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## REPRINT

# An Improved Method for Estimating Sign-Controlled Intersection Capacity

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### NOTE:

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


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# AN IMPROVED METHOD FOR ESTIMATING SIGN-CONTROLLED INTERSECTION CAPACITY

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## Abstract

The capacity, performance and level of service assessment of unsignalized intersections controlled by stop and give-way signs has a 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 assumptions made about the values of parameters representing driver gap acceptance behaviour at sign controlled intersections. This paper complements a paper to be presented at the ARRB 25th Conference (Akçelik 2012). The gap acceptance parameters recommended by the Austroads Road Design and Traffic Management Guides and the US Highway Capacity Manual are discussed. 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 is described. The method allows for the relationship between driver gap acceptance parameters and intersection geometry (number of lanes on the major road, one-way major road, T-intersection), minor road grade, reduced gap acceptance parameters for two stages of a staged crossing movement, special consideration of U-turn movements, differences in driver gap acceptance behaviour between give-way and stop sign control, decreases in critical gap and follow-up headway values with increased opposing flow rate, and the effect of movement classes (light vehicles, heavy vehicles, buses, bicycles, and so on). Other aspects of the new method for gap acceptance modelling are also discussed briefly. An example is given to demonstrate significant differences that may occur in gap acceptance parameters and the corresponding capacity and performance results under different geometry and control scenarios.

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## 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, Parts 3, 6 and 12 (Austroads 2007, 2009a,b) have varying approaches in relation to the importance of sign-controlled intersections, both recognizing it and at the same time playing it down, as discussed in a recent paper by the author (Akçelik 2012). Conflicting advice about gap acceptance parameters in Road Design Guide Part 4A and Traffic Management Guide Part 3 (Austroads 2009a, 2010) was also identified. Austroads Traffic Management Guide Parts 3 and 6 have been under review and a more consistent approach is expected in new editions of these publications.

In fact, the capacity and performance assessment of sign-controlled intersections has a special importance in the context of traffic impact assessment where choices between sign controlled intersections vs roundabout or signalized intersections can be controversial due to significant cost differences. Such controversy can often be traced back to assumptions made by traffic analysts about the values of parameters representing 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.

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.

The gap acceptance parameters recommended by the Austroads Road Design and Traffic Management Guides and the US Highway Capacity Manual are discussed, and a new method is presented for determining gap acceptance parameters (critical gap and follow-up headway) for minor road and major road movements for two-way stop and give-way sign controlled intersections. An example is given to demonstrate significant differences that may occur in gap acceptance parameters and the corresponding capacity and performance results under different geometry and control scenarios.

This paper assumes that the reader has a basic knowledge of gap acceptance modelling.

## 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 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 2* compares the default gap acceptance parameters used in SIDRA INTERSECTION for the *SIDRA Standard* model for Australia and New Zealand and the *SIDRA HCM model* for USA. This applies to a 4-way intersection with a 4-lane major road.

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

- The gap acceptance parameters depend on the intersection geometry, in particular, 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 simple rule of thumb "*the ratio of follow-up headway to critical gap is about 0.6*" is confirmed by the values given in *Tables 1 and 2* as well as the roundabout data collected during the Australian roundabout research (for detailed discussion, *see* Akçelik *2012)*.

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

The recent paper by the author (Akçelik 2012) presented an example (using SIDRA INTERSECTION) which demonstrated how the *SIDRA Standard* and the *SIDRA HCM* gave capacity estimates (therefore degrees of saturation, delay, queue length and level of service values) which differed substantially. The paper suggested that the *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, and recommended research aimed at refining the *Austroads - SIDRA Standard Model* gap acceptance parameters for improved calibration to represent Australian and New Zealand driving conditions.

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.

