Akcelik & Associates Pty Ltd
PO Box 1075G, Greythorn, Vic 3104 AUSTRALIA
info@sidrasolutions.com

Management Systems Registered to ISO 9001
ABN 79 088 889 687

REPRINT

Issues in Performance Assessment of Sign-Controlled Intersections

R. AKÇELIK

REFERENCE:

AKÇELIK, R. (2012). Issues in performance assessment of sign-controlled intersections.
Paper presented at the 25th ARRB Conference, Perth, Australia, Sep 2012.

NOTE:

This paper is related to the analysis methodology used in the SIDRA INTERSECTION software package.

PO Box 1075G, Greythorn Victoria 3104, Australia
Email: info@sidrasolutions.com

ISSUES IN PERFORMANCE ASSESSMENT OF SIGN-CONTROLLED INTERSECTIONS

Rahmi Akçelik, Akcelik & Associates Pty Ltd, Australia

ABSTRACT

The capacity, performance and level of service assessment of intersections controlled by stop and give-way signs has special importance in the context of traffic impact assessment where the choice of sign-controlled intersections rather than roundabouts or signalized intersections can be controversial due to significant cost differences. Such controversy can often be traced back to choices of input parameters by traffic analysts to represent driver gap acceptance behaviour at sign controlled intersections. This paper reviews guidelines available for the choice of driver behaviour parameters affecting capacity of sign-controlled intersections towards clearer guidance for practitioners in relation to this difficult and important task in sign-controlled intersection analysis. A number of related issues are discussed including the relationship between driver gap acceptance parameters and the intersection geometry, implications of analytical capacity models used in Australia and overseas, and the level of service and performance measures used for sign-controlled intersection assessment. An example is given for comparing the effect of differences in gap-acceptance parameters given in Austroads Road Design and Traffic Management Guides and the US Highway Capacity Manual on analysis results.

INTRODUCTION

The need for capacity, performance and level of service assessment of unsignalized intersections controlled by stop and give-way signs is often underestimated because of low minor road demand volumes resulting from low capacities at these intersections.

Austroads Traffic Management Guide Part 6 (Austroads 2007) recognizes the importance of unsignalized intersections: "*The vast majority of intersections are unsignalised and account for a high proportion of network delay, conflict between motor vehicles, and conflict between motor vehicles and other road users (e.g. pedestrians).*".

On the other hand, Austroads Traffic Management Guide Part 3 (Austroads 2009a) plays down the importance of assessment of traffic operation at unsignalised intersections: "*At unsignalised intersections, the major road traffic normally has priority over the minor road. From that perspective, unsignalised intersections cause neither reduced capacity nor delay. When the volumes of cross and turning traffic at intersections with minor roads are small, capacity considerations are usually not significant.*".

This statement does not recognize the special importance of unsignalised intersections in the context of impact assessment (related to Austroads Traffic Management Guide Part 12 (Austroads 2009b)) where choices between sign controlled intersections vs roundabout or signalized intersections can be controversial due to significant cost differences. Such controversy is often a result of the assumptions made by traffic analysts in determining input parameters to represent driver gap acceptance behaviour at sign controlled intersections. It is also important to realize that low minor movement demand flows at sign-controlled intersections are often a result of low capacities that occur due to the nature of difficult conditions for drivers. Minor road demand volumes should not be dismissed as being low since drivers trying to find gaps in major road traffic may experience long delays.

This paper reviews the guidelines available for the choice of driver gap acceptance parameters (critical gap and follow-up headway) affecting capacity of sign-controlled intersections towards provision of clearer guidance for practitioners in relation to this difficult and important task in sign-controlled intersection analysis. The related issues discussed include:

- the relationship between driver gap acceptance parameters and intersection geometry (number of lanes on major road, etc);
- conflicting advice about gap-acceptance parameters given in the AUSTROADS Road Design Guide Part 4A (Austroads 2010) based on traditional Australian parameters and the Traffic Management Guide Part 3 (Austroads 2009a) based on the US Highway Capacity Manual (TRB 2000, TRB 2010);
- implications of differing analytical capacity models used in Australia and overseas;
- performance measures appropriate for use in assessment of sign-controlled intersections;
- level of service methods used in Australia and overseas (the HCM 2010 and NSW methods in particular); and
- the need for research to establish gap acceptance parameters to represent driver behaviour in Australia and New Zealand.

Austroads Traffic Management Guide Parts 3 and 6 (Austroads 2009a, 2007) have been under review and various issues raised in this paper will be resolved in new editions of these publications.

The strong link between traffic safety and performance at sign-controlled intersections should also be considered in relation to the importance of performance assessment of these intersections.

This paper assumes that the reader has a basic knowledge of gap acceptance modelling. The presentation in this paper assumes driving on the left-hand side of the road.

CURRENT AUSTROADS GUIDELINES AND HCM 2010

Critical gap and follow-up headway are the key parameters representing driver gap-acceptance behaviour for the capacity and performance analysis of two-way sign-controlled (unsignalized) intersections (Akçelik 1994, 2007; Akcelik & Associates 2011; Austroads 1988, 2002, 2005, 2009a, 2010), TRB (2000, 2010).

The current Austroads Road Design and Traffic Management guides (Austroads 2007, 2008, 2009a,b, 2010) and the US Highway Capacity Manual, "HCM 2010" (TRB 2010) present various recommendations on appropriate critical gap and follow-up headway parameters for two-way sign controlled intersections.

The Austroads Road Design Guide Part 4A (Austroads 2010) adopted the guidelines for the choice of critical gap and follow-up headway parameters used in earlier Austroads guides (Austroads the 2002, 2005). On the other hand, the Austroads Traffic Management Guide Part 3 (Austroads 2009a) presented the HCM 2010 values and associated equations. A new edition of the Traffic Management Guide Part 3 which is in preparation will include guidelines consistent with the Road Design Guide Part 4A. The revised guide will also clarify the level of service concepts for consistent definitions and criteria to be used in practice in Australia and New Zealand.

