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A New Survey Method Using Vehicle Trajectory Data for Calibration of Roundabout Capacity Models

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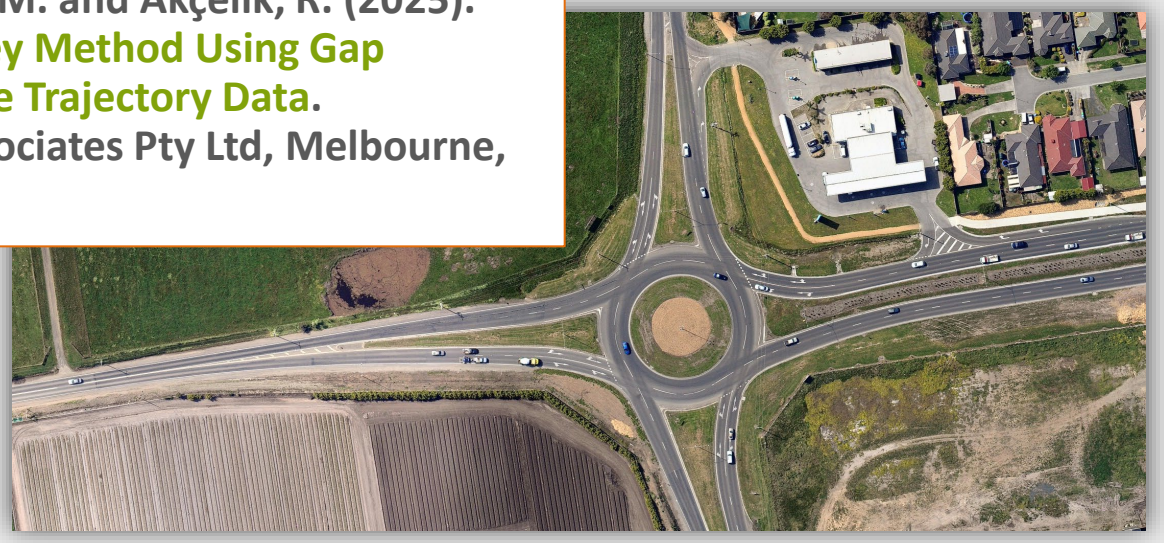
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Full research report will be available on sidrasolutions.com/learn/publications:

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A New Survey Method Using Vehicle Trajectory Data for Calibration of Roundabout Capacity Models

Introduction

- A new method for conducting roundabout capacity surveys using detailed vehicle trajectory data has been developed under funding by SIDRA SOLUTIONS.
- The survey method is proposed for use in calibration of roundabout and two-way sign control capacity.

  It is also applicable to all gap acceptance situations including permitted turns, turn on red and unsignalised bypass lanes at signalized intersections.

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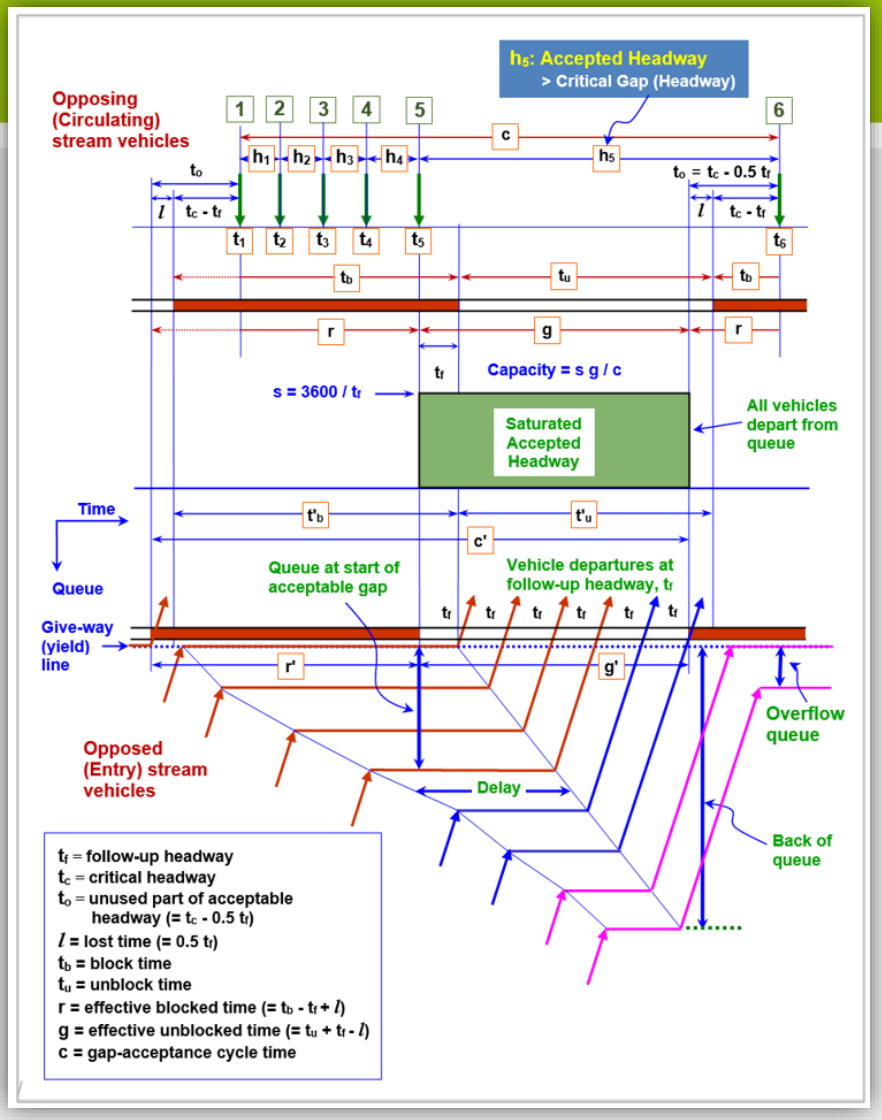
A gap acceptance cycle based on signal analogy concept

The new survey method uses the signal analogy concept developed by Dr Rahmi Akçelik. [8,9]

This concept was used to develop

- new gap acceptance capacity models and
- performance models for estimating
  - delay
  - back of queue and
  - stop rate

for roundabouts and sign-controlled intersections.



