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ROUNDABOUTS - Comments on the aaSIDRA model and the TRL (UK) linear regression model

by R. Akçelik

In the USA where roundabouts are relatively new, there has been some controversy regarding the aaSIDRA model and the TRL (UK) regression model for estimating the capacity of roundabouts.. This note presents Dr Akçelik's views on the subject.

This update includes discussions on related issues of priority sharing and priority emphasis, model calibration in aaSIDRA, and reasons for shortcomings of the TRL (UK) regression model.

In relation to this discussion, various websites promoting the RODEL software package in the USA include misleading statements about the aaSIDRA method for roundabout capacity analysis. Such statements present aaSIDRA as "simple theoretical gap-acceptance model" using arguments based on very old articles, which are not relevant to aaSIDRA. In addition to the discussion in this document, refer to the following publications presenting detailed discussions of related issues:

AKÇELIK, R. (2003). A Roundabout Case Study Comparing Capacity Estimates from Alternative Analytical Models. Paper presented at the 2nd Urban Street Symposium, Anaheim, California, USA, 28-30 July 2003.

AKÇELIK, R. (1997). Lane-by-lane modelling of unequal lane use and flares at roundabouts and signalised intersections: the SIDRA solution. Traffic Engineering and Control, 38 (7/8), pp 388-399.

These papers are available for download at http://www.aatraffic.com/downloads.htm

A new paper presenting model comparisons will be made available during August 2004.

It is not who is right, but what is right, that is important.

Thomas Huxley

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THEORETICAL OR EMPIRICAL?

The suggestion heard frequently about roundabout models that "the British model is EMPIRICAL and the Australian model (SIDRA) is THEORETICAL" is based on a widespread misconception promoted at various websites. The difference between the TRL (UK) regression model and the aaSIDRA model is not between an empirical model and a theoretical model but between "a model not based on any traffic theory (purely empirical)" and "a model BASED ON gap-acceptance theory (but still empirical)". The SIDRA gap-acceptance model parameters are based on empirical models derived from a large database of roundabout survey results.

If the SIDRA model is theoretical, MICROSIMULATION models are also theoretical. But instead, it is more accurate to state that the analytical SIDRA model and the microsimulation models are BASED ON traffic flow theory. For example, car-following theory is one of the important elements of microsimulation models. In a particular microsimulation software package, the parameters of the car-following algorithms can be based on empirical studies or can be based on guesswork! Application of the car-following method to different traffic environments and different traffic conditions (e.g. cruising vs queue discharge) is an important issue. Direct observation of driver car-following behaviour and the associated speed-flow relationships based on car-following theory are relevant (vast literature exists on this).

An analogy: A researcher may develop a linear regression model based on observation of speeds and volumes on a freeway or highway. This model may be based on statistical (regression) techniques without any basis in traffic theory. The statistical techniques may be used to prove that the relationship is linear for the particular data set. It is then a purely empirical REGRESSION model. Instead, the researcher may use the same field data to calibrate a non-linear speed-flow relationship based on car-following theory. The resulting model is not purely theoretical or purely empirical. It is based on traffic flow theory and it is empirical. This analogy may help to explain the difference between the existing roundabout models.

Implementation and continued success of modern roundabouts in the USA, as in many countries around the world, depend on improved understanding of major factors that affect the operation of roundabouts. Like all other traffic control devices, the road and intersection geometry, driver behavior, light and heavy vehicle characteristics, behavior and requirements of other road users, traffic flow characteristics and operation of traffic control to resolve vehicle to vehicle conflicts (as well as vehicle to pedestrian conflicts) are important factors that influence roundabout performance. Vehicle traffic flow characteristics represent collective behavior of vehicles in a traffic stream as relevant to, for example, car following, queue forming and queue discharge conditions.

The control rule at modern roundabouts is the yield (give-way) rule. Analytical and microsimulation models use gap-acceptance modeling to emulate behavior of entering drivers yielding to circulating vehicles, i.e. finding a safe gap (headway) before entering a roundabout. This behavior is affected by roundabout geometry (size, entry and circulating lane widths, entry angle, approach and circulating lane arrangements, etc.) which influences such important parameters as sight distance, speed and lane use. The headway distribution of vehicles in the circulating stream (influenced by queuing on the approach road and effective use of circulating lanes at multi-lane roundabouts) is the controlling variable that determines the ability of approach vehicles to enter the circulating road. This is as important as the critical gap (headway) and follow-up headway parameters of the entry stream in determining roundabout capacity, performance (delay, queue length, number of stop-starts, fuel consumption, emissions, and operating cost) and level of service.

Thus, complex interactions among the geometry, driver behavior, traffic stream and control factors determine the roundabout capacity and performance. The level of traffic performance itself can influence driver behavior, increasing the complexity of modeling roundabout operations.

For the practitioner, it is important to understand the reasons behind systematic differences between estimates from different models so that judgment can be made about accepting or rejecting results of a particular model, or a given model can be calibrated, in a specific situation.

Current discussion on roundabout models appears to concentrate on capacity alone without much discussion of performance (delay, queue length, emissions, etc). **A simplistic view of roundabout capacity models considers analytical models only, and classifies them into two mutually exclusive categories, namely "theoretical (gap-acceptance) only" and "empirical only".** This view presents the US Highway Capacity Manual and Australian (aaSIDRA, AUSTROADS, NAASRA) gap-acceptance based models *(1-12)* as belonging to the first group and a linear regression model developed by TRL (UK) *(13-19)* as belonging to the second group. As the use of roundabouts became more common in the USA, this narrow view resulted in some controversy as competing software packages based on the two categories, namely aaSIDRA representing the gap-acceptance methodology and the ARCADY and RODEL representing the TRL linear regression model, presented significant differences in some cases *(10,20-22)*. The issue, while narrowly focused, has been discussed widely among traffic engineering professionals in the USA *(23, 24)*, and has already been a subject of debate among researchers and practitioners *(25-30)*. The author has presented various thoughts about the limitations of the Australian gap-acceptance models as well as the UK linear regression model previously *(10,22)*.

In fact, the difference is between a *linear regression* model and a *gap-acceptance based* model not between an *empirical* and a *theoretical* model. The current Australian and US HCM models based on gap-acceptance modeling do have an empirical base *(4,6)*. The *Australian* gap-acceptance model *(7,8,10,11)* uses gap-acceptance parameters calibrated by field surveys conducted at a large number of modern roundabouts in Australia *(6)*. *Table 1* shows a summary of field data at 55 roundabout lanes used for calibrating the Australian gap-acceptance based capacity and performance models.

