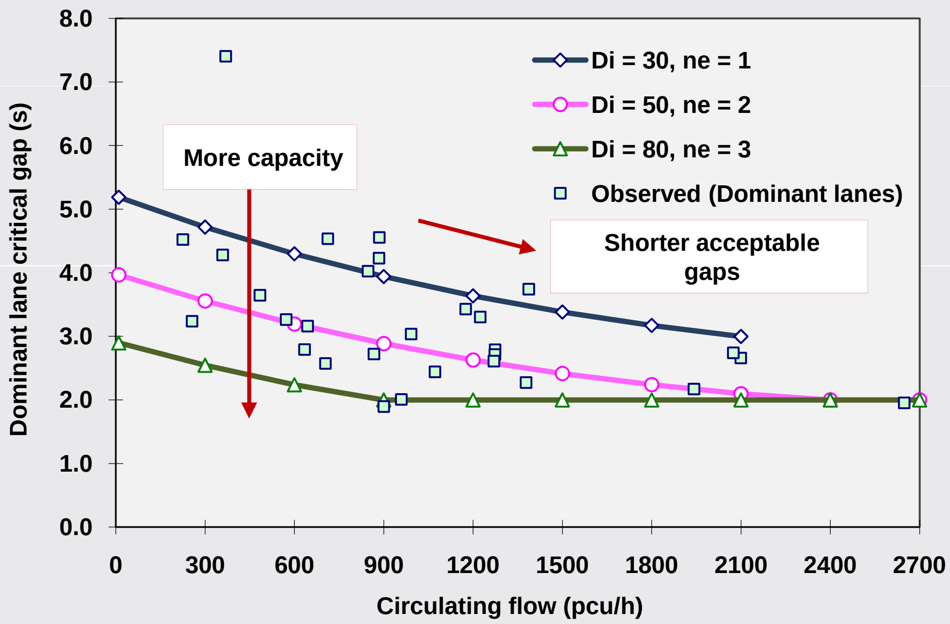
Driver Behavior and Geometry

Follow-up Headway and Critical Gap values:

- **decrease** with decreased unblock time, and
- depend on roundabout **geometry**





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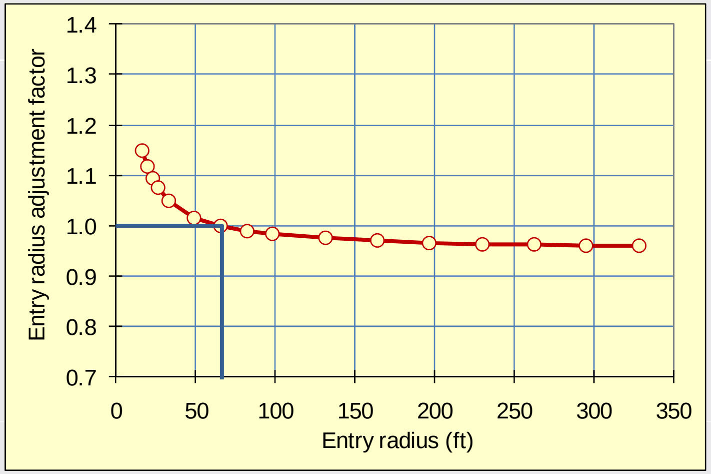
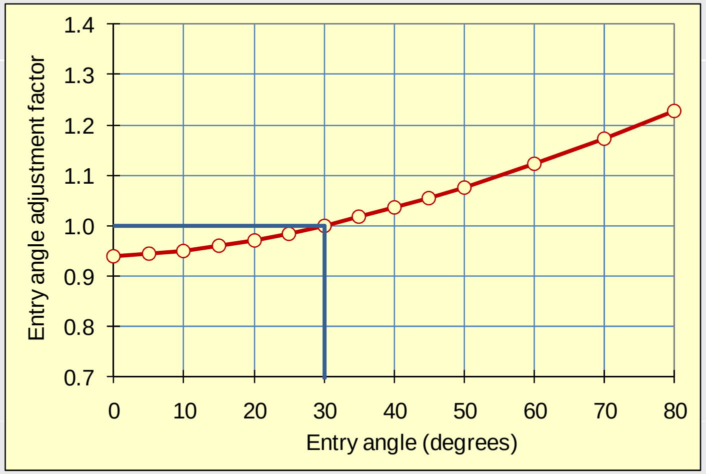
Entry Radius and Entry Angle in *SIDRA Standard* model