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About the new survey method

- Unlike previous methods, this survey method derives estimates of key gap acceptance parameters
  - follow-up headway and critical headway
  - blocked and unblocked times (virtual red and green times)
  - gap acceptance cycle time

  and
  - roundabout entry lane capacity.
- The method can be used at all levels of demand flows.
- The survey method is proposed for use in calibration of roundabout and two-way sign control capacity models in particular. It is applicable to all gap acceptance situations including permitted turns, turn on red and unsignalised bypass lanes at signalized intersections.

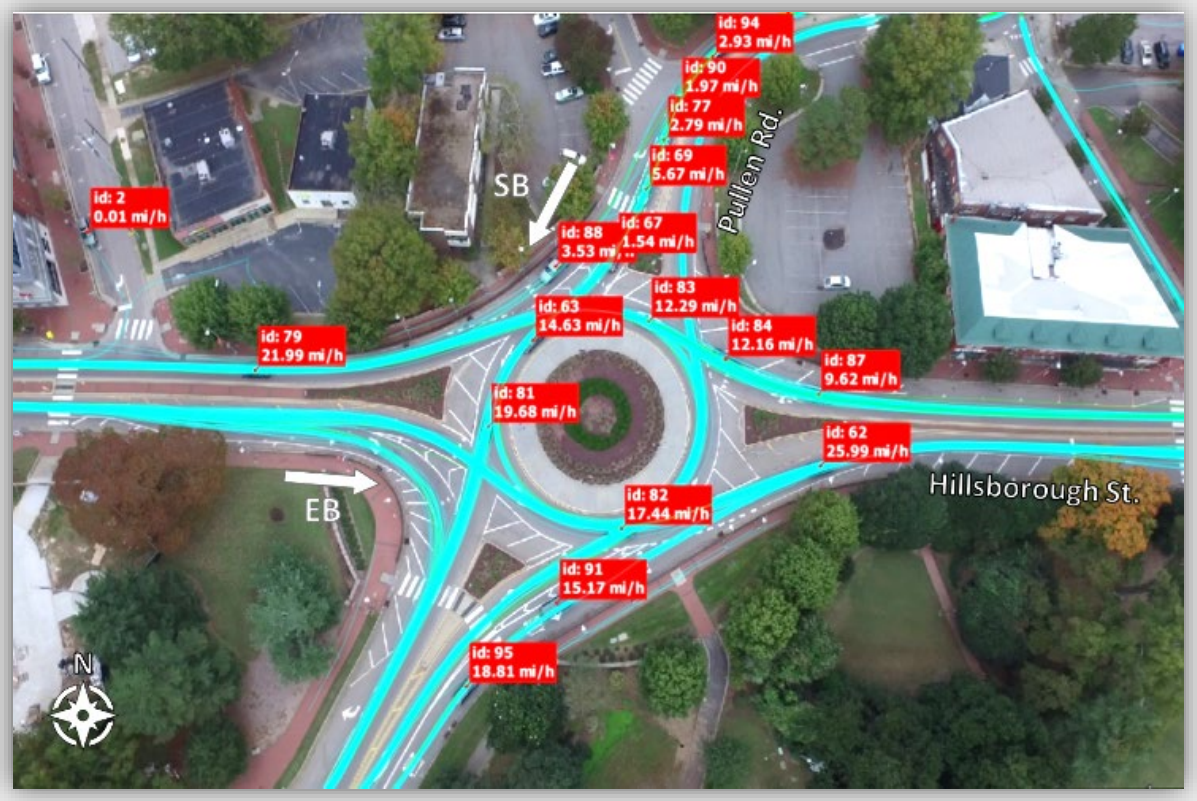
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Data collected at a single-lane roundabout in Raleigh, NC, USA, using drones

Digitized vehicle trajectories are used to observe gap acceptance parameters and capacity of entry lanes simultaneously on a cycle-by-cycle basis.

The method does not require long periods of continuous queued vehicle departures typically used by traditional gap acceptance capacity survey methods.

Data were collected at two approaches of a single-lane roundabout in Raleigh, NC, USA, using drones). Video processing was outsourced to DataFromSky™.

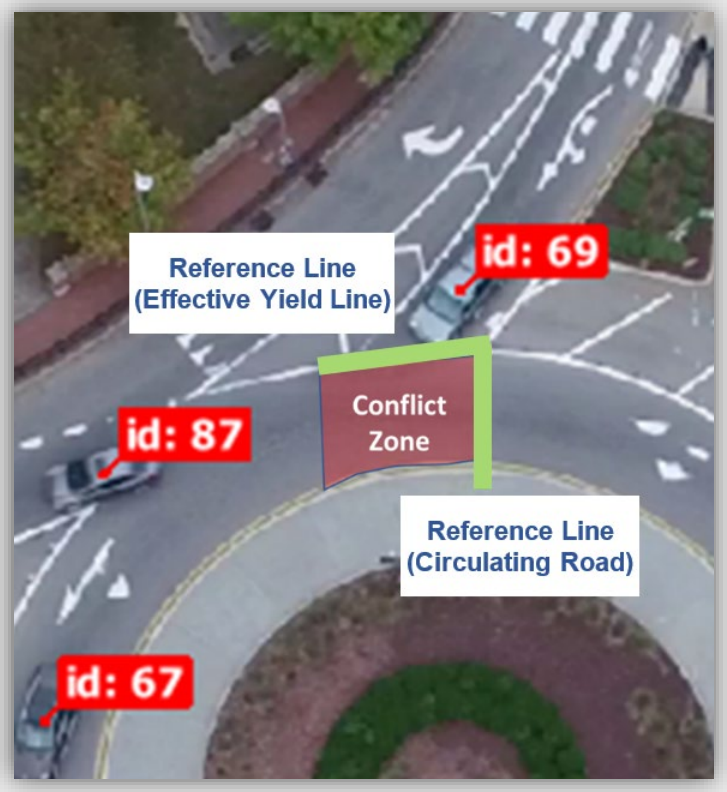


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Reference lines that define conflict zone

The research work involved development of time-space representations of vehicle trajectories from drone videos.

Gap acceptance cycles involving heavy vehicles and pedestrian effects were excluded from the analysis to enable model comparisons.