Table 1 - Summary of field data at 55 roundabout lanes used for calibrating the Australian gap-acceptance based capacity and performance models (points not used in critical gap and follow-up headway regressions not included)

	Total entry width (m)	No. of entry lanes	Average entry lane width (m)	Circul. width (m)	Inscribed Diameter (m)	Entry radius (m)	Conflict angle (°)
Minimum	3.7	1	3.20	6.5	16	4	0
Maximum	12.5	3	5.50	12.0	220	∞	80
Average	8.1	2	3.84	9.6	56	39	29
15th percentile	6.4	2	3.34	8.0	28	10	0
85th percentile	10.5	3	4.48	11.9	70	39.8	50
Count	55	55	55	55	55	55	55
	Follow-up Headway (s)	Critical Gap (s)	Crit. Gap / Fol. Hw Ratio	Circul. flow (veh/h)	Total entry flow (veh/h)	Dominant lane flow (veh/h)	Subdom. lane flow (veh/h)
Minimum	0.80	1.90	1.09	225	369	274	73
Maximum	3.55	7.40	3.46	2648	3342	2131	1211
Average	2.04	3.45	1.75	1066	1284	796	501
15th percentile	1.32	2.53	1.26	446	690	467	224
85th percentile	2.65	4.51	2.31	1903	1794	1002	732
Count	55	55	55	55	55	55	55

There are significant differences between various gap-acceptance models, e.g. a model that uses fixed gap-acceptance parameters *(1,5)* and another model that determines gap-acceptance parameters as a function of roundabout geometry and traffic flow conditions using empirical relationships *(6-8,12)*. Similarly, there is no reason why a linear regression model could not be based on a lane-by-lane *(12,29,30)* or lane group *(1)* approach and include other parameters related to driver behavior rather than treating all traffic using the approach road as a whole and being limited to roundabout geometry parameters only *(13-19,29,30)*. Thus, it is necessary to investigate the available models in a general framework, considering all aspects of models relevant to roundabout operation. Microsimulation models should be included in this general framework of discussion since most modeling issues relevant to analytical models are relevant to microsimulation models as well *(31)*.

Figure 1 - An example of dominant entry flow at a modern roundabout in Australia (photo modified for driving on the right-hand side of the road)

PRIORITY SHARING AND PRIORITY EMPHASIS

An important factor that influences the capacity and performance of entry stream is the origin-destination pattern of arrival (demand) flows as related to the approach and circulating lane use (see *Figure 1*). This impacts headway distributions of circulating streams, and as a result, affects approach lane capacities and performance. This factor is not taken into account in the TRL (UK) linear regression model, the HCM and the Australian gap-acceptance models other than aaSIDRA, or any other regression or gap-acceptance models known to the author. Various case studies of unbalanced flows have been reported by the author in previous publications *(10,20-22,32)*.

The limited-priority method of gap-acceptance modeling described by Troutbeck and Kako *(33-35)* allows for priority sharing between entering and circulating vehicles in order to introduce an adjustment to the gap-acceptance capacity formula based on absolute priority of circulating stream vehicles. The need for adjustment is due to low critical gap values at high circulating flow rates. The limited-priority adjustment *reduces* the capacity estimated by the absolute-priority method.

The O-D factor used in the aaSIDRA roundabout capacity model incorporates the effect of *priority sharing* in adjusting the roundabout capacity function. The O-D factor in aaSIDRA allows for the fact that vehicles entering from the approach queues are under *forced flow* conditions, and as such they are considered to be *bunched*. Without the O-D factor that reduces the unblock time ratio (in effect, modifying the circulating stream headway distribution model), the gap-acceptance capacity formula gives unduly high capacity estimates at medium to high circulating flow rates, especially for multilane roundabouts. **While the O-D factor allows for capacity reduction needed to model priority sharing, it also allows for reduced unblock time due to an opposite effect, which can be called *priority emphasis*.**

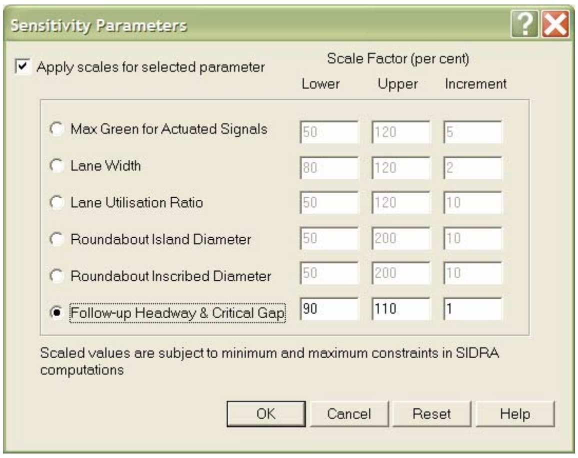
The priority emphasis condition occurs in the case of unbalanced flow patterns when a dominant flow restricts the amount of entering traffic since most vehicles in the circulating stream have entered from a queue at the upstream approach continuously due to a low circulating flow rate against them. Even a small amount of circulating flow can cause a significant proportion of vehicles to be queued on an approach with a heavy flow rate, although the capacity can be high. This also corresponds to the case of long back of queue and low delay.

A heavy stream that can enter the roundabout with little interruption due to a low circulating flow rate against it (*unbalanced flow* conditions) represents mainly forced flow conditions (with follow-up headways that can be larger than the intrabunch headway), and cause reduced capacity at a downstream entry. The *origin-destination factor* in aaSIDRA takes into account the flow balance as well as the amount of queuing in the circulating stream, in effect modifying the circulating stream headway distribution to allow for these factors.

Without allowance for *priority emphasis*, any method based on gap-acceptance modeling with or without limited-priority process, or any comparable empirical method, fails to provide satisfactory estimates of roundabout capacity with unbalanced flows as shown by many case studies.

CALIBRATING aaSIDRA FOR LOCAL CONDITIONS

It is very easy to calibrate aaSIDRA using the Sensitivity Analysis facility. If measured capacity values are available for an existing roundabout, aaSIDRA critical gap and follow-up headway values can be calibrated using the aaSIDRA Sensitivity Analysis method or specifying the critical gap and follow-up headway values to achieve observed capacity values. When measured capacity values are not available (as in the case of designing a new roundabout), the aaSIDRA Sensitivity Analysis method can be used to see the effect of changes in critical gap and follow-up headway parameters on capacity, delay and LOS easily.



COMPARING ALTERNATIVE MODELS

The discussion about "gap-acceptance" vs "empirical" models for estimating capacity of roundabouts has often been expressed in terms of alternative software packages, although the debate is essentially about alternative capacity models. There are many alternative gap-acceptance and "empirical" models around the world, but unfortunately the controversy has concentrated on "SIDRA" vs software packages that implement the TRL (UK) linear regression model.