$f_r = 0.95 + 1 / r_e$

$f_a = 0.94 + 0.00026 / \phi_e^{1.6}$

r_e is the entry radius (m)

ϕ_e is the entry angle (degrees)

Customary units:

$f_r = 0.95 + 3.28 / r_e$

r_e is the entry radius (ft)

The entry radius and entry angle factors in *SIDRA Standard* and *UK TRL* models

r_e (m)	r_e (ft)	ϕ_e (degrees)	*UK TRL*	*SIDRA Standard*
5	16	70	1.40	1.35
10	33	60	1.18	1.18
20	66	45	1.05	1.05
30	98	35	1.00	1.00
40	131	**30**	0.98	0.98
60	197	15	0.92	0.93
80	262	5	0.89	0.91
100	328	0	0.87	0.90

General importance the HCM 2010 model

Lane-based model

HCM 2010 roundabout capacity model is a lane-by-lane model consistent with the SIDRA Standard model.

It is unique in HCM 2010 in the sense that HCM models for other intersection types are by lane groups.

This also differs from approach-based model developed in the UK (TRL linear regression model.

Modeling an intersection lane-by-lane, by lane groups and by approaches indicate an increasing level of model coarseness.

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Modeling of circulating lanes

HCM 2010 and other models ignore modeling of circulating lane flows

- Number of circulating lanes (in HCM 2010 model)
- Bunching vs random arrival headways
- Unequal circulating lane flows
- Unbalanced O-D patterns (priority emphasis)

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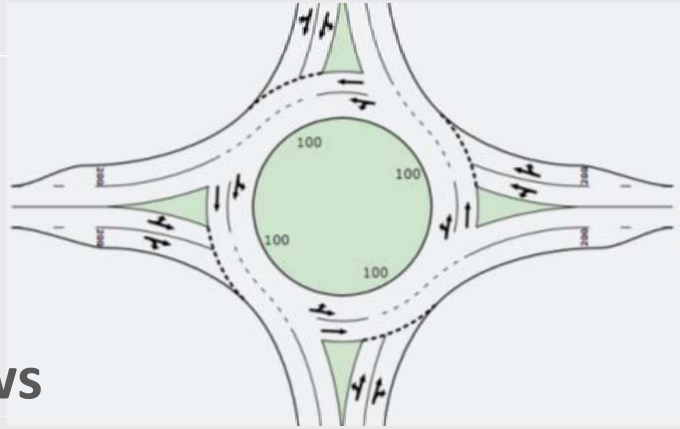
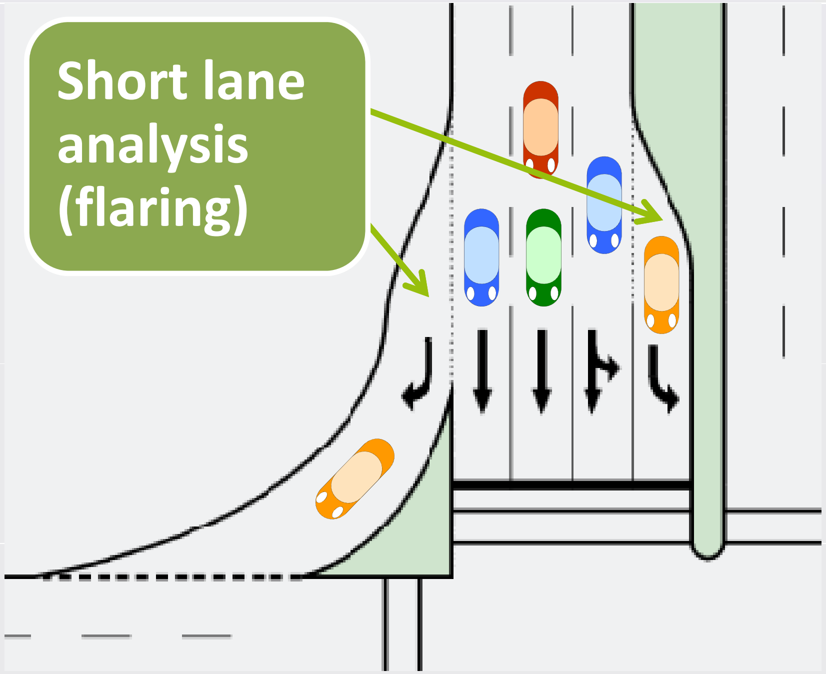
LANE – BASED method



- Lane flows
- Unequal lane use
- De facto exclusive lanes
- Approach short lanes
- Exit short lanes (lane use effects)
- Roundabout circulating lane use

These cannot be modelled using an APPROACH-BASED method



Effectiveness of flaring (short lanes) depends on flow conditions

Level of Service for Roundabouts

HCM 2010 methodology bias against roundabouts

The Level of Service (LOS) thresholds are same as those for stop sign-controlled intersections. This creates a bias against roundabouts when compared with signalized intersections. Also: How to treat a signalized roundabout?