The SIDRA INTERSECTION software (Akcelik & Associates 2011) incorporates the *SIDRA Standard* and *Highway Capacity Manual (HCM)* models which use the Austroads (2010) values (with some variations) and the HCM 2010 values respectively. These two sets of recommended parameter values are summarised in *Tables 1 and 2*.

Table 1 presents the critical gap and follow-up headway parameter values recommended by the Austroads Road Design Guide Part 4A (Table 3.4) together with the default and recommended values of these parameters for use in SIDRA INTERSECTION. It is seen that SIDRA INTERSECTION default values vary from the AUSTROADS Guide to some extent in order to provide more flexibility to match varying intersection geometry.

Table 1: Gap acceptance parameters based on AUSTROADS Road Design Guide Part 4A, Table 3.4 (AGRD04A-10) and the *SIDRA Standard Model in SIDRA INTERSECTION software*

Type of movement	AUSTROADS Guide (2010)		*SIDRA Standard Model*	
	Critical Gap (seconds)	Follow-up Headway (seconds)	Critical Gap (seconds)	Follow-up Headway (seconds)
Left Turn (1)	5	2 - 3	(3 - 6)	(2.0 - 3.5)
1-lane opposing			4.5	2.5
2-lane (or more) opposing			5.0	3.0
Through movement crossing one-way road				
2-lane one-way	4	2	4.5 (4 - 5)	2.5 (2 - 3)
3-lane one-way	6	3	5.5 (5 - 6)	3.0 (2.5 - 3.5)
4-lane one-way	8	4	6.0 (5 - 8)	3.5 (3 - 4)
Through movement crossing two-way road				
2-lane two-way	5	3	5.0 (4.5 - 5.5)	3.0 (2.5 - 3.5)
4-lane two-way	8	5	6.5 (5 - 8)	3.5 (3 - 5)
6-lane two-way	8	5	7.5 (7 - 8)	4.5 (4 - 5)
Right Turn from Major Road (2)				
Across 1 lane	4	2	4.0 (3.5 - 4.5)	2.0 (2 - 3)
Across 2 lanes	5	3	4.5 (4 - 5)	2.5 (2 - 3)
Across 3 lanes	6	4	5.5 (5 - 6)	3.5 (3 - 4)
Right Turn from Minor Road (3)				
One-way	3	3	Use Left turn values above	
2-lane two-way	5	3	5.5 (5 - 6)	3.5 (3 - 4)
4-lane two-way	8	5	7.0 (6 - 8)	4.0 (3 - 5)
6-lane two-way	8	5	8.0 (7 - 9)	5.0 (4 - 6)
Merge from acceleration lane	3	2	3.0 (2.5 - 3.5)	2.0 (1.5 - 2.5)

Notes:

These notes are not included in the Austroads Guide:

(1) This is considered to apply to Left-Turn movements from Minor Road, as well as Slip-Lane Left-Turn movements from Minor Road.

(2) This case is relevant to two-way Major Road conditions with one direction of the Major Road opposing (1-lane, 2-lane or 3-lane).

(3) The conditions specified (one-way, 2-lane two-way, 4-lane two-way, 6-lane two-way) are relevant to the opposing movement lanes on the Major Road.

Table 2: Gap acceptance parameters for the *SIDRA Standard Model* and the *HCM Model* in SIDRA INTERSECTION (template settings for 4-way intersections)

SIDRA Standard Model							
		2-Lane Major Road			**4-Lane Major Road**		
STOP Sign		**t_c**	**t_f**	**s**	**t_c**	**t_f**	**s**
Minor Road:	Left Turn	4.5	2.5	1440	5.0	3.0	1200
	Through	5.0	3.0	1200	6.5	3.5	1029
	Right Turn	5.5	3.5	1029	7.0	4.0	900
Right Turn from Major Road		4.0	2.0	1800	4.5	2.5	1440
GIVE-WAY / YIELD Sign		t_c	t_f	s	t_c	t_f	s
Minor Road:	Left Turn	4.0	2.2	1636	4.5	2.7	1333
	Through	4.5	2.7	1333	6.0	3.2	1125
	Right Turn	5.0	3.2	1125	6.5	3.7	973
Right Turn from Major Road		4.0	2.0	1800	4.5	2.5	1440
HCM Model							
		2-Lane Major Road			**4-Lane Major Road**		
STOP Sign		t_c	t_f	s	t_c	t_f	s
Minor Road:	Left Turn	6.2	3.3	1091	6.9	3.3	1091
	Through	6.5	4.0	900	6.5	4.0	900
	Right Turn	7.1	3.5	1029	7.5	3.5	1029
Right Turn from Major Road		4.1	2.2	1636	4.1	2.2	1636
GIVE-WAY / YIELD Sign		t_c	t_f	s	t_c	t_f	s
Minor Road:	Left Turn	5.7	3.0	1200	6.4	3.0	1200
	Through	6.0	3.7	973	6.0	3.7	973
	Right Turn	6.6	3.2	1125	7.0	3.2	1125
Right Turn from Major Road		4.1	2.2	1636	4.1	2.2	1636

Notes:

The *SIDRA Standard Model* values are based on the values recommended in AUSTROADS Road Design Guide Part 4A. See *Table 1* for the comparison of default and recommended values for use in SIDRA INTERSECTION and the values recommended in AUSTROADS Road Design Guide Part 4A.