**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: Default gap acceptance parameters for the *Standard Model* and the *HCM Model* in SIDRA INTERSECTION: 4-way intersection with 4-lane major road**

| | SIDRA Standard Model | | SIDRA HCM Model | |
|---|---|---|---|---|
| **STOP Sign** | $t_c$ | $t_f$ | $t_c$ | $t_f$ |
| Minor Road Left Turn | 5.0 | 3.0 | 7.5 | 3.5 |
| Minor Road Through | 6.5 | 3.5 | 6.5 | 4.0 |
| Minor Road Right Turn | 7.0 | 4.0 | 6.9 | 3.3 |
| Major Road Turn | 4.5 | 2.5 | 4.1 | 2.2 |

**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).

Major Road Turn is *right* turn for driving on the left-hand side of the road or *left* turn for driving on the right-hand side of the road

A new method to provide a more systematic approach to the estimation of critical gap and follow-up values for two-way sign control is described in the next section. The method makes use of the information available in the current Austroads guides and the HCM 2010 regarding the factors that affect critical gap and follow-up headway parameters. It could be improved by further research as suggested above.

## A New Method for Determining Gap Acceptance Parameters

A new method has been developed for determining gap acceptance parameters (critical gap and follow-up headway) for minor road and major road movements for two-way stop and give-way sign controlled intersections as a function of intersection geometry, control and flow conditions. The method allows for:

- the relationship between driver gap acceptance parameters and intersection geometry (number of lanes on the major road, one-way major road, T-intersection),
- minor road grade,
- reduced gap acceptance parameters for two stages of a staged crossing movement,
- special consideration of U-turn movements,
- differences in driver gap acceptance behaviour between give-way and stop sign control,
- decreases in critical gap and follow-up headway values with increased opposing flow rate,
- the effect of movement classes (light vehicles, heavy vehicles, buses, bicycles, and so on).

The method is being implemented in SIDRA INTERSECTION Version 6 and will be documented in detail in the User Guide with the release of the software.

The method treats the user input values of the critical gap and follow-up headway parameters as ***base values*** defined as representing ***passenger cars*** subject to ***stop-sign control*** under ***low (near-zero) opposing flow*** conditions at an intersection with ***standard geometry***.

***Standard geometry*** is defined as 4-way intersection configuration, two-way major road with a total number of 4 lanes, zero minor road grade, full (one-stage) crossing, and not a U-turn movement. The default values of the base values of the critical gap and follow-up headway parameters for the SIDRA Standard and SIDRA HCM models are as given in *Table 2*.

The new method involves automatic adjustments to the base values for:

- ***number of major road lanes***,
- ***geometry and control*** including
    - one-way major road (for minor road through and critical turning movements),
    - T intersection (for minor road critical turning movements),
    - minor road grade,
    - staged crossing (minor road through and critical turning movements) for two-way major road,
    - major road U-turn movements, and
    - give-way (yield) sign control,
- ***reduction with increasing opposing flow rate*** (options for level of reduction: None, Low, Medium, High), and
- ***gap acceptance factor*** and ***opposing vehicle factor*** parameters to account for different vehicle characteristics (movement classes) in entry lanes and opposing lanes, respectively.

The term *minor road critical turn* refers to the *right turn* for driving on the left-hand side of the road or the *left turn* for driving on the right-hand side of the road.

Some of the parameters listed above were accounted for via templates in previous versions of the software. In the new method, these adjustments will be made automatically so that changes made to the intersection geometry and control conditions are taken into account without additional user effort. This means a more standardized method that overcomes problems with user-specified constant parameter values which become unsuitable when changes are made, for example, to the intersection geometry and control.

The critical gap and follow-up headway values are adjusted for specific Movement Classes (Light Vehicles, Heavy Vehicles, Buses, etc) using the ***Gap Acceptance Factor*** for entry lanes and the ***Opposing Vehicle Factor*** for opposing lanes. The method is a generalisation of the Heavy Vehicle Adjustment method used in previous versions of the software. The differences from the method used in previous versions of SIDRA INTERSECTION are:

(i) The ***HVE (Gap Acceptance)*** parameter used in previous versions has been separated into the ***Gap Acceptance Factor*** and the ***Opposing Vehicle Factor*** parameters. The ***Gap Acceptance Factor*** is used to adjust the critical gap and follow-up headway parameters for the entry lane whereas the ***Opposing Vehicle Factor*** is used for adjusting the opposing lane flow rate. The default values are 2.0 for Heavy Vehicles and Buses, and 1.0 for Light Vehicles for both parameters.