Continuous assessment of existing capacity models in the light of real-life experience of practicing engineers and planners should be encouraged for further improvement of our knowledge in this area, as in other areas of science and technology.

As developers of aaSIDRA, we have therefore introduced a facility to compare the capacity estimates from the TRL (UK) linear regression model and the aaSIDRA gap-acceptance model on a case-by-case basis. This is an Excel application supplied with the aaSIDRA package (see the figure in previous page). Furthermore, aaSIDRA presents comparisons with other linear regression and gap-acceptance capacity estimates as well (German, old Australian NASRA 1986, HCM 2000 models).

We believe that case-by-case evaluation of results from alternative models is the best way of helping software users who wish to understand the differences between these models. However, various general notes are included in the following pages.

It is not who is right, but what is right, that is important.

Thomas Huxley

ROUNDABOUT CAPACITY AND PERFORMANCE MODELS

Firstly, the "capacity" and "performance" (delay, queue length, stops) models should not be considered in isolation from each other. The emphasis should be on complete methodology with consistency in modeling capacity and performance of not only roundabouts but all intersection types.

Secondly, all relevant fundamental aspects of capacity and performance modeling should be identified to avoid a narrow focus on capacity equations. Distinguishing alternative methodologies in terms of aggregation levels, i.e. the use of approach flows (TRL (UK) method), lane groups (HCM method) or lane by lane analysis (aaSIDRA method), is a more important task for determining the accuracy levels of capacity and performance models, irrespective of them being "empirical" or "gap-acceptance based".

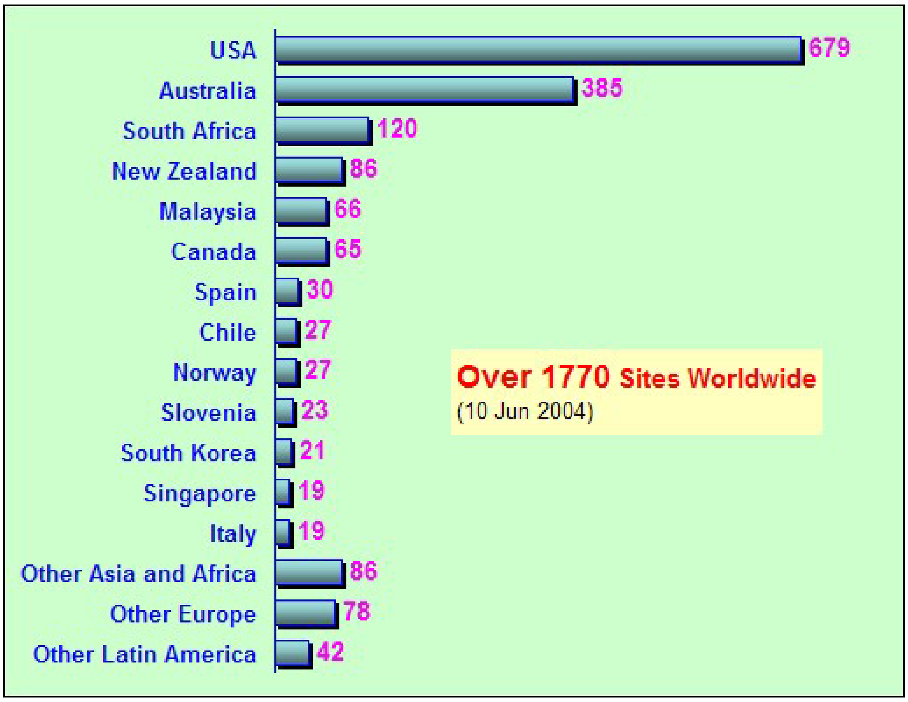
Thirdly, a satisfactory method for predicting capacity and performance of roundabouts should include modeling of both

- DRIVER YIELD BEHAVIOUR and
- ROUNDABOUT GEOMETRY.

The model used in aaSIDRA satisfies both criteria using a gap-acceptance based method to model driver yield behaviour, at the same time allowing for the effects of geometric variables. The TRL (UK) linear regression model allows for only the geometric variables.

MODEL VALIDATION IN THE USA

A survey of US traffic professionals at the Roundabout Conference in Seattle WA in May 2000 indicated that aaSIDRA is by far the most popular roundabout analysis tool in the USA. At that time, there were 450 aaSIDRA sites in the USA, and aaSIDRA use in the USA has increased significantly since then. In June 2004, it was in use at approximately 680 sites in the USA. Therefore the aaSIDRA models are being tested continually for their applicability to US traffic conditions.



For a more formal field validation study, refer to the following article which concluded " aaSIDRA can accurately predict delay for American single-lane roundabouts":

Flannery, A., Elefteriadou, L., Koza, P. and McFadden, J. Safety, delay, and capacity of single-lane roundabouts in the United States. Transportation Research Record 1646, pp. 63-70. 1998.

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Australian driving conditions and traffic engineering practices are much closer to the US conditions than other countries (e.g. Europe and UK) which makes aaSIDRA more suitable for US conditions. The US Florida Roundabout Guide *(36)* states:

" Several methods of roundabout modeling have been developed, most of them in other countries where roundabouts are common intersection treatments. The Australian methods are most comparable with HCM methods, and are implemented in software that is most compatible with the computational structure that has been developed in Florida for comparing other control modes. For example, the SIDRA program offers an option to implement the HCM procedures for many computations. SIDRA is used in the Florida Roundabout Guide as the primary model for evaluating roundabout performance. ... Like all of the other evaluation models, SIDRA has its own data entry and editing capability. Its user interface is graphics based, and is very well documented and user-friendly. "

Modern Roundabout Practice in the United States *(23)* states:

"There are two primary capacity methods and software programs used in the United States: the Australian method with the SIDRA software and the British method with either the RODEL or the ARCADY software. ... SIDRA appears to be the most commonly used in the United States. This is in line with the fact that two-thirds of the survey respondents mentioned that they followed, or at least consulted, the Australian guidelines for roundabout design. ... "

In Establishing Roundabout Guidelines for a State DOT, Kinzel *(24)* writes:

"After much discussion, the technical committee (of the the Missouri Department of Transportation) decided that ... aaSIDRA would be the required software for detailed operational analysis. The SIDRA software's increasing prevalence of use in the United States, and the committee's comfort level with a gap-acceptance-based analysis approach, were key factors in this decision."

Maryland DOT Roundabout Design Guidelines *(37)* states:

"Until more data is gathered concerning the performance of roundabouts in Maryland, the Maryland State Highway Administration recommends that designers use the Australian practice at this time. ... This section provides an analytical technique which can be expected to give quite accurate results which reflect current Australian experience and practice. SIDRA software is recommended and is available from McTrans at the University of Florida."