The *HCM Model* values are based on HCM 2010 (TRB 2010). The values in this table are a mirror-image of HCM values for comparison with the values for the *SIDRA Standard Model*. Two-way give-way (yield) sign control of intersections is not used in the USA. Values are provided in SIDRA INTERSECTION to facilitate analysis of this type of control.

The Minor Road Right Turn is generally the most critical movement in two-way sign control analysis with the highest critical gap and follow-up headway values and the largest total opposing flow rate.

The parameter $s = 3600 / t_f$ is the equivalent saturation (queue discharge) flow rate in a gap acceptance process. This represents the largest capacity that can be obtained under very low opposing flow conditions.

Table 2 compares the gap-acceptance parameters used in SIDRA INTERSECTION for the *SIDRA Standard* model for Australia and New Zealand and the *HCM model* for USA (left and right turn movement values swapped for comparison purposes).

The following can be observed from *Tables 1 and 2*:

- The gap acceptance parameters depend on the intersection geometry, namely the number of opposing movement (major road) lanes. The wide variation in gap acceptance parameters according to the intersection geometry indicates that it is important to vary the gap acceptance parameters for intersection geometry for sign control capacity and performance analysis in practice.
- The give-way sign control values for Minor Road movements given in *Table 2* were derived from the those for stop-sign control by subtracting 0.5 s for the critical gap and 0.3 s for the follow-up headway parameters.

HCM 2010 recommends adjustments to gap acceptance parameters for T-intersections, staged crossings, U-turn movements and road grade.

A simple rule of thumb in relation to the gap acceptance parameters can be stated as "*the ratio of follow-up headway to critical gap is about 0.6*". This is confirmed by the values given in *Tables 1 and 2*. In *Table 1*, the average value of parameters for all cases *is* 0.60 (range 0.46 to 0.67). In *Table 2*, the average values are 0.57 for the *SIDRA Standard model* and 0.54 for the *HCM model* (the overall average is 0.56).

The roundabout data collected during the Australian roundabout research (Troutbeck 1989; Akçelik and Troutbeck 1991) indicated an average value of 0.61 with the 15th and 85th percentile values of 0.43 and 0.79. *Figure 1* shows the relationship between the follow-up headway and critical gap parameters using all data for sign control shown in *Table 2* and the Australian roundabout data (extreme values eliminated by using the data in the range 4th to 95th percentile). The average value for data shown in *Figure 1* is 0.58 (range 0.40 to 0.87). Since both the follow-up headway and the critical gap parameters represent the behaviour of the same driver population, the relationship shown in *Figure 1* (R^2 = 0.83) is not surprising.

In practice, when a gap acceptance survey is limited to measuring the follow-up headway, the rule about the ratio of follow-up headway to critical gap can be useful for estimating the critical gap as *Critical Gap = Follow-up Headway / 0.6*. More conservatively, a factor of 0.55 could be used instead of 0.6, and a *likely range of critical gap values* could be estimated using factors 0.45 and 0.65.

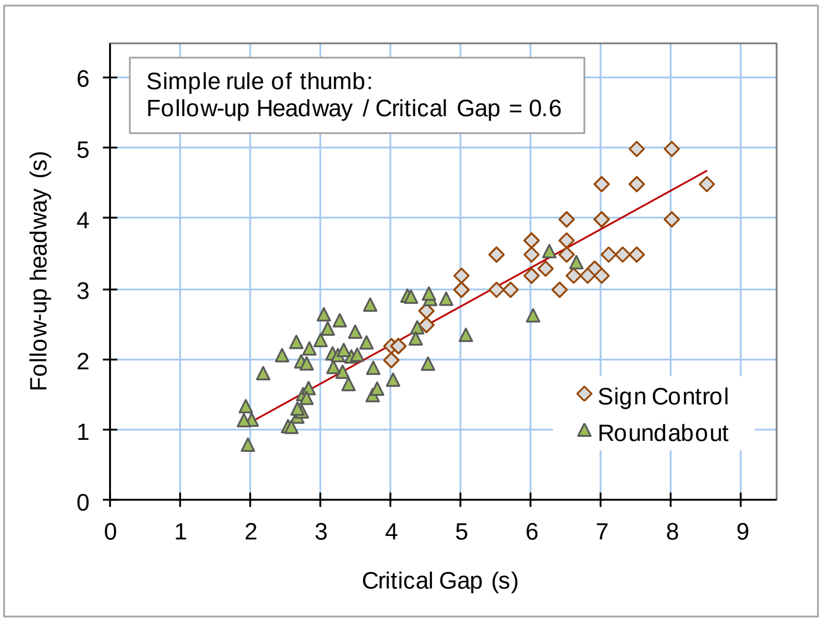


Figure 1: The relationship between the follow-up headway and critical gap parameters for the SIDRA Standard Model and HCM Model shown in Table 2, and for the Australian roundabout research

A COMPARISON

Figure 2 shows an example (using SIDRA INTERSECTION) which demonstrates how the *SIDRA Standard Model* and the *HCM Model* parameters shown in *Table 2* can give capacity estimates (therefore degrees of saturation, delay, queue length and level of service values) which differ substantially. The T-intersection adjustment to gap acceptance parameters suggested in HCM 2010 was not used for this example. Thus, for the critical Minor Road Right-Turn movement, parameter values of critical gap = 5.5 s and follow-up headway = 3.5 s for the *SIDRA Standard Model*, and critical gap = 7.1 s and follow-up headway = 3.5 s for the *HCM Model* were used. In other words, the only difference is in the critical gap value which is about 30 per cent higher for the *HCM Model*.

It is seen that with the *HCM Model* parameters, the average delay and queue length for the critical Minor Road Right-Turn movement (North Approach, Lane 2) are more than doubled. *Level of Service F* is obtained with the *HCM Model* parameters instead of *Level of Service C* with the *SIDRA Standard Model* parameters.