Compared with two-way STOP sign control with Roundabouts are significantly easier to negotiate being subject to YIELD (GIVE-WAY) sign control with:

- only one conflicting (opposing) stream
- slower opposing stream speeds
- lower follow-up headway and critical gap values and higher capacities.

This bias is emphasised when coupled with concerns about estimation of low capacity and high delay estimates given by the HCM 2010 roundabout model. Alternative LOS thresholds for roundabouts including the SIDRA Roundabout LOS should be given further consideration.

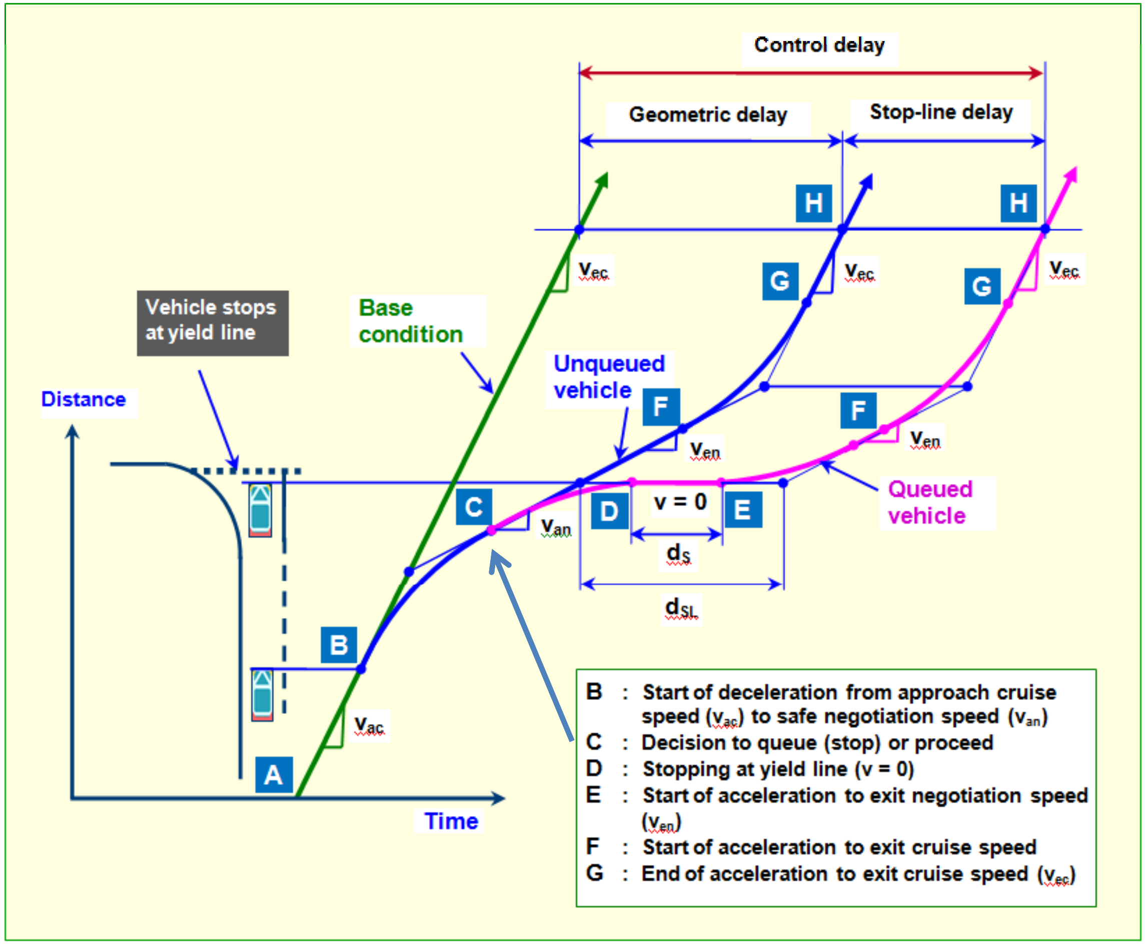
Level of Service for Roundabouts

Level of Service for v/c ≤ 1.0	Average delay per vehicle in seconds (d)			Level of Service for v/c > 1.0
	Signals (*SIDRA standard default for roundabouts*)	SIDRA Roundabout LOS option	Sign Control (*HCM 2010 default for roundabouts*)	All Intersection Types
A	d ≤ 10	d ≤ 10	d ≤ 10	**F**
B	10 < d ≤ 20	10 < d ≤ 20	10 < d ≤ 15	**F**
C	20 < d ≤ 35	20 < d ≤ 35	15 < d ≤ 25	**F**