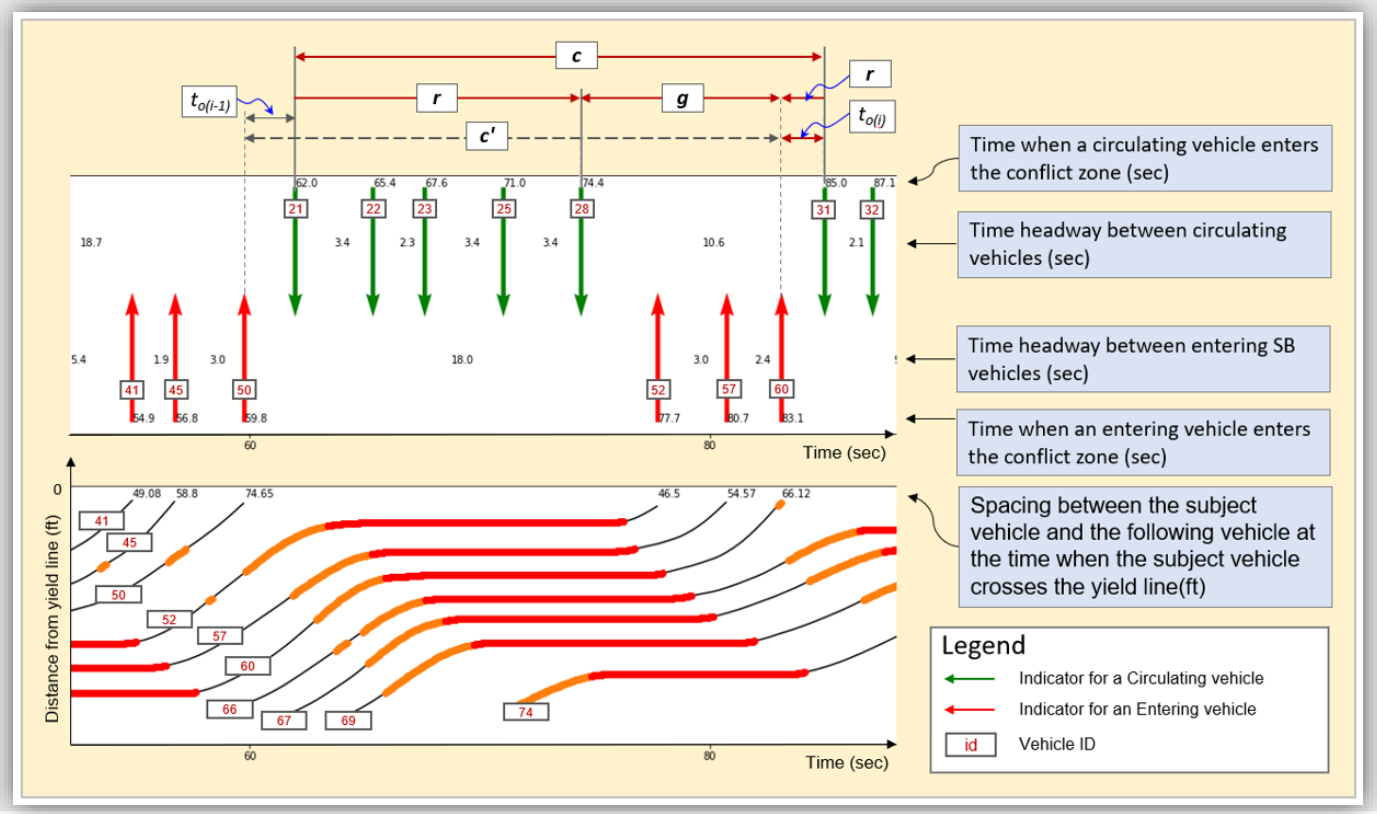


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Time-space representations of vehicle trajectories from drone videos

The digitized method used the definition of the gap acceptance cycle based on the *circulating vehicles*

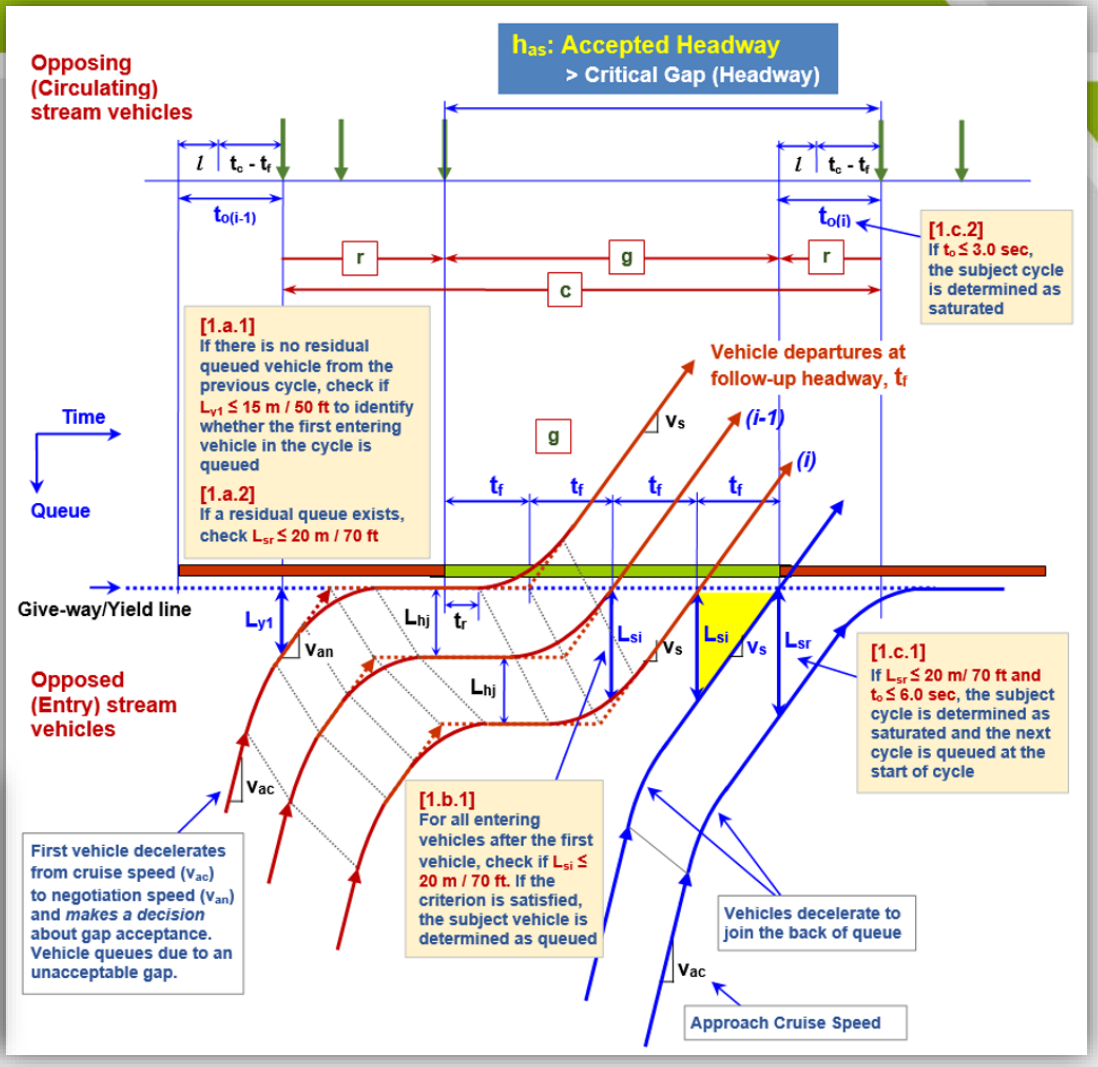
The red arrows indicate the times when the *entry vehicles pass the effective yield line*, while the green arrows represent *circulating vehicles at the point they cross the reference line* in the circulating lane.