In view of significant differences in capacity and performance estimates using the *Austroads - SIDRA Standard Model* and the *HCM Model* parameters (*Tables 1 and 2*), it is important to discuss some aspects of differences in guidelines and capacity methods.

Austroads Traffic Management Guide Part 3 (Austroads 2010) stated that "The critical acceptance headway and follow-up time values used in the HCM 2000 represent the most well-evaluated values available at this time." and presented the HCM Model parameters (as given in Table 2). HCM 2010 presents the same parameter values as in HCM 2000.

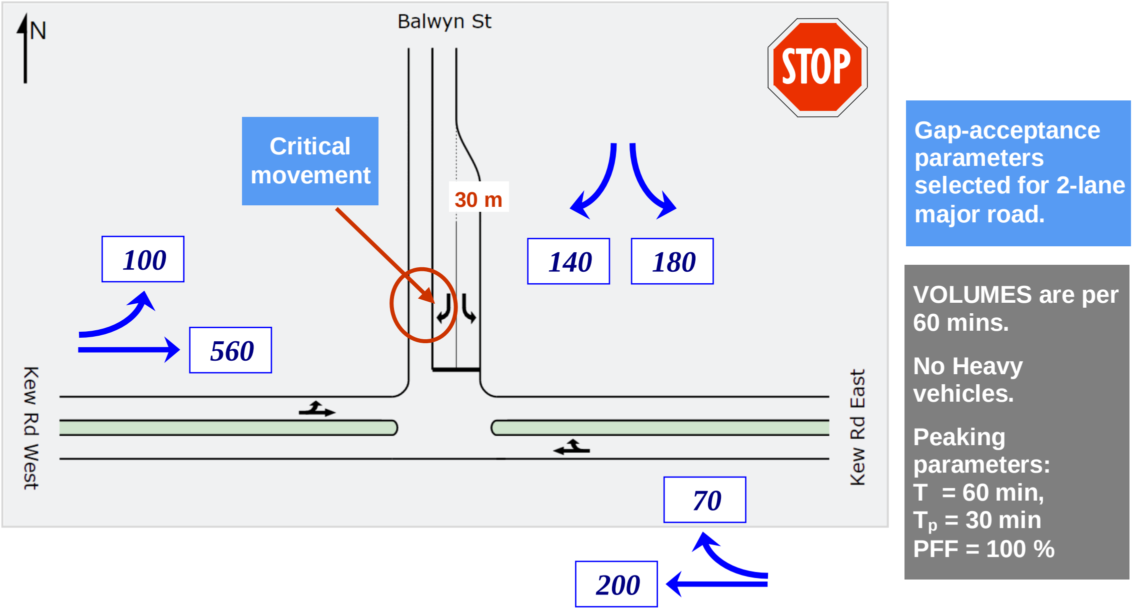
However, being based on surveys conducted in the USA, the HCM models are calibrated for US driving conditions which are based on different driver behaviour compared with Australia and New Zealand. Generally, lower saturation flow rates for traffic signals and higher critical gap and follow-up headway values for roundabouts and sign control, and therefore lower capacities, are observed in the USA. The reasons for this have been discussed in the literature (Akçelik 2011b) and include such factors as:

- larger vehicles, and
- more hesitant driving culture resulting from:
  - extensive use of *all-way stop control* (extremely rare in Australia and New Zealand) and
  - lack of use of *two-way give-way (yield) control* at intersections (common in Australia and New Zealand), and
- roundabouts being not as common and well-established in practice as in Australia and New Zealand.

However, it should be noted that some *HCM Model* parameter values (mostly follow-up headways) in *Table 2* are lower than (about 90% of) the *SIDRA Standard Model* values.

When the HCM gap acceptance parameters were adopted in an earlier version of SIDRA INTERSECTION as default values, there were strong objections from Australian practitioners that they were too large for Australian conditions, and subsequently they were changed back to the traditional parameter values based on Austroads guides.

It is therefore suggested that the traditional *Austroads - SIDRA Standard Model* gap acceptance parameters and the associated capacity and performance models are more appropriate for driving conditions in Australia and New Zealand. However, research aimed at refining the *Austroads - SIDRA Standard Model* gap acceptance parameters for improved calibration to represent Australian and New Zealand driving conditions is recommended strongly.



Lane Summary - 2-Lane Major Road Standard Model Parameters

LANE SUMMARY

Site: 2-Lane Major Road Standard Model Parameters

Example 3
Stop (Two-Way)

Results based on the based on the *SIDRA Standard Model* parameters

Lane Use and Performance

	Demand Flows L veh/h	Demand Flows T veh/h	Demand Flows R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
East: Kew Rd East																
Lane 1	0	200	70	270	0.0	1476	0.183	100	5.8	LOS A	1.4	9.9	500	–	0.0	0.0
Approach	0	200	70	270	0.0		0.183		5.8	NA	1.4	9.9				
North: Balwyn St																
Lane 1	180	0	0	180	0.0	700	0.257	100	14.9	LOS B	1.1	7.5	30	Turn Bay	0.0	0.0
Lane 2	0	0	140	140	0.0	311	0.450	100	24.4	LOS C	1.9	13.3	500	–	0.0	0.0
Approach	180	0	140	320	0.0		0.450		19.0	LOS C	1.9	13.3				

Lane Summary - 2-Lane Major Road HCM Model Parameters

LANE SUMMARY

Site: 2-Lane Major Road HCM Model Parameters

Example 3
Stop (Two-Way)