D	35 < d ≤ **55**	35 < d ≤ **50**	25 < d ≤ **35**	**F**
E	**55** < d ≤ 80	**50** < d ≤ 70	**35** < d ≤ 50	**F**
F	80 < d	70 < d	50 < d	**F**

v/c (demand volume / capacity) ratio, or degree of saturation: v/c > 1.0 represents oversaturated conditions.

Control Delay and Geometric Delay

Geometric delay:
All vehicles slow down to a safe negotiation speed at roundabouts.
Geometric delay depends on approach and exit cruise speeds as well as the roundabout negotiation speeds, which depend on the geometric characteristics of the roundabout



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Back of Queue

Different queue definitions in the HCM for signalized and unsignalized intersections.

It is desirable to use the back of queue formulation in HCM models for roundabouts and sign-controlled intersections including estimation of percentile queues other than 95th percentile queue.

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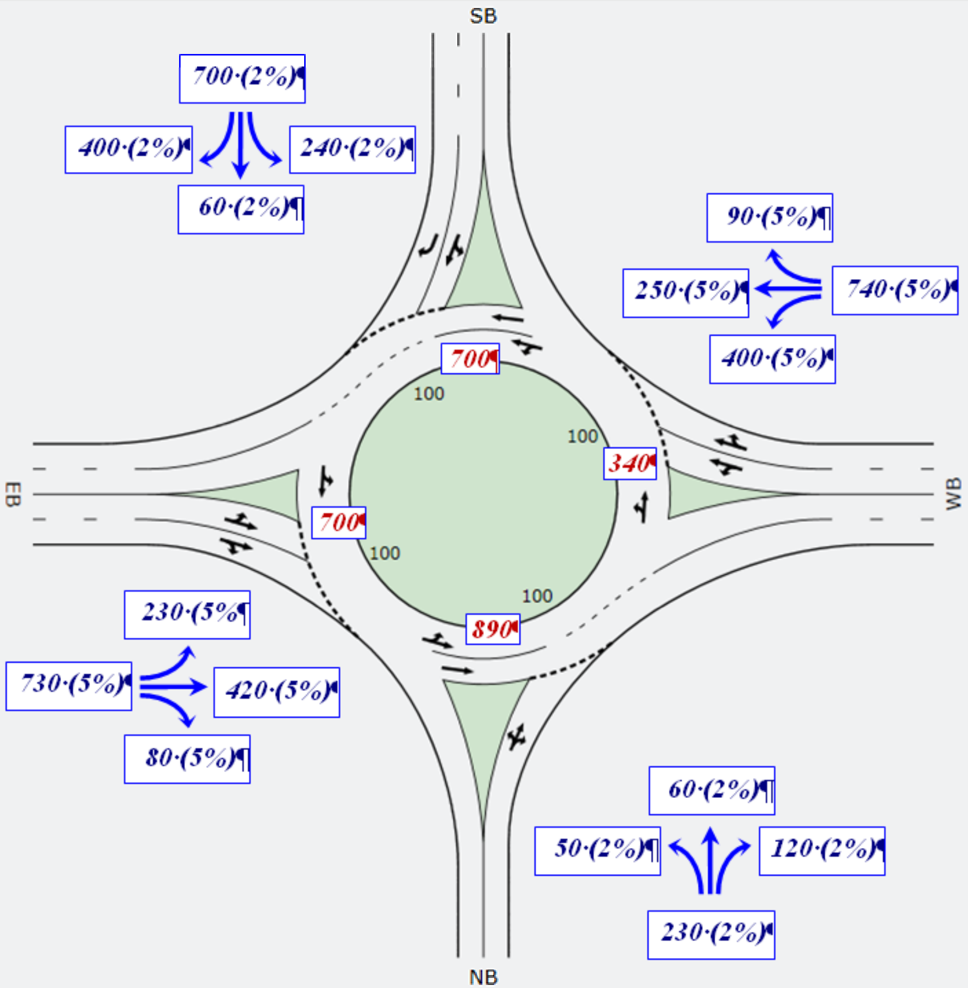
HCM 2010 multi-lane roundabout example