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Definition of reliable gap acceptance cycles

The research work involved development of detailed rules to identify **reliable gap acceptance cycles** for use in observing **saturated unblocked periods** occurring when **all entry vehicles are queued** (moving queues included).



t_f = follow-up headway
t_c = critical headway
t_o = unused part of accepted headway
l = 0.5 t_f = lost time
h_{as} = accepted headway
r = effective blocked time
g = effective unblocked time
c = gap acceptance cycle time

L_{hj} = jam spacing
L_{si} = spacing of i_{th} entering vehicle
L_{y1} = distance of the front of the *first vehicle in the cycle* to the give-way/yield line
L_{sr} = spacing of the residual queued vehicle
t_r = first vehicle reaction time
v_s = saturation speed
v_{an} = approach negotiation speed
v_{ac} = approach cruise speed

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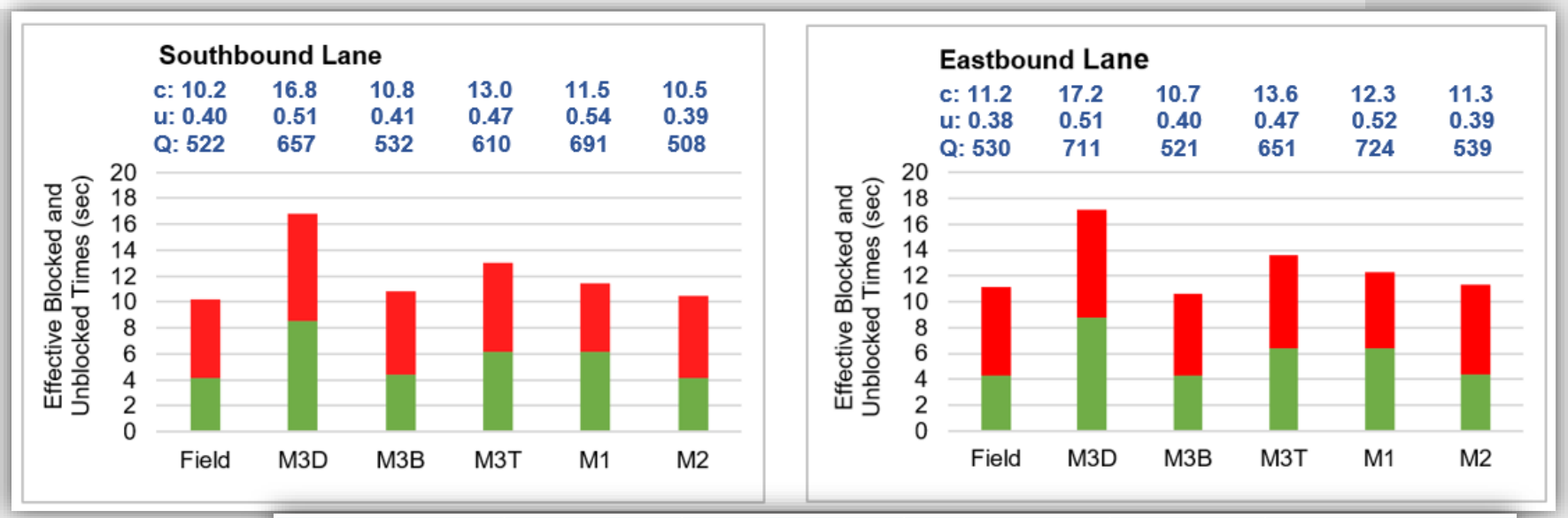
Results for key parameters from observation of reliable gap acceptance cycles

Approaches	Southbound (SB) Pullen	Eastbound (EB) Hillsborough
Total number of Cycles	268	216
Number of Reliable Cycles	136	82
Average Circulating Flow Rate (pcu/h)	758	706
Average Gap Acceptance Cycle Time, c (sec)	10.19	11.15
Average Effective Unblocked Time, g (sec)	4.12	4.27
Average Effective Blocked Time, r (sec)	6.07	6.88
Average Follow-up Headway, t_f (sec)	2.79	2.60
Average Critical Headway, t_c (sec)	4.19	4.47
Ratio of Follow-up Headway to Critical Headway, t_f / t_c	0.67	0.58
Effective Unblocked Time Ratio, u = g/c	0.404	0.383
Average Saturation Flow (intercept), s = 3600 / t_f (pc/h)	1290	1385
Average Entry Flow Rate, q_e (pc/h)	406	372
Capacity, Q_g = s (g / c) (pc/h)	522	530
Average Volume to Capacity Ratio x = q_e / Q_g	0.78	0.70

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Observed and estimated values of effective blocked and unblocked times using average values of survey parameters

The observed **effective blocked and unblocked times** (virtual red and green times) were assessed using well-known **headway distribution models** applied to circulating flows. The results indicated model estimates are close to the field values.