Results based on the based on the HCM 2010 Model parameters

Lane Use and Performance

	Demand Flows L veh/h	Demand Flows T veh/h	Demand Flows R veh/h	Total veh/h	HV %	Cap. veh/h	Deg. Satn v/c	Lane Util. %	Average Delay sec	Level of Service	95% Back of Queue Vehicles veh	95% Back of Queue Distance m	Lane Length m	SL Type	Cap. Adj. %	Prob. Block. %
East: Kew Rd East																
Lane 1	0	200	70	270	0.0	1410	0.191	100	6.1	LOS A	1.5	10.3	500	–	0.0	0.0
Approach	0	200	70	270	0.0		0.191		6.1	NA	1.5	10.3				
North: Balwyn St																
Lane 1	180	0	0	180	0.0	387	0.465	100	23.1	LOS C	2.5	17.5	30	Turn Bay	0.0	0.0
Lane 2	0	0	140	140	0.0	194	0.723	100	53.4	LOS F	4.5	31.8	500	–	0.0	0.0
Approach	180	0	140	320	0.0		0.723		36.4	LOS E	4.5	31.8				

Figure 2: SIDRA INTERSECTION example showing differences in capacity and performance estimates using gap-acceptance parameters based on the "Austroads - SIDRA Standard Model" and "HCM model" values

Future research on this topic should take into account the relationship between driver gap acceptance parameters and intersection geometry (number of lanes on the major road, T-intersection and other variations in intersection configuration), differences in driver gap acceptance behaviour between give-way and stop sign control, decreases in critical gap and follow-up headway values with increasing opposing flow rate, and the effect of such factors as heavy vehicles, opposing (major road) traffic speed, road grade (both minor road and major road) and sight distance restrictions (e.g. due to parking on the major road).

While the US Highway Capacity Manual (TRB 2010) is a powerful document based on good research on this topic (sometimes borrowing from research in other countries), capacity analysis methods developed in Australia for signalised intersections, roundabouts and sign-controlled intersections can be considered to be more advanced than those offered in the HCM in many ways:

- Australian methods use *lane-based* analysis whereas HCM uses more aggregate analysis by *lane groups* (the only exception is the roundabout capacity method in HCM 2010).
- Australian methods use a *bunched exponential* model of headway distributions for opposing traffic streams in gap-acceptance analysis (roundabouts, sign control, signals) whereas the HCM assumes a *simple exponentia*l distribution of headways that is not sensitive to the number of lanes or lane flow distribution of opposing flows (Akçelik 2005, 2007, 2011a; Akçelik and Besley 2005; Akçelik and Chung 1994a,b; Akçelik and Troutbeck 1991; Cowan 1975; Luttinen 1999; Sullivan and Troutbeck 1993; Vasconcelos, et al 2011). The bunched exponential model allows modelling of the effect of upstream signals in a simple way.

  It is recommended that description of the widely-used bunched exponential model of headway distributions is included in the Austroads Traffic Management Guide Part 2 (Austroads 2008).
- HCM has not been able to offer *geometric delay* models and adequate modelling of *short lanes*. The method used in SIDRA INTERSECTION to model gap acceptance cycles provides a good basis for modelling short lanes at sign-controlled intersections and roundabouts.
- HCM is inconsistent in queue modelling for intersections as it uses *back of queue* for signals but *cycle-average queue* for roundabouts and sign control. The back of queue model for sign-controlled intersections and roundabouts based on gap-acceptance modelling was developed by the author and is used in the SIDRA INTERSECTION software (Akçelik 1994, 2007).
- HCM only deals with stop-sign control. It does not cover two-way give-way (yield) control as this type of unsignalised intersection control is not used in the USA.

LEVEL OF SERVICE FOR TWO-WAY SIGN-CONTROL

Another issue for intersection analysis practice that needs to be addressed is the use of the level of service concept for assessing sign-controlled and other intersections.

While US practice has used level of service for a long time now, this concept had limited use in Australia and New Zealand where direct analysis of degree of saturation, delay and queue length has been the common practice. Austroads Traffic Management guides appear to introduce the level of service concept more strongly than before but there are some issues related to this.

Austroads Traffic Management Guide Part 3 (Austroads 2009a) did not give level of service tables for roundabouts and signals but adopted the HCM 2000 level of service table for sign control. The SIDRA INTERSECTION software uses the HCM 2000 method by default for signalised and sign-controlled intersections. For all intersection types, HCM 2010 uses the additional criterion that, if the degree of saturation is larger than 1.0 (oversaturated conditions), *Level of Service F* is chosen irrespective of the average delay value. This is also available as an option in SIDRA INTERSECTION.

Table 3: Level of Service definitions for intersections (vehicle movements)

Level of Service	Average delay per vehicle in seconds			
	NSW Method	Method for *SIDRA Standard Model*		
	All intersection types	Signalised intersections (1)	Roundabouts (2)	Sign control (1)
A	d ≤ 14.5	d ≤10	d ≤10	d ≤ 10
B	14.5 < d ≤ 28.5	10 < d ≤ 20	10 < d ≤ 20	10 < d ≤ 15
C	28.5 < d ≤ 42.5	20 < d ≤ 35	20 < d ≤ 35	15 < d ≤ 25
D	42.5 < d ≤ 56.5	35 < d ≤ 55	35 < d ≤ 50	25 < d ≤ 35
E	56.5 < d ≤ 70.5	55 < d ≤ 80	50 < d ≤ 70	35 < d ≤ 50
F	70.5 < d	80 < d	70 < d	50 < d

Notes:

(1) The standard level of service method used in SIDRA INTERSECTION for signalised intersections and sign control is based on the US Highway Capacity Manual (HCM 2000) method.

(2) The *Roundabout Level of Service* criteria have been developed as an option in SIDRA INTERSECTION.