- Example 2 in HCM 2010, Chapter 21.
- A fairly balanced origin-destination flow pattern. No pedestrian effects.
- For the SIDRA Standard capacity model, Environment Factor = 1.2
- PFF = 95 % (all)
- HV % values shown

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HCM 2010 two-lane roundabout example

Three sets of geometric parameters are used in order to examine sensitivity to these parameters

Entry lane width	Central island diameter	Circulating road width 1-lane	Inscribed diameter (1-lane circulating)	Circulating road width 2-lane	Inscribed diameter (2-lane circulating)	Entry radius	Entry angle
Default values							
13 ft (4.0 m)	100 ft (30 m)	25 ft (7.5 m)	150 ft (45 m)	30 ft (9 m)	160 ft (48 m)	65 ft (20 m)	30^{o}
Less favorable values							
12.5 ft (3.8 m)	80 ft (25 m)	21 ft (6.5 m)	122 ft (38 m)	26 ft (8 m)	132 ft (41 m)	50 ft (15 m)	40^{o}
More favorable values							
14 ft (4.3 m)	120 ft (36 m)	28 ft (8.5 m)	176 ft (53 m)	33 ft (10 m)	186 ft (56 m)	100 ft (30 m)	20^{o}

Refer to LENTERS, M. and RUDY, C. (2010). HCM Roundabout Capacity Methods and Alternative Capacity Models. ITE Journal, 80 (7).

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HCM 2010 two-lane roundabout example

Capacity, performance and LOS results

Approach	Approach Flow (veh/h)	Circulating Flow (pcu/h)	Capacity Lane 1 (veh/h)	Capacity Lane 2 (veh/h)	Degree of saturation (v/c ratio)	Average delay (s/veh)	LOS	95%Back of Queue (ft)
Capacity model = *HCM 2010* (SIDRA INTERSECTION implementation) Delay model = HCM 2010, Roundabout LOS method = "Same as Sign Control"								
NB (South)	242	937	559	na	0.433	13.4	B	37
WB (East)	779	358	742	742	0.568	12.9	B	87
SB (North)	737	737	621	645	0.653	16.8	C	80
EB (West)	768	737	501	501	0.811	31.5	D	159
Capacity model = *SIDRA Standard* (Environment Factor = 1.2) Delay model = SIDRA, Roundabout LOS method = "Same as Signalized Intersections"								
Geometric parameters: Default values								
NB (South)	242	937	367	na	0.660	17.7	B	82
WB (East)	779	358	909	842	0.463	8.2	A	77
SB (North)	737	737	558	584	0.721	15.1	B	120
EB (West)	768	737	578	615	0.644	15.5	B	113
Geometric parameters: Less favorable values								
NB (South)	242	937	288	na	0.842	29.4	C	133
WB (East)	779	358	773	759	0.545	13.5	B	106
SB (North)	737	737	475	475	0.886	24.1	C	207
EB (West)	768	737	491	491	0.782	22.2	C	167
Geometric parameters: More favorable values								
NB (South)	242	937	474	na	0.510	12.6	B	54
WB (East)	779	358	1061	935	0.397	10.8	B	58
SB (North)	737	737	661	772	0.583	11.9	B	78
EB (West)	768	737	661	768	0.538	12.1	B	81