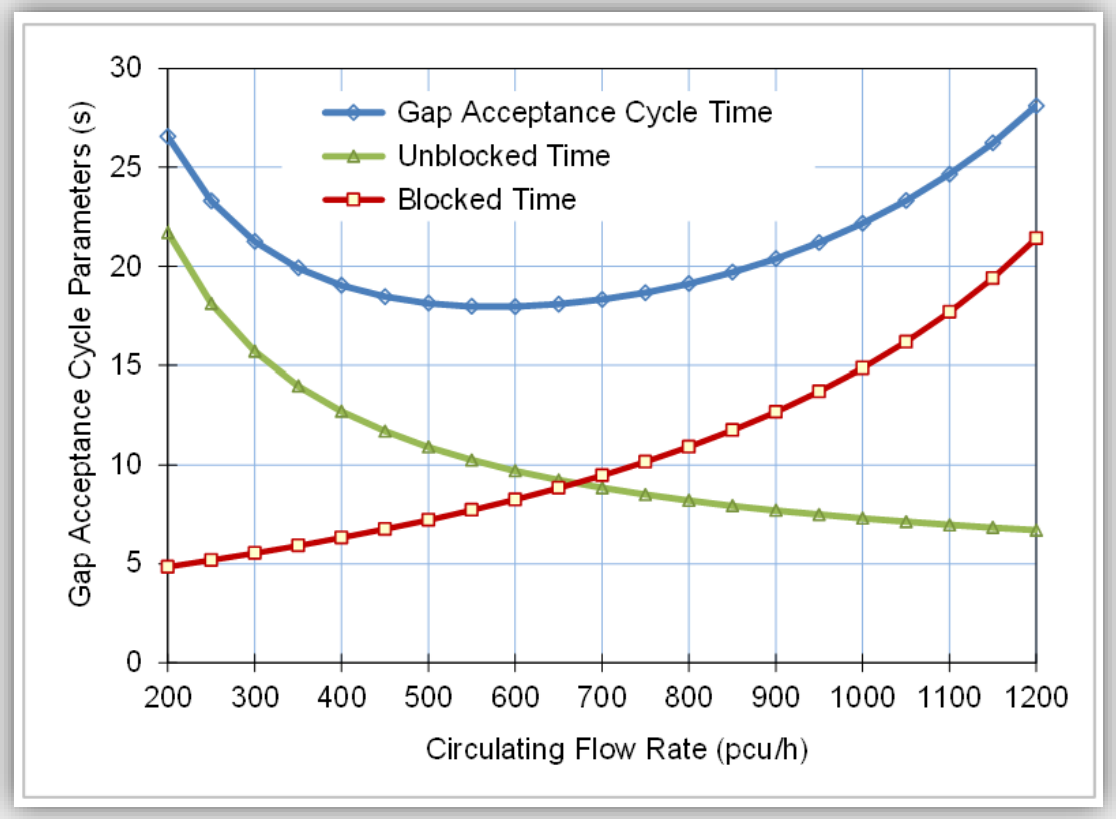


Headway distribution model	M3D: Bunched Exponential	M3B: Bunched Exponential	M3T: Bunched Exponential	M1: Negative Exponential	M2: Shifted Negative Exponential
Proportion of unbunched vehicles	Bunching delay parameter	Shifted (two-piece) linear	Tanner's (linear)	No bunching	No bunching

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The blocked and unblocked times and the gap acceptance cycle time as a function of the circulating flow rate

The graphs in this figure are derived using the *Akçelik-M3D* model using the HCM capacity model defaults for a single-lane roundabout
(follow-up headway = 2.61 s
critical headway = 4.98 s)



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Roundabout capacity model estimates

Capacity Models Applied to Disaggregate Gap Acceptance Cycle Data

- Data for SB and EB lanes were combined (218 reliable cycles).
- Capacity estimates using models used for based on different headway distributions:
  HCM, Siegloch M1, Akçelik M3D, Akçelik M3B, M2 and M1 models.
- Three methods used in applying the models (except HCM):
  - (i) using survey results for the average of gap acceptance parameters (follow-up headway, t_f = 2.71 s and critical headway, t_c = 4.30 s),
  - (ii) free (unconstrained) regression of capacity vs circulating flow, and
  - (iii) anchored regression with 3600 / t_f as the intercept using the survey value of the follow-up headway, t_f.

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Roundabout capacity model estimates

The anchored regression method is applied in order to mitigate the risk of unreliable capacity estimations stemming from data scarcity under low circulating traffic conditions as it was applied in deriving the HCM model.

Generally speaking, the statistical indicators for all exponential capacity models derived by anchored regression method are found to fall within the range of values observed for the other methods:

> Akçelik, R., C. Shirke, M. Besley, I. Espada, and D. Billinghurst. *A Comparative Analysis of Exponential and Linear Roundabout Capacity Models Using HCM Research Data*. Technical Note, Akcelik & Associates Pty Ltd, Melbourne, Australia, 2022.