Oregon DOT Research Document on Modern Roundabouts *(38)* suggests:

"Currently, three major software packages from other countries are used to analyze or design roundabouts: SIDRA, ARCADY, and RODEL. Recently, a test of the SIDRA program in the US environment found agreement between SIDRA delay output and collected field data at low volume. The RODEL package has been used to design roundabouts in the US. However, there has been no study or information on the ability of this program to predict roundabout performance in the US."

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MODEL COMPARISON

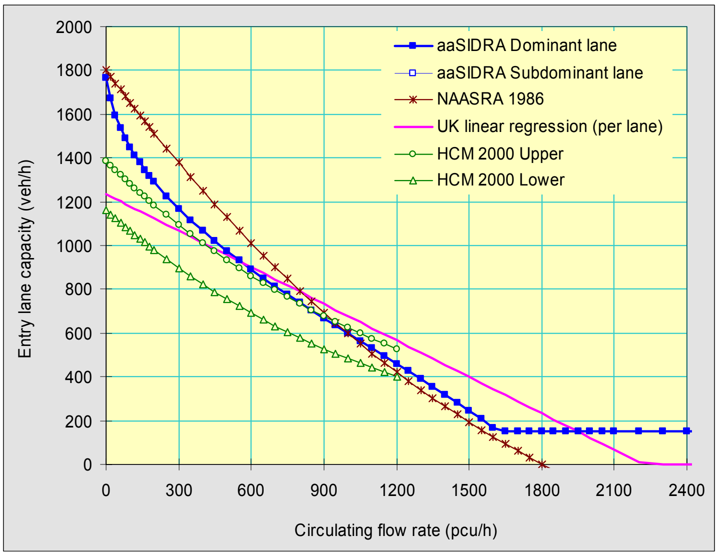

Figure 2 - Model comparison (single-lane roundabout example)

Figure 2 **presents comparison of the following capacity estimates for a single-lane roundabout example (inscribed diameter = 40 m, entry lane width = 4.0 m, approach half width = 3.6 m, flare length 20 m, entry radius = 30 m, and entry angle = 30 degrees).**

- **aaSIDRA**
- **TRL (UK) linear regression**
- **HCM upper and lower** *(1)*
- **Old Australian gap-acceptance model: NAASRA (1986)** *(5)*

A moderate Origin-Destination flow pattern effect (balanced flows) and a moderate kevel of adjustment for the ratio of entry lane flow rate to circulating flow rate are assumed for aaSIDRA.

It is seen that the TRL (UK) model may significantly underestimate capacity at low circulating flow conditions (below 300 veh/h) and overestimates capacity at high circulating flow conditions (above 900 veh/h). Reasons for this are given below.

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COMMENTS ON MODEL DIFFERENCES

Possible reasons for the TRL (UK) Linear Regression model to give lower capacities at low circulating flows and higher capacities at high circulating flows as seen in *Figure 2* include the following:

(i) **reliance on a purely *statistical (regression) approach*** in its development rather than an analytical approach supported by a statistical approach,

(ii) **the *peculiarities of the geometric features* of the roundabouts included in the database** used for capacity model derivation, and

(iii) the use of a ***linear regression* model** that is inevitably biased when trying to describe a relationship which is likely to be of an exponential nature when very low and high circulating flow conditions are accounted for appropriately.

These are discussed considering low and high circulating flow regions.

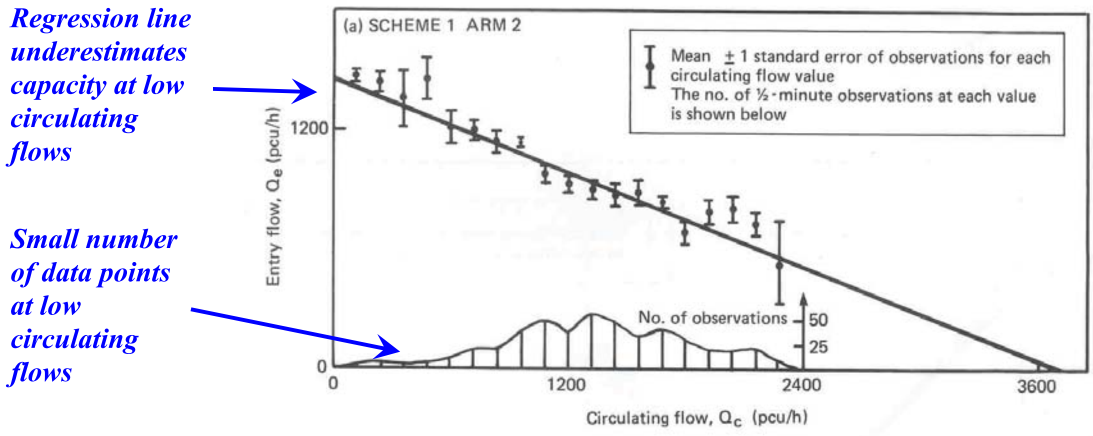
TRL (UK) Linear Regression Model Capacity Estimates: Low Circulating Flow Rates

With the TRL (UK) Linear Regression model, it is difficult to avoid underestimation of capacity (overestimation of driver response times) at very low circulating flow conditions due to its linearity combined with the "best fit" nature of the regression method. **The nature of this regression relationship appears to be biased since it seems that the database it is derived from includes a relatively small number of data points with low circulating flow rates** (and probably very few data points with high arrival flow rate against low circulating flow rate). This is because capacity observations for the TRL (UK) Linear Regression model relied on using data from saturated approaches which are difficult to find under low circulating flow conditions.

Examples from two UK roundabout research reports shown in *Figure 3* indicate that relative frequencies of data at circulating flows below 600 pcu/h were very small *(17,18)*. This is likely to be similar for the overall database used in deriving the TRL Linear Regression model for at-grade roundabouts *(15)*. These examples also show how the "observed regression line" can underestimate capacity at low circulating flows. In *Figure 3(b)*, the broken line representing the TRL Linear Regression model for at-grade roundabouts displays substantial underestimation of capacity at low circulating flows and overestimation of capacity at high circulating flows for a different type of roundabout design *(18)*.

For the combined "high entry lane flow and low circulating flow" conditions, the aaSIDRA model implies alert drivers with small reaction times (around **1 second**) whereas the TRL Linear Regression and HCM 2000 models imply relaxed drivers with large reaction times (**around 2 seconds**), accepting to wait in a long queue in congested conditions in spite of very large gaps available in the circulating stream *(22)*.