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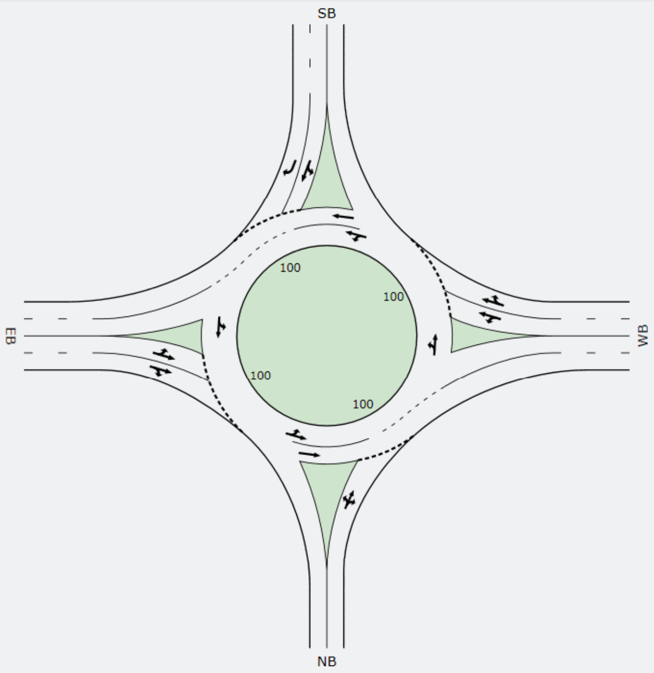
HCM 2010 two-lane roundabout example

Both the HCM 2010 and SIDRA Standard models identify the Westbound approach, Lane 1 as a defacto (exclusive) left-turn lane.

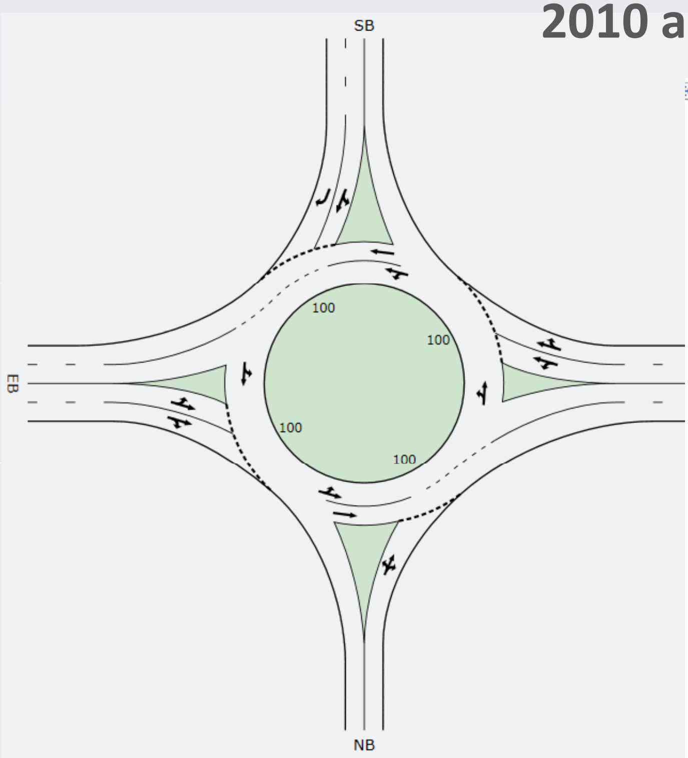


Unequal degrees of saturation (v/c ratios) for the two entry lanes (critical lane degree of saturation is higher than the result that would be obtained by making balanced distribution of lane flows).

This is an advantage of the lane-by-lane analysis method

HCM 2010 two-lane roundabout example

Results obtained using three sets of geometric parameters indicate a wider range of differences between the HCM 2010 and SIDRA Standard models.



Approach	Approach Flow (veh/h)	Circulating Flow (pcu/h)	Capacity Lane 1 (veh/h)	Capacity Lane 2 (veh/h)	Degree of saturation (v/c ratio)	Average delay (s/veh)	LOS	95%Back of Queue (ft)
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Geometric parameters: Default values								
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Possible increases in roundabout capacities in the USA over time

- Lower capacities at US roundabouts compared with those in Australia and UK.
- The question arises about whether capacity of US roundabouts will increase as a result of "changes in driver experience over time".
- Higher capacities from the models derived in Australia and UK might indicate potential increases in capacities.

Possible increases in roundabout capacities in the USA over time

Rodegerdts (2008) suggested that possible reasons for lower capacities at US roundabouts include:

- **driver unfamiliarity with roundabouts as a relatively new control device**
- **larger vehicles**
- **prevalence of stop control, especially use of all-way stop control and lack of use of two-way yield control, and**
- **lack of use of turn signals on exits causing driver hesitation during the yield process.**

RODEGERDTS, L. (2008). Updated Roundabout analysis procedures for the next Highway Capacity Manual. Presentation at the National Roundabout Conference, Transportation Research Board, Kansas City, MO, USA.