HCM 2000 did not give a level of service table for roundabouts, and HCM 2010 suggested the use of the stop-sign control table for roundabouts. The author has discussed the HCM 2010 method for roundabouts and suggested the use of a separate level of service table for roundabouts (Akçelik 2011b).

Various level of service methods available as options in SIDRA INTERSECTION are summarised in *Table 3*. This includes the level of service method used by practitioners in New South Wales (RTA NSW 1993) which uses the same level of service criteria for all types of intersection (and hence differs from the use of different criteria for signalised and unsignalised intersections in the HCM).

The *NSW* method is more tolerant in terms of level of service criteria for sign-controlled intersections. For example, the Minor Road Right-Turn movement (North Approach, Lane 2) for the *HCM Model* case in *Figure 2* which has an average delay value of 53.4 s is allocated *Level of Service F* according to the HCM 2000 or HCM 2010 method whereas *Level of Service D* would be allocated according to the NSW method, which is a substantially different assessment.

The new edition of Austroads Traffic Management Guide Part 3 will include level of service tables for roundabouts and signals as well which will be consistent with SIDRA INTERSECTION. It is recommended that level of service criteria for different types of intersections (vehicles and pedestrians) are reviewed and the criteria recommended for use in Australia and New Zealand clarified.

PERFORMANCE MEASURES

It has been mentioned in the previous section that it is more common to use the degree of saturation, delay and queue length measures in intersection analysis practice in Australia and New Zealand. Various issues related to this practice should be mentioned.

Austroads Traffic Management Guide Part 12 (Austroads 2009b), in the section titled "Intersection Performance Criteria", does not appear to provide clear advice in relation to performance measures, and seems to be suggesting the use of the degree of saturation measure only for this purpose.

While it is a fundamental performance measure to consider, it would be poor practice to use the degree of saturation alone for intersection performance assessment. The results for the critical Minor Road Right-Turn movement (North Approach, Lane 2) for the *HCM Model* case in *Figure 2* provides a good example for this: while the degree of saturation (0.72) is satisfactory as it is below the target degree of saturation of 0.80, the average delay is very high (53.4s) resulting in *Level of Service F*.

The case of low degree of saturation but large delay is quite common as it can occur with large total opposing (major road) flow rates. Under these conditions, the proportion of time that opposing stream gaps are acceptable is low. This results in low capacity but since the demand flow rate is also low, the degree of saturation appears to be acceptable. Thus the degree of saturation alone does not reflect the difficulty experienced by minor road drivers.

The *Unblocked Time Ratio* parameter estimated by SIDRA INTERSECTION can be used to represent the driver difficulty in finding acceptable gaps. *Figure 3* shows how the *Unblocked Time Ratio* decreases with increasing total opposing flow rate for the critical Minor Road Right-Turn movement (North Approach, Lane 2) in the example shown in *Figure 2*. Gap acceptance parameter values for *Figure 3* are critical gap = 5.5 s and follow-up headway = 3.5 s for the *SIDRA Standard Model* and, and critical gap = 7.1 s and follow-up headway = 3.5 s for the *HCM Model.*

It is seen that the *Unblocked Time Ratio* (proportion of time opposing stream gaps are acceptable) is around 20 per cent when the opposing flow rate (adjusted for heavy vehicle effects) is around 800 to 1000 pcu/h.

SIDRA INTERSECTION determines capacity as the product of the *Unblocked Time Ratio* and the *saturation flow rate* parameter (see *Table 2*). This means that the *Unblocked Time Ratio* is similar to the green time ratio used in determining capacity for signalised intersections (Akçelik 1994). Thus, the effect of low values of the *Unblocked Time Ratio* is like the long red time delay at signalised intersections which can be experienced even when the degree of saturation is low.

It is therefore recommended strongly that the degree of saturation, delay and queue length parameters should be used *together* to assess intersection performance generally. For two-way sign control, the queue length is usually low since the demand flow rates for the critical minor road movements are usually low.

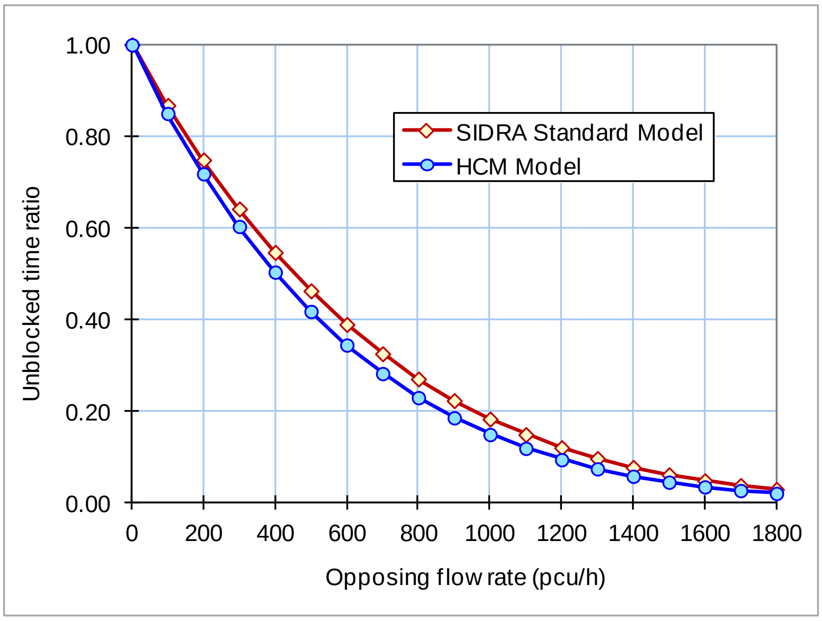


Figure 3: Unblocked time ratio (proportion of time opposing stream gaps are acceptable) example for Minor Road Right Turn (4-lane Major Road)

It is also important to note that the definitions of delay and queue length are important:

- HCM level of service definitions are based on *Control Delay* not *Stopped Delay* . There are issues related to this since the HCM delay equations do not include *Geometric Delays* whereas the SIDRA INTERSECTION method defines the Control Delay as sum of *Control Delay* and *Geometric Delay*.
- SIDRA INTERSECTION recommends that the *Back of Queue* rather than the *Cycle-Average Queue* should be used for all intersections consistently. The US HCM uses the former for signals but the latter for roundabouts and sign control.