(a) At-grade roundabout in Wincheap, Canterbury, UK (17)



(b) Grade-separated roundabout in Bradford, UK (18)

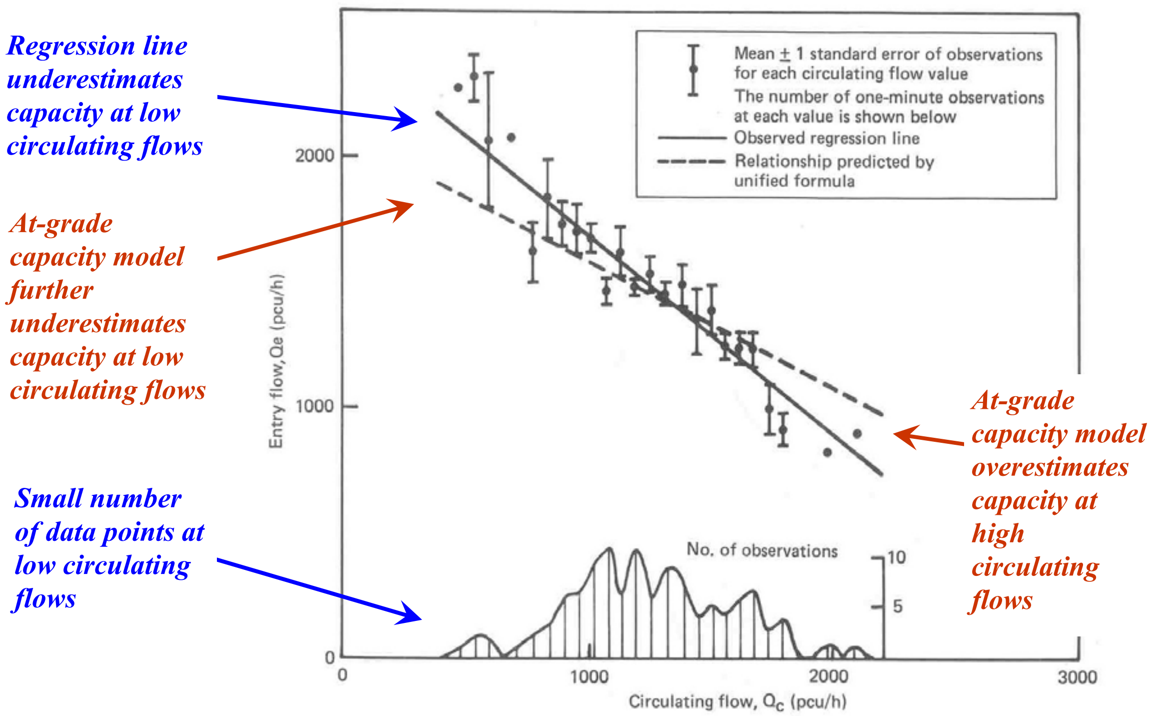


Figure 3 - Data from roundabout capacity surveys at UK roundabouts

TRL (UK) Linear Regression Model Capacity Estimates: High Circulating Flow Rates

Contrary to the low circulating flow region, the TRL Linear Regression model estimates higher capacity than other models in the high circulating flow region. The reasons are different from those for low circulating flows.

The TRL research leading to the linear regression model was preoccupied with the effect of roundabout geometry:

> "*The intention was to provide a single method for estimating the capacity of entries to all at-grade roundabouts. The unified formula was developed using observations made on the TRRL Test Track and at a large number of public road sites; these observations covered a wide range of values of those geometric parameters which were found to affect the entry capacity." (18 p.1).*
>
> *"... capacity prediction for both 'conventional' and 'offside-priority' roundabouts has thus been brought together into a common framework in which capacity is predicted entry by entry. However,* ***the two types are designed according to geometric principles evolved as a result of differently perceived mechanisms - weaving for conventional designs and gap-acceptance for offside priority designs****. Consequently their characteristic geometric features and sizes are different: conventional roundabouts have large and often irregularly shaped central islands, parallel sided weaving sections and unflared entries (usually two-lane), whereas offside priority designs have smaller, usually circular, central islands and flared approaches." (15 p.3).*

Examples of the two design types used in capacity measurements for the TRL (UK) Linear Regression model discussed in the above quote are shown in *Figure 4* *(17)*. Large numbers of both types of roundabouts were included, and *represented equally*, in the TRL capacity database. This diversity of roundabout designs with a very wide range of geometric parameters may have contributed to the linearity of the TRL (UK) capacity model due to the regression (best fit) approach used. Other reasons for the linearity would be the lack of data at low circulating flow range (discussed above) and aggregation of data for all lanes of multi-lane approaches as well as flared single lane approaches *(10 Section 7.4.2)*.

The approach-based method adopted for the TRL (UK) Linear Regression model was an improvement over the method that existed then, which estimated capacity of the roundabout as a whole. However, lack of sensitivity to variations in lane arrangements (e.g. difference between exclusive and shared lanes) and to possible lane underutilisation effects cause serious capacity estimation problems with the TRL (UK) Linear Regression model *(29,30)*.