(ii) In previous versions, the parameter ***HV Method for Gap Acceptance*** was available with two options: "Include HV Effect if Above 5%" and "Include HV Effect for All Percentages". In Version 6 only the "Include HV Effect for All Percentages" method will be used. This will apply to gap acceptance modelling for signalised intersections and roundabouts as well.

## Other Model Improvements

There will be other significant changes to the two-way sign control analysis method in SIDRA INTERSECTION 6. These include:

(i) ***Intra-Bunch Headway Adjustment for Multi-Lane Streams with Unequal Lane Flows***: A method similar to that used for roundabout circulating streams is applied to allow for unequal lane use by opposing movements in determining the intra-bunch headway value for multi-lane opposing streams at two-way sign controlled and signalised intersections. This adjustment ensures improved continuity of capacity predictions in response to changes in opposing lane flow distributions, especially in cases of low lane utilisation ratio.

(ii) ***Percent Opposed by Nearest Lane Only***: This parameter is used to specify the percentage of the minor road movement giving way to the nearest lane only. For example, Percent Opposed by Nearest Lane Only = 80% means that 80% of the minor road movement gives way to the nearest lane only, and 20 % gives way to all opposing traffic lanes.

(iii) ***Gap Acceptance Data for Specific Applications***: User-specified gap acceptance parameter values will be allowed for Turn on Red for signalised intersections, Merging and Zipper Merging (general), and Slip Lanes at AWSC Sites.

It is also likely that ***pedestrians at two-way sign control*** will be included in Version 6. Pedestrian movements will contribute to opposing flow rates for vehicle movements as described in the HCM 2010.

## An Example

*Figure 1* shows an example (using SIDRA INTERSECTION) which demonstrates significant differences that may occur in gap acceptance parameters and resulting capacity and performance under different geometry and control scenarios. The example is for driving on the left-hand side of the road and uses the SIDRA Standard model parameters.

Two scenarios are defined. Both scenarios have the following conditions in common:

- two-way major road,
- T-Intersection (affecting minor road right-turn (critical) movement), and
- one-stage crossing.

The following conditions differ between the two scenarios:

| | Scenario 1 | Scenario 2 |
|---|---|---|
| Sign Control | Stop | Give-way |
| Major Road Number of Lanes | 4 | 3 |
| Minor Road Grade (%) | 0% | -3% |
| Level of Reduction with Opposing Flow Rate | None | Low |

Note that the number of major road lanes is determined at the intersection considering the minor road gap acceptance process.

The values of critical gap and follow-up headway for the opposed turns under the two Scenarios are summarised in *Table 3*. It is seen that there are significant differences between the values for the two scenarios (around 20% to 30%).

As seen in *Figure 2,* the differences in critical gap and follow-up headway values lead to substantial differences in capacity, performance and level of service results for the critical minor road movement (right turn from North approach).

**Table 3: Critical gap and follow-up headway values for opposed turns under the two scenarios shown in *Figure 1***

| | ***Scenario 1*** (4-lane Major Road, Stop Control) | | | ***Scenario 2*** (3-lane Major Road, Give-way Control) | | |
|---|---|---|---|---|---|---|
| | $t_c$ | $t_f$ | $t_f / t_c$ | $t_c$ | $t_f$ | $t_f / t_c$ |
| Minor Road Left Turn | 5.5 | 3.3 | 0.60 | 3.8 | 2.3 | 0.63 |
| Minor Road Right Turn | 6.9 | 4.0 | 0.57 | 5.2 | 3.1 | 0.74 |
| Major Road Right Turn | 5.0 | 2.8 | 0.56 | 3.8 | 2.1 | 0.57 |

## Concluding Remarks

More detailed documentation of the method described in this paper will be available in the User Guide with the release of the software. The method described is based on the information available in Austroads guides and the US Highway Capacity Manual regarding the factors that affect critical gap and follow-up headway parameters. It aims to achieve a more standardized method to eliminate data that become inappropriate when changes are made to intersection and control conditions. The method could be improved by further research into critical gap and follow-up headway parameters at two-way sign-controlled intersections in order to establish parameter values (base values and adjustment parameters) appropriate for local traffic conditions.