For more detailed discussion on issues related to performance measures and level of service, refer to a recent paper by the author (Akçelik 2011b).

CONCLUSIONS AND RECOMMENDATIONS

This paper has reviewed the guidance given in the Austroads guides and the US Highway Capacity Manual (HCM) for the choice of driver gap acceptance parameters (critical gap and follow-up headway) affecting the capacity of sign-controlled intersections. It is recommended that the Austroads guides present a better recognition of the importance of unsignalised intersection analysis, especially in relation to traffic impact assessment, and provide better guidance to avoid controversies that may occur from assumptions involved in determining gap acceptance parameters for sign-control analysis.

While it is recognized that the gap acceptance parameter values given in the HCM are based on extensive surveys in the USA, it is suggested that the traditional *Austroads - SIDRA Standard* gap acceptance parameters and the associated capacity and performance models are more appropriate for driving conditions in Australia and New Zealand. However, research aimed at refining the *Austroads - SIDRA Standard Model* gap acceptance parameters for improved calibration to represent driver behaviour in Australia and New Zealand is recommended strongly.

Research on this topic should take into account the relationship between driver gap acceptance parameters and intersection geometry (number of lanes on major road, T intersection and other variations in intersection configuration), differences in driver gap acceptance behaviour between give-way and stop sign control, decreases in critical gap and follow-up headway values with increasing opposing flow rate, and the effect of such factors as heavy vehicles, opposing (major road) traffic speed, road grade (both minor road and major road) and sight distance restrictions (e.g. due to parking on major road).

The conflicting advice about gap-acceptance parameters given in AUSTROADS Road Design Guide Part 4A (Austroads 2010) based on traditional Australian parameters and Traffic Management Guide Part 3 (Austroads 2009a) based on the US Highway Capacity Manual (TRB 2000, TRB 2010) has been noted. A new edition of the Traffic Management Guide Part 3 will provide advice consistent with the Road Design Guide Part 4A. The revised guide will also clarify the level of service concepts for consistent definitions and criteria to be used in practice in Australia and New Zealand.

The simple rule of thumb "*the ratio of follow-up headway to critical gap is about 0.6*" has been shown to be valid, and it has been suggested that this could be useful in practice for estimating the critical gap as *Critical Gap = Follow-up Headway / 0.6* when the gap acceptance survey is limited to measuring the follow-up headway.

It is also recommended that:

- level of service criteria for different types of intersections (vehicles and pedestrians) are reviewed and criteria recommended for use in Australia and New Zealand are clarified in all Austroads Traffic Management guides, especially in view of the different method used in New South Wales;
- a description of the widely-used bunched exponential model of headway distributions is included in Austroads Traffic Management Guide Part 2 (Austroads 2008);

- the section titled "Intersection Performance Criteria" in Austroads Traffic Management Guide Part 12 (Austroads 2009b) is improved to provide clear advice in relation to performance measures adopting the suggestion that the degree of saturation, delay and queue length parameters should be used *together* to assess intersection performance generally.

It is suggested that the capacity analysis methods developed in Australia and New Zealand for signalised intersections, roundabouts and sign-controlled intersections can be considered to be more advanced than those offered in the HCM in many ways including the use of *lane-based* analysis for sign-controlled intersections (instead of analysis by *lane groups* in the HCM), modelling of give-way sign control (not just stop control), the use of a bunched exponential model of headway distributions and the use of consistent definitions of delay and queue length including the use of *back of queue* consistently for all types of intersection. It is expected that Austroads Traffic Management and Road Design guides will continue to use the methods developed in Australia and New Zealand while adopting useful developments from the US Highway Capacity Manual.

A recent report by Turner, et al (2012) presenting findings of research conducted in New Zealand indicated that the default critical gap parameters used in SIDRA INTERSECTION match those found in surveys reasonably well.

Also refer to a recent paper by the author (Akçelik 2012) describing a new method developed for the SIDRA INTERSECTION software for determining the critical gap and follow-up headway parameters for two-way stop and give-way sign controlled intersections as a function of intersection geometry, control and flow conditions.

REFERENCES

AKCELIK AND ASSOCIATES (2011). *SIDRA INTERSECTION User Guide for Version 5.1*. Akcelik and Associates Pty Ltd, Melbourne, Australia.

AKÇELIK, R. (1994). Gap acceptance modelling by traffic signal analogy. *Traffic Engineering and Control*, 35 (9), pp 498-506.

AKÇELIK, R. (2005). Roundabout Model Calibration Issues and a Case Study. *TRB National Roundabout Conference*, Vail, Colorado, USA.

AKÇELIK, R. (2007). A Review of Gap-Acceptance Capacity Models. Paper presented at the *29th Conference of Australian Institutes of Transport Research (CAITR)*, University of South Australia, Adelaide, Australia, 2007.

AKÇELIK, R. (2011a). Some common and differing aspects of alternative models for roundabout capacity and performance estimation. Paper presented at the *International Roundabout Conference,* Transportation Research Board, Carmel, Indiana, USA.

AKÇELIK, R. (2011b). An Assessment of the Highway Capacity Manual 2010 Roundabout Capacity Model. Paper presented at the *TRB International Roundabout Conference*, Carmel, Indiana, USA, 2011.