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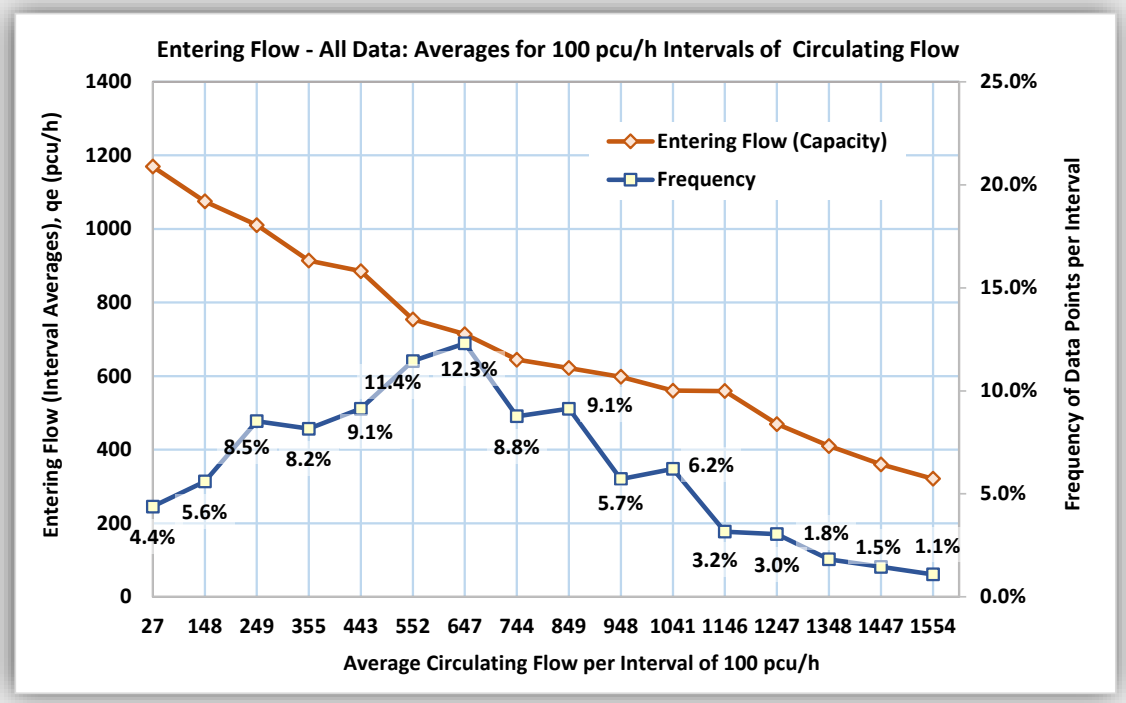
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Frequency distribution of data points

From: Rahmi Akçelik, Chaitrali Shirke, Mark Besley, Ian Espada and David Billinghurst (2022). [4]

"Model developers should pay attention to the effect of the **frequency of data points** by circulating flow on best fit regression results for the linear and nonlinear models as **this is likely to cause a bias towards hiding non-linearity** of the capacity curve."
(Akçelik, et al 2022) [4]

HCM Research data used for the HCM Edition 6 single-lane roundabout capacity model



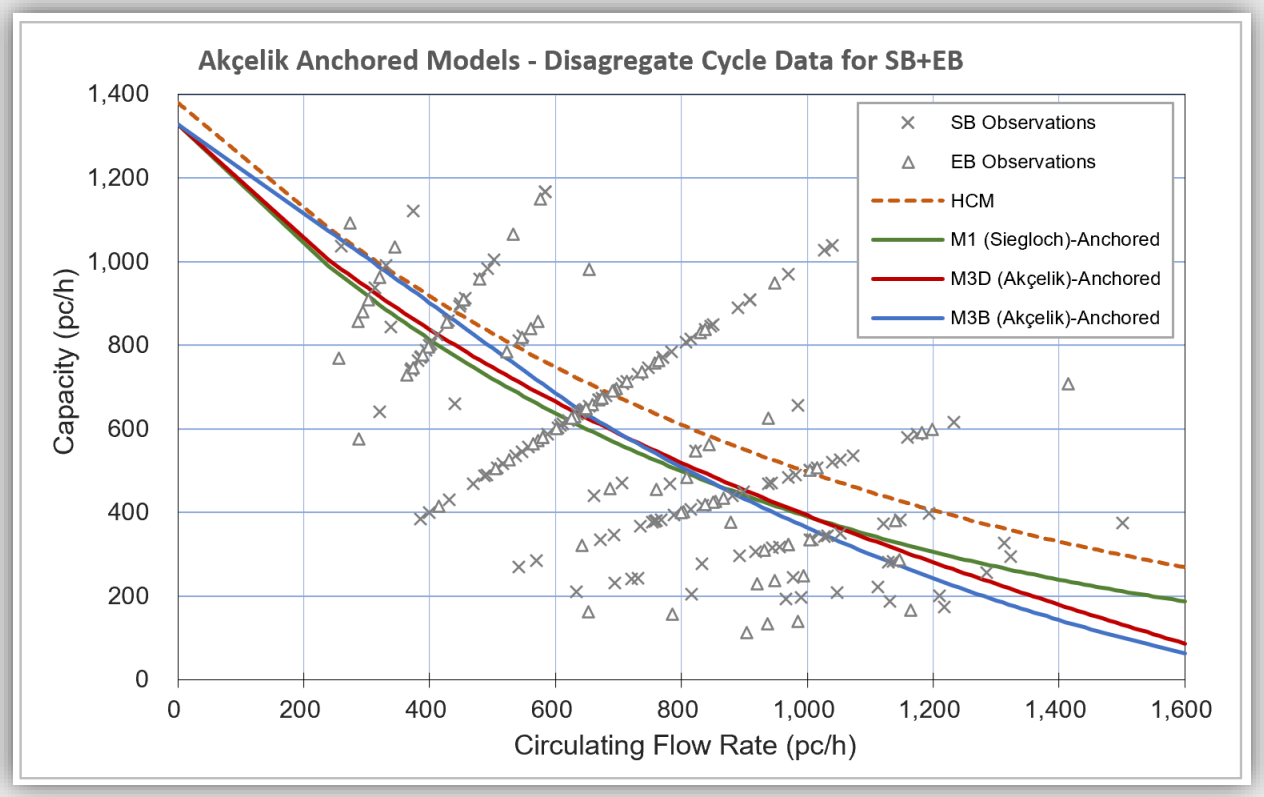
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Roundabout capacity model estimates

Roundabout capacity estimates from HCM, Siegloch M1 (calibrated HCM), Akçelik M3D and Akçelik M3B models:

- All models are anchored to the intercept (saturation flow) based on the measured follow-up headway value.
- The fanning-out of multiple linear patterns resulting from cycle-by-cycle observations is discussed in the following slides.