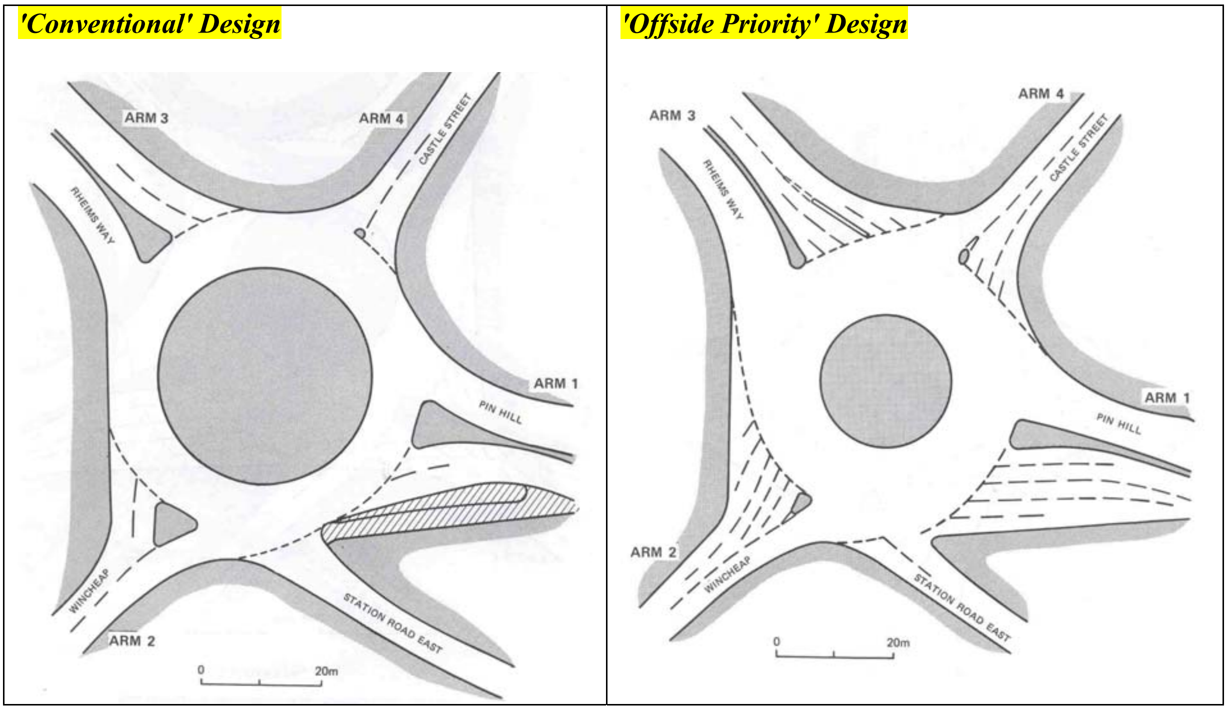


Figure 4 - Examples of 'Conventional' and 'Offside Priority' roundabout designs used in capacity measurements for TRL linear regression model (17)

As seen in *Figure 4*, a highly flared offside priority design means a significantly increased number of entry lanes (this would be modeled as short lanes in aaSIDRA). This arrangement can increase the entry capacity substantially. Flared offside priority designs with very low entry angles (range 0 to 77 degrees) and large entry radius values (range 3.4 m, or 11 ft to ∞) would encourage merging behavior and possibly induce priority reversal at high circulating flow rates (see *Table 1* for the entry angle and turn radius values in the Australian database). Similarly, conventional designs encouraged merging behavior according to the TRL research reports. It appears that capacity of some continuous entry lanes, expected to contribute to high capacities observed at large circulating flows, were also included in the TRL database. **It also seems that various experimental designs used by TRL encouraged merging and this was observed at high circulating flows** *(14 p.4 and 15 p.4)*. All these factors must have contributed to high capacity values observed at high circulating flow rates. Increased capacities at high circulating flows combined with the lack of data at low circulating flows would have contributed to the linearity of the TRL regression model.

Merging and priority reversal observed at the UK roundabouts were stated among the reasons for not using the gap-acceptance methodology, in addition to the gap-acceptance parameters not being sensitive to roundabout geometry and circulating flow level in the gap-acceptance models that existed at the time *(15,26,28)*. These concerns appear to have resulted from the geometric design features adopted at roundabouts included in the UK roundabout capacity surveys. See the discussion on this matter at the start of this document.

It is interesting to note that UK research on grade-separated roundabouts led to a modified capacity formula that estimates lower capacity at high circulating flow rates (requiring a much higher slope of the regression line as seen in *Figure 3(b)*). Semmens *(18 p.3)* suggested that "*This result is consistent with the* ***behavioral mechanism that drivers at grade-separated roundabout entries appear to conform more to strict 'give-way' behavior****, which leads to steeper entry-circulating flow relationship, than to more usual mixture of 'give-way' and 'merging' at the larger (conventional) at-grade roundabouts.*" and explained this with poorer sight distances associated with extra barriers and supports at these roundabouts. Data given by Semmens *(18 p.10)* indicates that these roundabouts had negligible or no flaring *(18 p.10)*, and this is probably the reason for more strict give-way (yield) behavior and lack of merging that explains lower capacities observed at high circulating flows.

Semmens *(18 p.6)* investigated the effect of changes to approach geometry at two grade-separated roundabouts. These changes "*caused substantial changes in give-way behavior, with a marked swing towards merging movements.*", and resulted in increased capacity at high circulating flow rates (slope of the regression line was reduced).

Thus, the type of roundabout design clearly affects the driver behavior and the resulting capacity relationship. **The TRL (UK) Linear Regression model reflects the conventional and offside-priority designs used in that country at the time, which seem to have encouraged merging behavior**. It is believed that these roundabout designs are not representative of modern roundabout designs adopted in Australia *(8)* and the USA *(23,36-40)*, whose approaches are more like the unflared entries at *grade-separated* roundabouts discussed by Semmens *(18)*.

MICROSIMULATION MODELS

This document focused on comparison of analytical models. **Microsimulation models** offer a great potential for modeling complex gap-acceptance situations experienced in many situations in urban traffic. Modeling issues discussed in this paper are also applicable to microsimulation models since driver behavior rules and gap-acceptance parameter values used in microsimulation will affect the resulting capacity and performance estimates *(31)*. Comparisons of capacity and performance estimates from different microsimulation models and between microsimulation and analytical models are also recommended.

Pattern of Difference Between the aaSIDRA and the TRL (UK) Linear Regression Models

Our comparisons of the two models using the aaSIDRA package to date indicate that while the two models tend to agree for medium demand flow rates (around 600-900 veh/h) with balanced origin-destination demand flow patterns, there are significant differences for low and high circulating flows, especially with unbalanced origin-destination patterns. All case studies with such conditions we have looked at indicate that aaSIDRA estimates represent real-life conditions reasonably well.

The following is a risk analysis of design implications of the differences between the two models.

1. LOW CIRCULATING FLOWS

aaSIDRA capacity estimates are HIGHER

	Design by TRL (UK) model	Design by aaSIDRA
If aaSIDRA model is correct	TRL (UK) model may impose a capacity constraint when the demand flow rate is high against a low circulating flow rate. This may cause over-optimistic estimate of the capacity of the next entry. The method may fail to predict poor performance of the next entry under such unbalanced flow conditions.	OK
If TRL (UK) model is correct	OK	Real-life cases support the aaSIDRA case.

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2. HIGH CIRCULATING FLOWS

The TRL (UK) model capacity estimates are HIGHER

	Design by TRL (UK) model	Design by aaSIDRA
If aaSIDRA model is correct	May cause under-design (resulting in high degrees of saturation).	OK
If TRL (UK) model is correct	OK	Many real-life cases indicate that roundabout performance deteriorates quickly as the demand flow rates increase.

The US study reported earlier in this document found that while aaSIDRA predicted delay "very well" for low-volume sites, it tended to underestimate delay for high-volume sites. This, in fact, supports lower capacities estimated by aaSIDRA for high volume conditions, otherwise much lower delays would be estimated by the delay model (note that the TRL (UK) and aaSIDRA delay models do not differ much, so the issue here is the capacity model not the delay model).