AKÇELIK, R. (2012). An Improved Method for Estimating Sign-Controlled Intersection Capacity. Paper to be presented at the New Zealand Modelling User Group NZMUGS 2012 Conference, Auckland, 10-11 Sep 2012.

AKÇELIK, R. and BESLEY, M. (2005). Differences between the AUSTROADS Roundabout Guide and aaSIDRA roundabout analysis methods. *Road and Transport Research* 14(1), pp 44-64.

AKÇELIK, R. and CHUNG, E. (1994a). Calibration of the bunched exponential distribution of arrival headways. *Road and Transport Research* 3 (1), pp 42-59.

AKÇELIK, R. and CHUNG, E. (1994b). Traffic performance models for unsignalised intersections and fixed-time signals. In: R. Akçelik (ed.), *Proceedings of the Second International Symposium on Highway Capacity*, Sydney, 1994, Volume I, Australian Road Research Board Ltd, Melbourne, pp. 21-50.

AKÇELIK, R., CHUNG, E. and BESLEY M. (1997). Analysis of Roundabout Performance by Modelling Approach Flow Interactions. In: Kyte, M. (Ed.), *Proceedings of the Third International Symposium on Intersections Without Traffic Signals*, Portland, Oregon, USA, University of Idaho, Moscow, Idaho, USA, pp 15-25.

AKÇELIK, R. and TROUTBECK, R. (1991). Implementation of the Australian Roundabout Analysis Method in SIDRA. In: U. Brannolte (Ed.), *Highway Capacity and Level of Service – Proc. of the International Symposium on Highway Capacity*, Karlsruhe. A.A. Balkema, Rotterdam, pp 17-34.

AUSTROADS (1988). *Roadway Capacity*. Guide to Traffic Engineering Practice, Part 2. Association of Australian State Road and Transport Authorities, Sydney.

AUSTROADS (2002). *Urban Road Design - Guide to the Geometric Design of Major Urban Roads*. Association of Australian State Road and Transport Authorities, Sydney.

AUSTROADS (2005). *Intersections at Grade*. Guide to Traffic Engineering Practice, Part 5. Association of Australian State Road and Transport Authorities, Sydney.

AUSTROADS (2007). *Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings*. AGTM06-07. Association of Australian State Road and Transport Authorities, Sydney.

AUSTROADS (2008). *Guide to Traffic Management Part 2: Traffic Theory*. AGTM02-08. Association of Australian State Road and Transport Authorities, Sydney.

AUSTROADS (2009a). *Guide to Traffic Management Part 3: Traffic Studies and Analysis*. AGTM03-09. Association of Australian State Road and Transport Authorities, Sydney.

AUSTROADS (2009b). *Guide to Traffic Management Part 12: Traffic Impacts of Developments*. AGTM12-09. Association of Australian State Road and Transport Authorities, Sydney.

AUSTROADS (2010). *Guide to Road Design Part 4A: Unsignalised and Signalised Intersections*. AGRD04A-10. Association of Australian State Road and Transport Authorities, Sydney.

COWAN, R.J. (1975). Useful headway models. *Transportation Research* 9 (6), pp. 371-375.

LUTTINEN, R.T. (1999). Properties of Cowan's M3 headway distribution. T*ransportation Research Record* 1678, pp 189-196.

RTA NSW (1993). *Guide to Traffic Generating Developments*. Roads and Traffic Authority of New South Wales, Sydney, Australia.

SULLIVAN, D. and TROUTBECK, R.J. (1993). *Relationship Between the Proportion of Free Vehicle and Flow Rate on Arterial Roads*. Research Report 93-21. Physical Infrastructure Centre, Queensland University of Technology, Brisbane, Australia.

TRB (2000). *Highway Capacity Manual*. Transportation Research Board, National Research Council, Washington, DC, USA. ("HCM 2000")

TRB (2010). *Highway Capacity Manual*. Transportation Research Board, National Research Council, Washington, DC, USA. ("HCM 2010")

TROUTBECK, R.J. (1989). *Evaluating the Performance of a Roundabout*. Special Report SR 45. ARRB Transport Research Ltd, Vermont South, Australia.

TURNER, S., SINGH, R., SOPER, M. and SUN, D. (2012). *Gap Acceptance Road Safety Modelling: Pilot Study*. NZ Transport Agency Research Report 480. Beca Infrastructure Limited, Christchurch, New Zealand.

VASCONCELOS, A.L.P., SECO, Á.J.d.M. and SILVA, A.B. (2011). Estimating the parameters of Cowan's M3 headway distribution for roundabout capacity analyses. *The Baltic Journal of Road and Bridge Engineering* (paper accepted for publication).

AUTHOR BIOGRAPHY

Dr Rahmi Akçelik is a leading scientist and software developer with 40 years of practical, research and training experience in the area of traffic engineering, management and control. He is Director of Akcelik and Associates Pty Ltd (trading as SIDRA SOLUTIONS). Dr Akçelik has about 300 technical publications in his area of expertise. He is the author of the SIDRA INTERSECTION and SIDRA TRIP software packages. Dr Akçelik served as member of the US Transportation Research Board Committees on Highway Capacity and Quality of Service, and Traffic Signal Systems. He has contributed to various Austroads Guides and the US Highway Capacity Manual. He has trained several thousand professionals in about 200 workshops, courses and seminars. Awards received by Dr Akçelik include the 1999 Clunies Ross National Science and Technology award for outstanding contribution to the application of science and technology, the ITE (USA) 1986 Transportation Energy Conservation Award, and the ITE (Australia & New Zealand) 2008 Contribution to the Transportation Profession Award.

Email: rahmi.akcelik@sidrasolutions.com
Mail: P O Box 1075G, Greythorn Vic 3104, Australia