Capacity model estimates for combined Southbound and Eastbound approaches: disaggregate cycle data used



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Roundabout capacity model estimates

Key parameters and statistical measures for the subject capacity models for combined Southbound and Eastbound approaches using individual cycle data

Models / Parameters		t_f	t_c	Intercept (pc/hr)	R^2	RMSE
HCM		2.609	4.976	1380	0.291	230.03
Siegloch	Survey	2.712	4.301	1327	0.289	262.11
	Anchored	2.712	5.757	1327	0.292	213.68
Akçelik-M1	Survey	2.712	4.301	1327	0.289	250.21
	Anchored	2.712	5.385	1327	0.291	213.43
Akçelik-M2	Survey	2.712	4.301	1327	0.289	250.49
	Anchored	2.712	3.949	1327	0.285	244.46
Akçelik-M3D	Survey	2.712	4.301	1327	0.284	240.67
	Anchored	2.712	5.656	1327	0.289	216.31
Akçelik-M3B	Survey	2.712	4.301	1327	0.291	227.52
	Anchored	2.712	4.187	1327	0.291	226.87

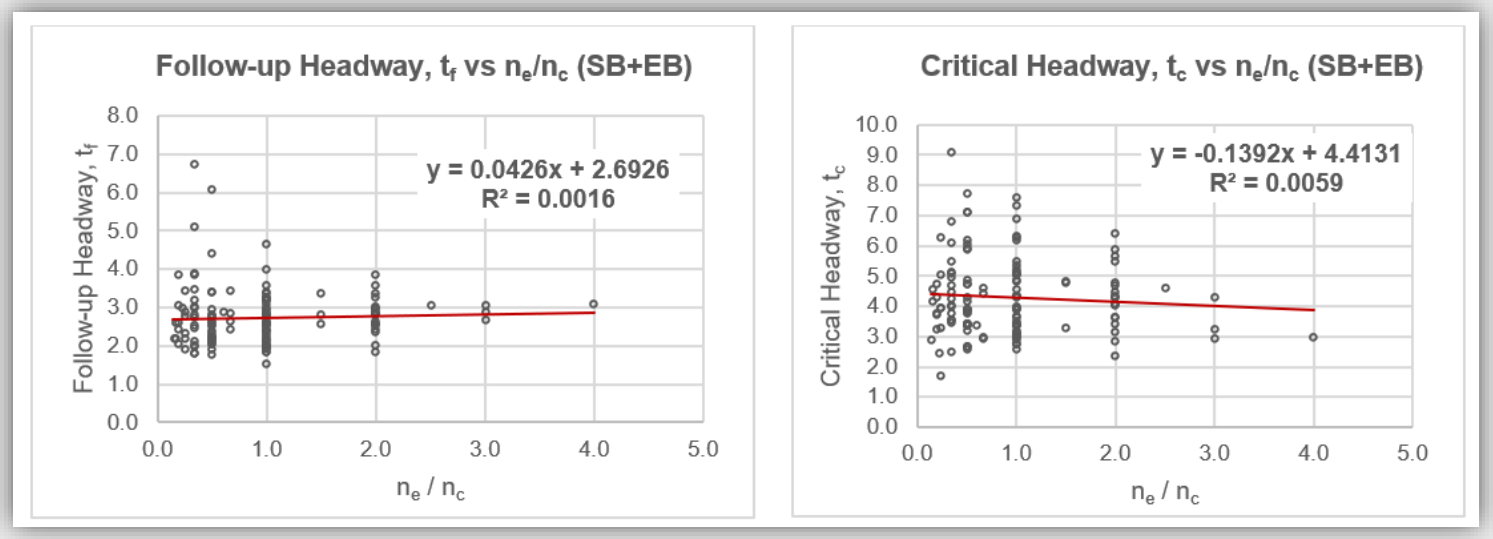
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Linear Patterns in Disaggregate Gap Acceptance Cycle Data

The disaggregate gap acceptance cycle data points are seen to form a fanning-out of multiple linear patterns resulting from cycle-by-cycle observations.

This is because the ratio of capacity to circulating flow rate, Q_g / q_c in each reliable cycle is identical to the ratio of the number of entering vehicles to the number of circulating vehicles, n_e / n_c in that cycle.

These linear patterns are independent of the key gap acceptance parameters follow-up headway and critical headway.



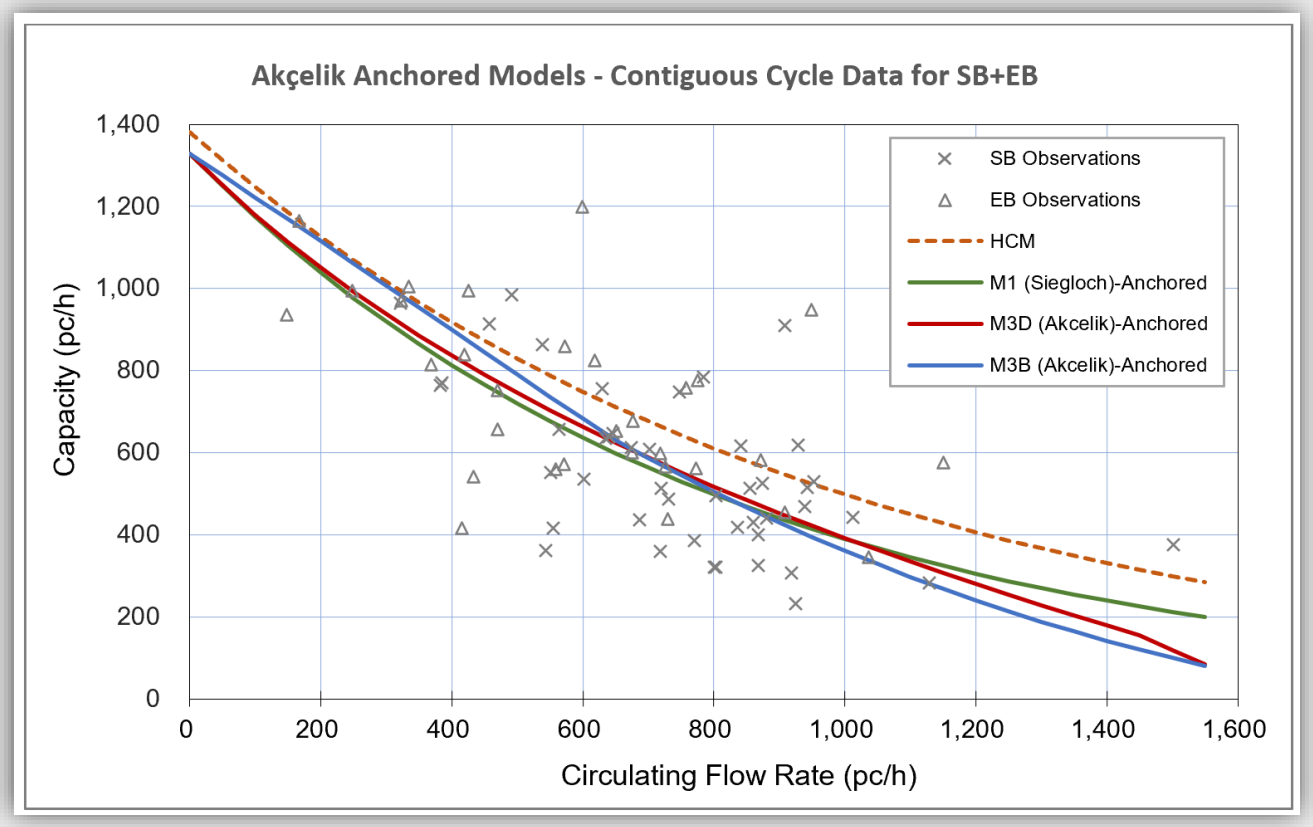
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Roundabout capacity model estimates