Advantages of Using aaSIDRA

- aaSIDRA uses a lane-by-lane analysis method with an advanced gap-acceptance model of the “yield” behaviour of drivers at modern roundabouts.
- You can use the parameter sensitivity facility of aaSIDRA to obtain graphs of how capacity and a large number of performance parameters (delay, queue length, cost, etc) change with roundabout geometry and driver behaviour (gap-acceptance parameters).
- Unlike the TRL (UK) linear regression method, the aaSIDRA gap-acceptance method is consistent with the US Highway Capacity Manual.
- aaSIDRA includes the HCM roundabout model results, and also presents results from alternative roundabout capacity models including the German linear regression and gap-acceptance models.
- aaSIDRA provides a special Excel application to use the TRL (UK) linear regression model to support model comparisons.
- aaSIDRA will help you with comparing alternative intersection treatments (roundabouts, actuated and pretimed signals, sign control) in one package.

  A special Excel application called "Annual_Sums.xls" provides total yearly values of variables such as operating cost, fuel consumption, CO_2, other emissions, total person delay, stops and so on. Graphs comparing alternative designs are given. This enables the user to demonstrate benefits of alternative intersection treatments and improvements to existing intersection conditions in a more powerful way.

The rest of this document presents more detailed points about the aaSIDRA and the TRL (UK) Linear Regression Models.

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Geometric Parameters in the aaSIDRA and TRL (UK) Models

The TRL (UK) regression model is oversensitive to

- inscribed diameter
- approach (lane) width
- and other variables

representing roundabout geometry.

This is probably because the TRL (UK) roundabout database used for developing the TRL (UK) regression model in 1980s included a large number of sub-standard roundabout designs that existed in the TRL (UK) historically.

This makes the TRL (UK) model not readily applicable in other countries where modern roundabouts are being used.

Modern roundabout designs are more uniform, and therefore, the more recent models based on them are less sensitive to the geometric variables (as in the case of the Australian roundabout model used in aaSIDRA).

German linear regression and gap-acceptance models use only the number of entry and circulating lanes as significant variables!

In the aaSIDRA roundabout capacity model, gap acceptance (driver behaviour) parameters are related to …

- **roundabout geometry** — ***<< in the TRL (UK) model***
- **circulation flow rate** — ***<< in the TRL (UK) model***
- **entry flow rates** — ***<< NOT in the TRL (UK) model***

Therefore, past criticism of gap-acceptance models that use constant critical gap and follow-up headway IS NOT RELEVANT to the aaSIDRA method.

Geometric factors affecting capacity through gap acceptance parameters …

- **Inscribed diameter** — ***<< in the TRL (UK) model***
- **Average entry lane width** — ***the TRL (UK) model uses***
- **Number of entry lanes** — ***total entry width***
- **Number of circulating lanes** — ***<< NOT in the TRL (UK) model***

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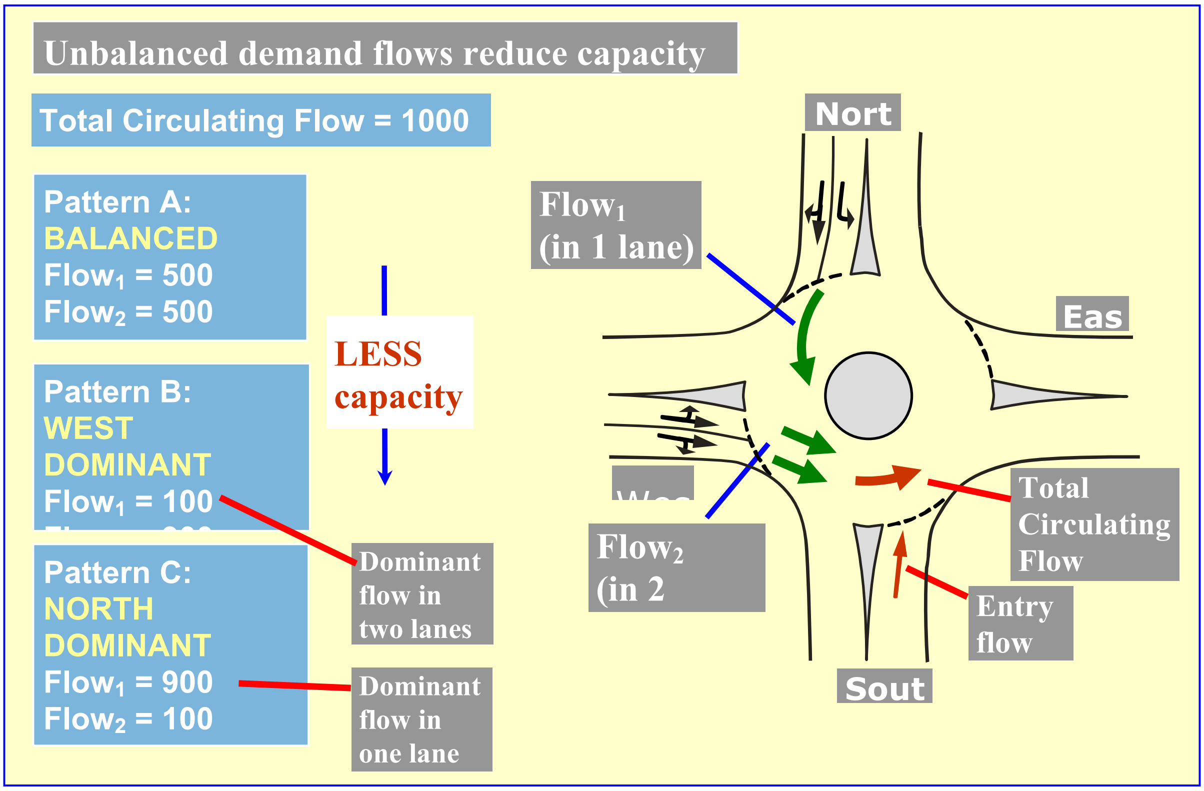
Parameters in the aaSIDRA Model but NOT in the TRL (UK) model

Effect of origin-destination pattern, proportion queued and lane usage

The aaSIDRA model estimates capacity according to the give-way (yield) behavior, and allows for the effect of highly directional circulating flows originating mostly from a single approach, thus reducing the entry capacity for such unbalanced flow conditions. Dominant circulating flows reduce the entry capacity as evident from the use of metering signals in Australia and the UK to help low-capacity roundabout approaches. The TRL (UK) Linear Regression model does not consider these factors, and has been found to be too optimistic, i.e. it has failed to predict congested conditions observed at many roundabouts in Australia and the UK.

The effect of the Origin-Destination (O-D) pattern on capacity in modeling unbalanced flows by aaSIDRA is shown below



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Lane use: exclusive vs shared lanes and lane underutilisation

A major shortcoming of the UK (TRL) model is lack of sensitivity to approach and circulating lane use. See example by CHARD.

CHARD, B. (1997). **ARCADY Health Warning: Account for unequal lane usage or risk damaging the Public Purse!**. *Traffic Engineering and Control*, 38 (3), pp. 122-132.