Possible increases in roundabout capacities in the USA over time

Factors in favor of increased capacity:

- Expected increase in efficiency in driver behavior due to increased familiarity
- Increased congestion levels resulting in more aggressive driver behavior
- Reduced vehicle length
- Better vehicle acceleration capabilities

Possible increases in roundabout capacities in the USA over time

Factors against increased capacity:

- All-way stop control and two-way yield control: Practice in Australia is opposite to the US practice, i.e. all-way stop control is almost non-existent, and two-way yield signs are used commonly. If this difference is a significant factor, this aspect of US driving culture and traffic control environment would continue to affect roundabout capacities in the future.

  Lower gap-acceptance parameters are used in Australia for two-way sign-control as well.

- Our recent roundabout research in Australia indicated that, the follow-up headway and critical gap values in Australia did not change much since 1980s in spite of significant increases in demand and congestion levels at roundabouts.
- Preference for larger vehicles may not change over time, or changing vehicle population may mean somewhat reduced acceleration capabilities.

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Calibrating the HCM 2010 Capacity Model for Expected Future Conditions

Driver response time (t_r) during queue discharge as a function of the queue discharge headway (t_f) , spacing between vehicles in the queue (L_{hj}) and saturation (queue discharge) speed (v_s) :

$$t_r = t_f - L_{hj} / v_s$$

Follow-up (queue discharge) headway and driver response time estimated by SIDRA INTERSECTION for the example given in this paper are summarized in *the following slide.*

The results are given for the *HCM 2010* capacity model and *SIDRA Standard* capacity model with *Environment Factor of 1.2* to represent "current" US conditions.

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HCM 2010 two-lane roundabout example

Follow-up (queue discharge) headway and driver response times estimated for the example

Approach Flow (veh/h)	Circulating Flow (pcu/h)	Capacity (veh/h)	Follow-up headway (s)	Driver response time (s)
Capacity model = ***HCM 2010*** using parameters given in *Table 1* ("current" US conditions)				
242 - 779	358 - 937	501 - 742	3.19	2.07 - 2.54
Capacity model = ***SIDRA Standard*** with Environment Factor = **1.2** ("current" US conditions)				
Geometric parameters: ***Default values***				
242 - 779	358 - 937	367 - 909	2.61 - 3.37	1.49 - 2.43
Geometric parameters: ***Less favorable values***				
NB (South)	358 - 937	288 -773	2.89 - 3.68	1.67 - 2.78
Geometric parameters: ***More favorable values***				
242 - 779	358 - 937	474 - 1061	2.38 - 3.12	1.33 - 2.34
Capacity model = ***HCM 2010*** with calibration factors $f_A = f_B$ = **1.1** ("future" US conditions)				
242 - 779	358 - 937	591 - 844	2.90	1.78 - 2.14
Capacity model = ***SIDRA Standard*** with Environment Factor = **1.1** ("future" US conditions)				
Geometric parameters: ***Default values***				
242 - 779	358 - 937	435 - 1024	2.39 - 3.09	1.27 - 2.26
Geometric parameters: ***Less favorable values***				
NB (South)	358 - 937	347 - 876	2.65 - 3.38	1.43 - 2.47
Geometric parameters: ***More favorable values***				
242 - 779	358 - 937	555 - 1190	2.18 - 2.86	1.13 - 2.08

MODEL EXTENSIONS:
SIDRA INTERSECTION as an alternative tool

HCM 2010, Chapter 21 lists various "limitations of the HCM procedures that might be addressed by alternative tools". These limitations as addressed by SIDRA INTERSECTION through extensions to the HCM 2010 model option or as part of the SIDRA Standard model option are listed in following slides.

These are in addition to the issues raised about level of Service thresholds, delay definitions and back of queue.