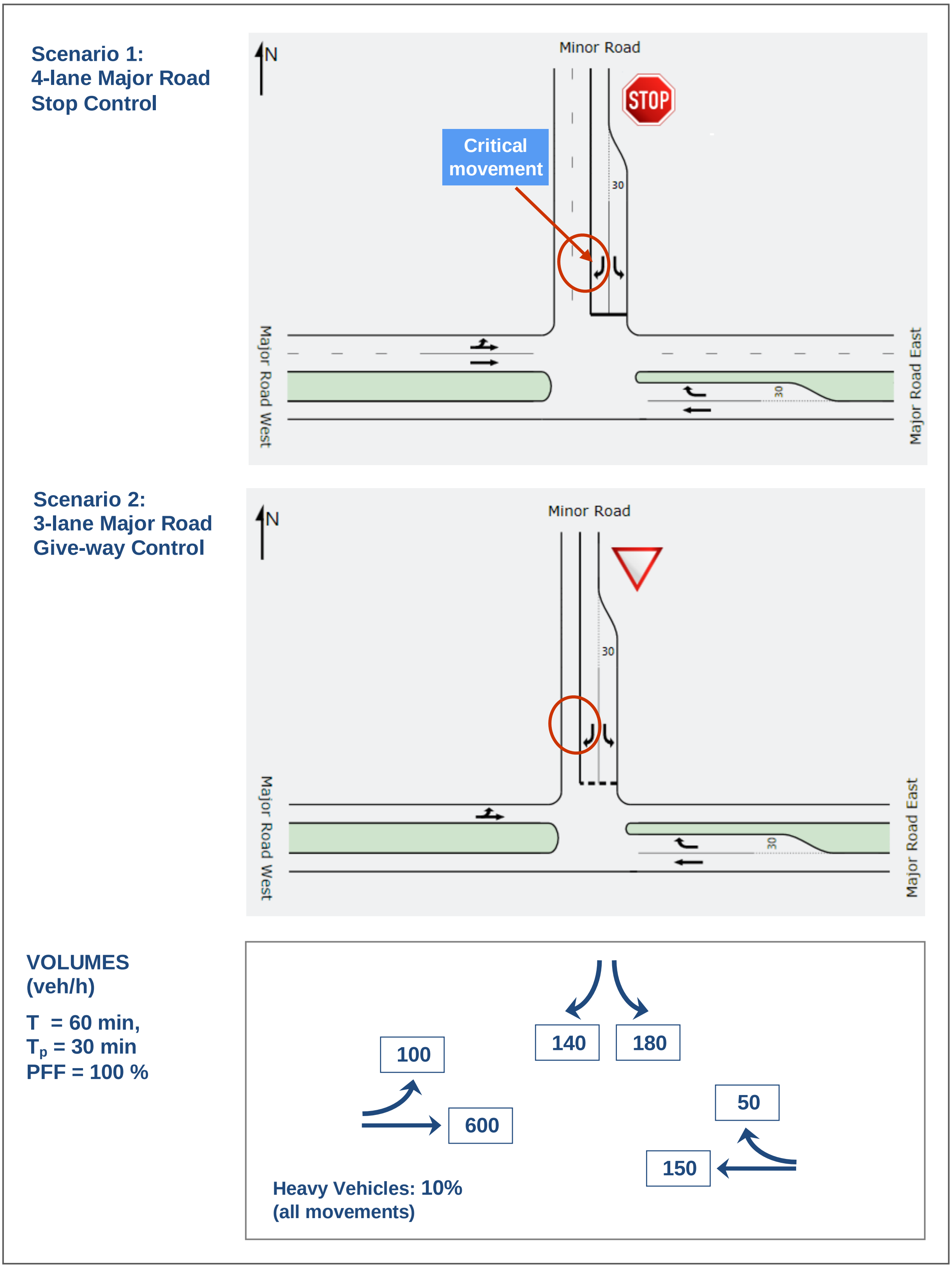


***Figure 1: Example to demonstrate differences in gap acceptance parameters for two different geometry - layout scenarios***

## Scenario 1: 4-lane Major Road, Stop Control

### LANE SUMMARY

**Site: Scenario 1: Stop 4-Lane Major Rd**

T intersection with 4-lane major road (Stop control)
Stop (Two-Way)