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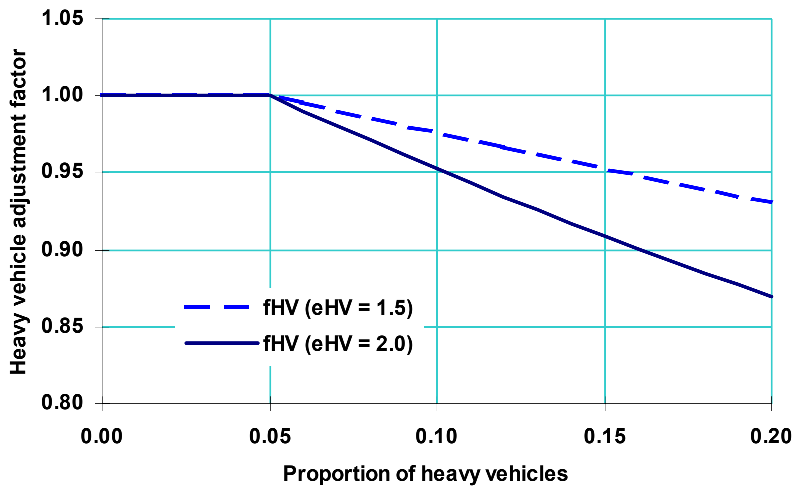
HEAVY VEHICLES in the circulating stream and entry lane

Heavy vehicles in the circulating stream and entry lane reduce capacity.



Extra bunching due to upstream signals

This has limited effect at medium to high flow conditions.

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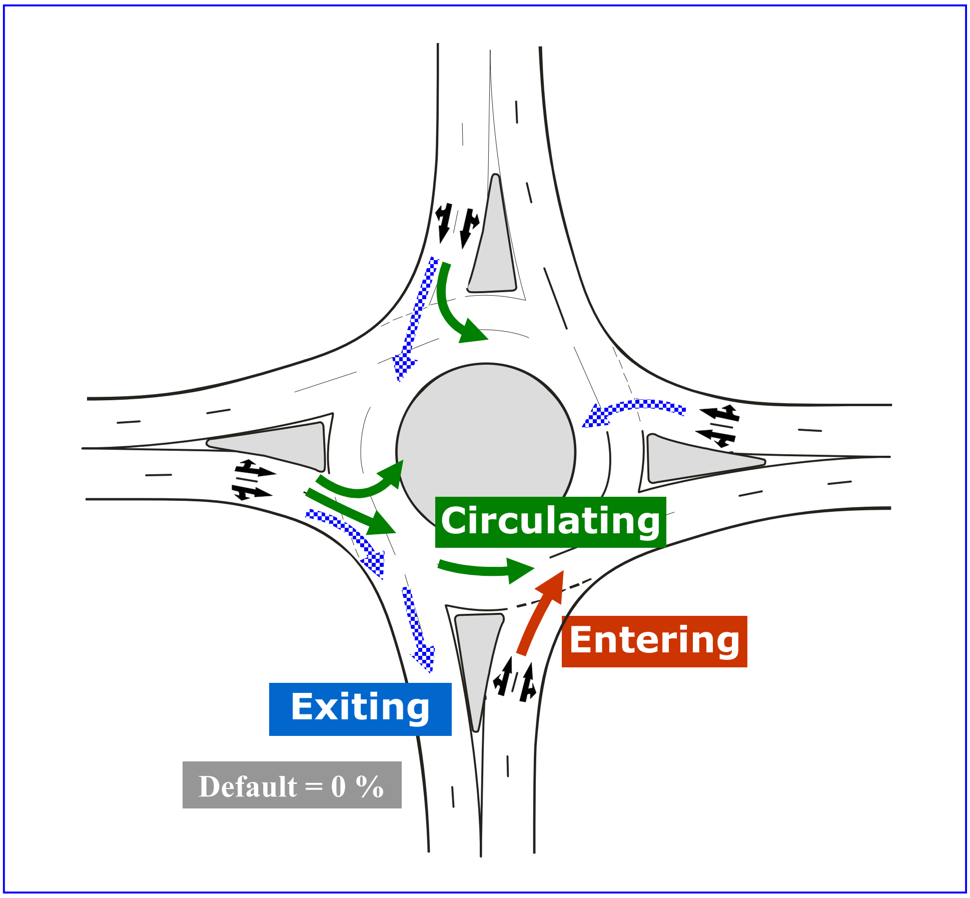
Exiting flow

When exiting flows influence entering vehicles, entry capacity is reduced.



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Approach lane flows

Multi-lane approaches have unequal lane capacities for dominant and subdominant lanes; additional lanes add LESS to capacity (similar to AWSC).

Ratio of entry flow to approach flow

Capacity increases as this ratio increases, but subject to constraints. TRL (UK) model predicts low capacities when circulating flow is very low and entry flow is high as discussed in previous pages.

Parameters NOT in the TRL (UK) model or aaSIDRA

- **Grade**
- **Speed**

Future research should pay attention to these parameters.

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Parameters in the TRL (UK) model but NOT in the aaSIDRA model

☞Australian data indicated that the following geometric parameters used in the TRL (UK) model were **not significant**:

- Entry radius
- Entry angle
- Approach half-width
- Flare length

☞This is partly due to the lane-by-lane analysis and the use of SHORT LANES, and probably due to the roundabout design standards used in Australia.

Note: SHORT LANE is a flare that allows full queuing.
TRL (UK) model predicts a FIXED amount of extra capacity due to flare. aaSIDRA estimate of additional capacity due to a short lane is DYNAMIC (depends on demand flow levels).

Entry radius, entry angle, approach half-width parameters have small impact on capacity for reasonable range of data. TRL (UK) database includes roundabouts with extreme range of geometric conditions due to the historical development in the TRL (UK). This explains why these parameters have been found significant in statistical analysis.

Furthermore, this makes the TRL (UK) model NOT APPLICABLE in other countries without collection of a new database and recalibration. The need for recalibration is recognised by the TRL (UK) model.

CONCLUSION

You may have heard strong arguments for and against the aaSIDRA and TRL (UK) "empirical" models from different sources (including this document!). We recommend that, if you are not sure, you use alternative models and compare the results on a case-by-case basis.

To facilitate this, alternative models are provided in the aaSIDRA software package. These include:

- HCM roundabout model (upper and lower limit results for single-lane roundabouts only),
- German linear regression model,
- German gap-acceptance model,
- old Australian (NAASRA 1986) gap-acceptance model, and
- TRL (UK) linear regression model (using special Excel application).

We find that aaSIDRA results are often:

- between the upper and lower capacity estimates from the HCM roundabout model, and
- between the capacity estimates from the German and TRL (UK) linear regression models.

But we suggest that you compare alternative models on a case-by-case basis.

DISCLAIMER

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