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MODEL EXTENSIONS: SIDRA INTERSECTION as an alternative tool

- Roundabout Metering Signals
- Upstream Signals: Effect of upstream signals on roundabout capacity is modeled using the extra bunching
- Closely Spaced Intersections: Probability of blockage and capacity adustment
- Capacity Constraint
- Unbalanced Flow Conditions: The Origin-Destination factor and adjustment factor for Entry /Circulating Flow Ratio
- Priority Reversal and Priority Emphasis
- Heavy Vehicle Effects

MODEL EXTENSIONS:
SIDRA INTERSECTION as an alternative tool

- More Than Two Entry and Circulating Lanes (any combination)
- Single and multiple shared and exclusive slip lanes (yielding bypass lanes) controlled by yield or stop signs and continuous bypass lanes.
- Approach short lanes (flared entries)
- Exit short lanes: effect on approach lane utilisation
- Lane Flow Calculations
- Model Calibration: Adjustment factors f_A and f_B can be used for easy calibration of all parameters, e.g. considering conditions in the future.
- Performance Calculations: Back of queue and stop rate estimates, as well as fuel consumption, emission (including CO2) and operating cost estimates

No model is perfect ...

There is no more common error than to assume that, because prolonged and accurate mathematical calculations have been made, the application of the result to some fact of nature is absolutely certain.

Alfred N. Whitehead (1861-1947), English mathematician and philosopher
(In: M.J. Moroney, Facts from Statistics, Penguin Books, 1951, p. 271)

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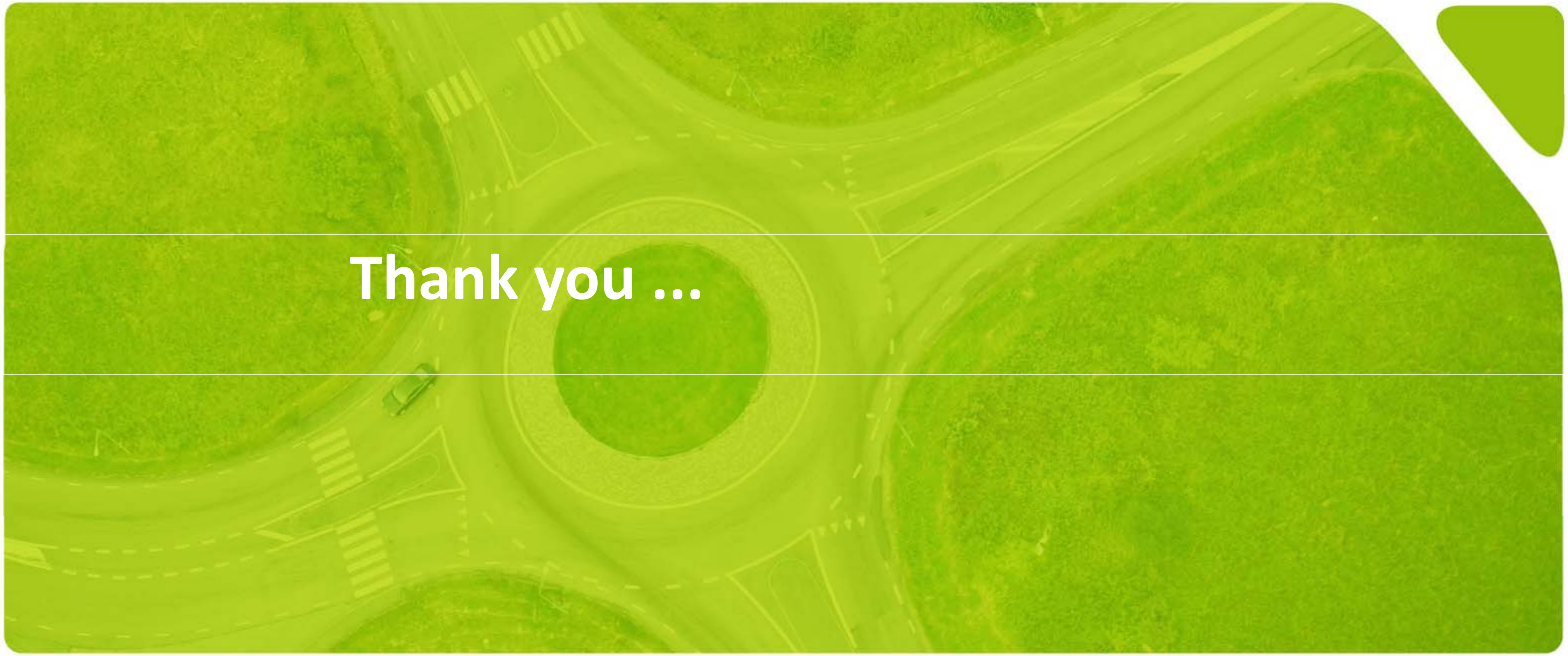

Thank you ...

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