Capacity model estimates for combined Southbound and Eastbound approaches: contiguous cycle data used

Two data aggregation methods were explored for comparing capacity model estimates:

- combining contiguous reliable cycles and
- aggregating cycles that have the same n_e / n_c ratio.



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Roundabout capacity model estimates

Key parameters and statistical measures for the subject capacity models for combined Southbound and Eastbound approaches using aggregate contiguous cycle data

Models / Parameters		t_f	t_c	Intercept (pc/hr)	R^2	RMSE
HCM		2.609	4.976	1380	0.339	196.73
Siegloch	Survey	2.712	4.301	1327	0.336	238.19
	Anchored	2.712	5.768	1327	0.341	175.66
Akçelik-M1	Survey	2.712	4.301	1327	0.336	223.27
	Anchored	2.712	5.424	1327	0.340	174.90
Akçelik-M2	Survey	2.712	4.301	1327	0.336	200.56
	Anchored	2.712	4.020	1327	0.332	194.93
Akçelik-M3D	Survey	2.712	4.301	1327	0.325	209.19
	Anchored	2.712	5.686	1327	0.333	177.12
Akçelik-M3B	Survey	2.712	4.301	1327	0.339	183.22
	Anchored	2.712	4.211	1327	0.338	182.66

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Roundabout capacity model estimates

Key parameters and statistical measures for the subject capacity models for combined Southbound and Eastbound approaches: cycles with the same n_e / n_c ratio aggregated

Models / Parameters		t_f	t_c	Intercept (pc/hr)	R^2	RMSE
HCM		2.609	4.976	1380	0.827	209.15
Siegloch	Survey	2.712	4.301	1327	0.827	271.83
	Anchored	2.712	6.998	1327	0.820	147.41
Akçelik-M1	Survey	2.712	4.301	1327	0.828	248.71
	Anchored	2.712	6.152	1327	0.825	133.76
Akçelik-M2	Survey	2.712	4.301	1327	0.835	125.74
	Anchored	2.712	4.326	1327	0.836	125.68
Akçelik-M3D	Survey	2.712	4.301	1327	0.819	210.63
	Anchored	2.712	6.556	1327	0.823	134.51
Akçelik-M3B	Survey	2.712	4.301	1327	0.832	131.87
	Anchored	2.712	4.655	1327	0.831	122.75

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Conclusions

- Using real-world data, the results of this research validated the novel signal analogy concept used in developing gap acceptance capacity and performance models which have been employed in the SIDRA INTERSECTION software.
- Future advancements should focus on the development of an automated tool for determination of reliable gap acceptance cycles and survey data analysis to enhance efficiency and accuracy.
- This study excluded cycles involving heavy vehicles and pedestrian effects due to insufficient data size. Preliminary investigation indicated that this survey method can be used for determining gap acceptance factors for different vehicle classes.

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Conclusions

- A preliminary assessment of bunching models for the circulating flows indicated low levels of bunching in circulating flows as used in the Akçelik M3B capacity model. Future research is recommended on bunching models for circulating stream headway distributions at single lane and multilane roundabouts.
- The survey method reported in this paper applied to a single-lane roundabout. It can be used for multi-lane roundabouts as well as other gap acceptance situations including
  - stop and give-way/yield controlled) intersections,
  - permitted turns, turn on red, and unsignalised bypass lanes at signalized intersections, and
  - various merge situations.

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ABSTRACT

Various field survey methods for the calibration of roundabout capacity models have been reported in the literature [1-4]. This presentation describes a new survey method to estimate roundabout capacity by utilizing detailed vehicle trajectory data [5-7]. The survey uses gap acceptance cycles based on a signal analogy concept used for developing gap acceptance capacity and performance models employed in the SIDRA INTERSECTION software [8,9].

The method was applied to two approaches of a single-lane roundabout with moderate traffic conditions in Raleigh, NC, USA, using vehicle trajectory data extracted from drone footage]10]. The survey method defines reliable gap acceptance cycles for measuring follow-up headway, critical headway and cycle-by-cycle capacity simultaneously. This is done by observing the departure of queued vehicles in saturated, unblocked periods. Average blocked time, unblocked time and gap acceptance cycle time estimates were assessed by applying the observed follow-up and critical headway values to a number of arrival headway distribution models.

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ABSTRACT - continued

Gap acceptance capacity estimates were assessed for the Highway Capacity Manual (HCM), Siegloch and Akçelik models [10-12]. Key parameters within each model were estimated through direct observations using the new survey method, unconstrained regressions, as well as anchored regressions applied in order to mitigate the risk of unreliable capacity estimations stemming from data scarcity under low traffic conditions.

Various aggregation methods were investigated for their effect on the fitness of the capacity models. The results of the capacity model assessments are presented to show the validity of the survey method, supporting the novel signal analogy concept with real-world data.

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ABSTRACT - continued

Future research is recommended for determining Gap Acceptance Factors for different vehicle classes in entry lanes, and for assessing bunching models for roundabout circulating flows for use in bunched exponential headway distribution models [2,4,8,9].

The new survey method can be applied to a wide range of gap acceptance processes including unsignalised intersections with two-way sign control (stop and yield controlled) as well as permitted turns, unsignalised bypass lanes and turn on red at signalized intersections. Research is recommended applying the survey method at these facilities and at multi-lane roundabouts.

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END OF PRESENTATION



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