**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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| East: Major Road East | | | | | | | | | | | | |
| Lane 1 | 0 | 150 | 0 | 150 | 10.0 | 1831 | 0.082 | 100 | 0.0 | LOS A | 0.0 | 0.0 |
| Lane 2 | 0 | 0 | 100 | 100 | 10.0 | 512 | 0.195 | 100 | 14.6 | LOS B | 0.7 | 5.6 |
| Approach | 0 | 150 | 100 | 250 | 10.0 | | 0.195 | | 5.8 | NA | 0.7 | 5.6 |
| North: Minor Road | | | | | | | | | | | | |
| Lane 1 | 180 | 0 | 0 | 180 | 10.0 | 426 | 0.422 | 100 | 20.9 | LOS C | 2.0 | 15.3 |
| Lane 2 | 0 | 0 | 140 | 140 | 10.0 | **171** | **0.817** | **100** | **63.8** | **LOS F** | **5.2** | **39.8** |
| Approach | 180 | 0 | 140 | 320 | 10.0 | | 0.817 | | 39.7 | LOS E | 5.2 | 39.8 |
| West: Major Road West | | | | | | | | | | | | |
| Lane 1 | 100 | 247 | 0 | 347 | 10.0 | 1802 | 0.193 | 100 | 2.5 | LOS A | 0.0 | 0.0 |
| Lane 2 | 0 | 353 | 0 | 353 | 10.0 | 1831 | 0.193 | 100 | 0.0 | LOS A | 0.0 | 0.0 |
| Approach | 100 | 600 | 0 | 700 | 10.0 | | 0.193 | | 1.2 | NA | 0.0 | 0.0 |
| Intersection | | | | 1270 | 10.0 | | 0.817 | | 11.8 | NA | 5.2 | 39.8 |

## Scenario 2: 3-lane Major Road, Give-way Control

### LANE SUMMARY

**Site: Scenario 2: Giveway 3-Lane Major Rd**

T intersection with 3-lane major road (Give-Way control)
Giveway / Yield (Two-Way)

**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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| East: Major Road East | | | | | | | | | | | | |
| Lane 1 | 0 | 150 | 0 | 150 | 10.0 | 1831 | 0.082 | 100 | 0.0 | LOS A | 0.0 | 0.0 |
| Lane 2 | 0 | 0 | 100 | 100 | 10.0 | 744 | 0.134 | 100 | 12.4 | LOS B | 0.5 | 3.7 |
| Approach | 0 | 150 | 100 | 250 | 10.0 | | 0.134 | | 5.0 | NA | 0.5 | 3.7 |
| North: Minor Road | | | | | | | | | | | | |
| Lane 1 | 180 | 0 | 0 | 180 | 10.0 | 748 | 0.241 | 100 | 12.2 | LOS B | 0.9 | 6.8 |
| Lane 2 | 0 | 0 | 140 | 140 | 10.0 | **349** | **0.402** | **100** | **20.9** | **LOS C** | **1.7** | **13.1** |
| Approach | 180 | 0 | 140 | 320 | 10.0 | | 0.402 | | 16.0 | LOS C | 1.7 | 13.1 |
| West: Major Road West | | | | | | | | | | | | |
| Lane 1 | 100 | 600 | 0 | 700 | 10.0 | 1816 | 0.385 | 100 | 1.2 | LOS A | 0.0 | 0.0 |
| Approach | 100 | 600 | 0 | 700 | 10.0 | | 0.385 | | 1.2 | NA | 0.0 | 0.0 |
| Intersection | | | | 1270 | 10.0 | | 0.402 | | 5.7 | NA | 1.7 | 13.1 |

***Figure 2: SIDRA INTERSECTION example showing differences in capacity and performance estimates using gap acceptance parameters for the two scenarios shown in Figure 1***

## References

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

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

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

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. and CHUNG, E. (1994). 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., CHRISTENSEN, B. and CHUNG, E. (1998). A comparison of three delay models for sign-controlled intersections. In: *Third International Symposium on Highway Capacity*, Copenhagen, Denmark, 22-27 June 1998, Volume 1 (Edited by R. Rysgaard). Road Directorate, Ministry of Transport, Denmark, pp 35-56.

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 (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.

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

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.