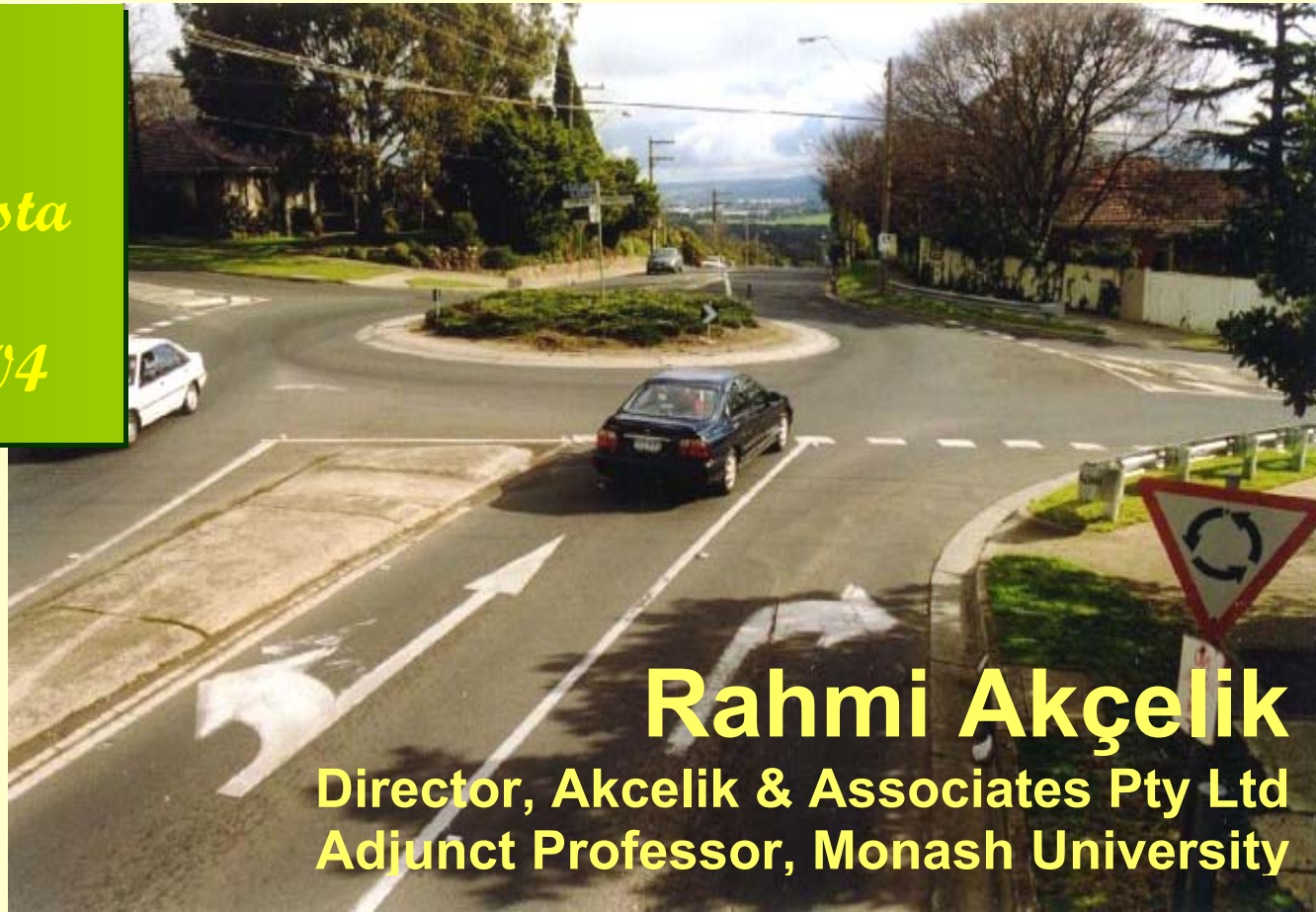


Roundabouts with Unbalanced Flow Patterns

ITE Annual
Meeting
*Lake Buena Vista
Florida, USA
August 1-4, 2004*



Rahmi Akçelik

Director, Akcelik & Associates Pty Ltd
Adjunct Professor, Monash University



Unbalanced Flow Patterns

Dominant heavy circulating flows that originate mostly from a single approach with **high levels of queuing** and **unequal lane use**, cause **PRIORITY EMPHASIS** and

- ♦ reduce the entry capacity significantly, and
- ♦ may cause excessive delay and queuing.

Part-time **METERING SIGNALS** are used under peak demand conditions to **create gaps** in the circulating stream for alleviating the problem.

This is a cost-effective measure to **avoid the need for full signalization**.

The Australian guides (roundabout and traffic signal) acknowledge the problem and discuss the use of metering signals.



Huddart, UK (1983)

"... the proper operation of a roundabout depends on there being a reasonable balance between the entry flows. ... an uninterrupted but not very intense stream of circulating traffic can effectively prevent much traffic from entering at a particular approach."

"The capacity of roundabouts is particularly limited if traffic flows are unbalanced. This is particularly the case if one entry has very heavy flow and the entry immediately before it on the roundabout has light flow so that the heavy flow proceeds virtually uninterrupted. This produces continuous circulating traffic which therefore prevents traffic from entering on subsequent approaches."



Unbalanced Flow Patterns

Improved understanding of the effect of unbalanced flow patterns on roundabout capacity and level of service is important:

- ♦ design **new roundabouts** that will cope with future increases in demand levels
- ♦ solve any problems resulting from unbalanced flow patterns at **existing roundabouts** (metering signals to avoid full signalization)
- ♦ may not be a problem when the overall **demand level is low** but problem appears with traffic growth even at medium demand levels
- ♦ demand flow patterns and demand levels **may change significantly** after the introduction of a roundabout (no direct control over turning movements unlike signalized intersections)
- ♦ modeling of **origin-destination demand pattern** of traffic is important in optimizing the roundabout geometry including approach and circulating lane use.



Case Studies

Case studies are presented to show that roundabout capacity and level of service depend not only on the **circulating flow rate** but also the **characteristics of approach flows** contributing to the circulating flow:

- ♦ the amount of queuing on the approach road
- ♦ circulating lane use
- ♦ priority sharing and priority emphasis

Country

- ♦ Australia
- ♦ UK
- ♦ USA

Roundabout size

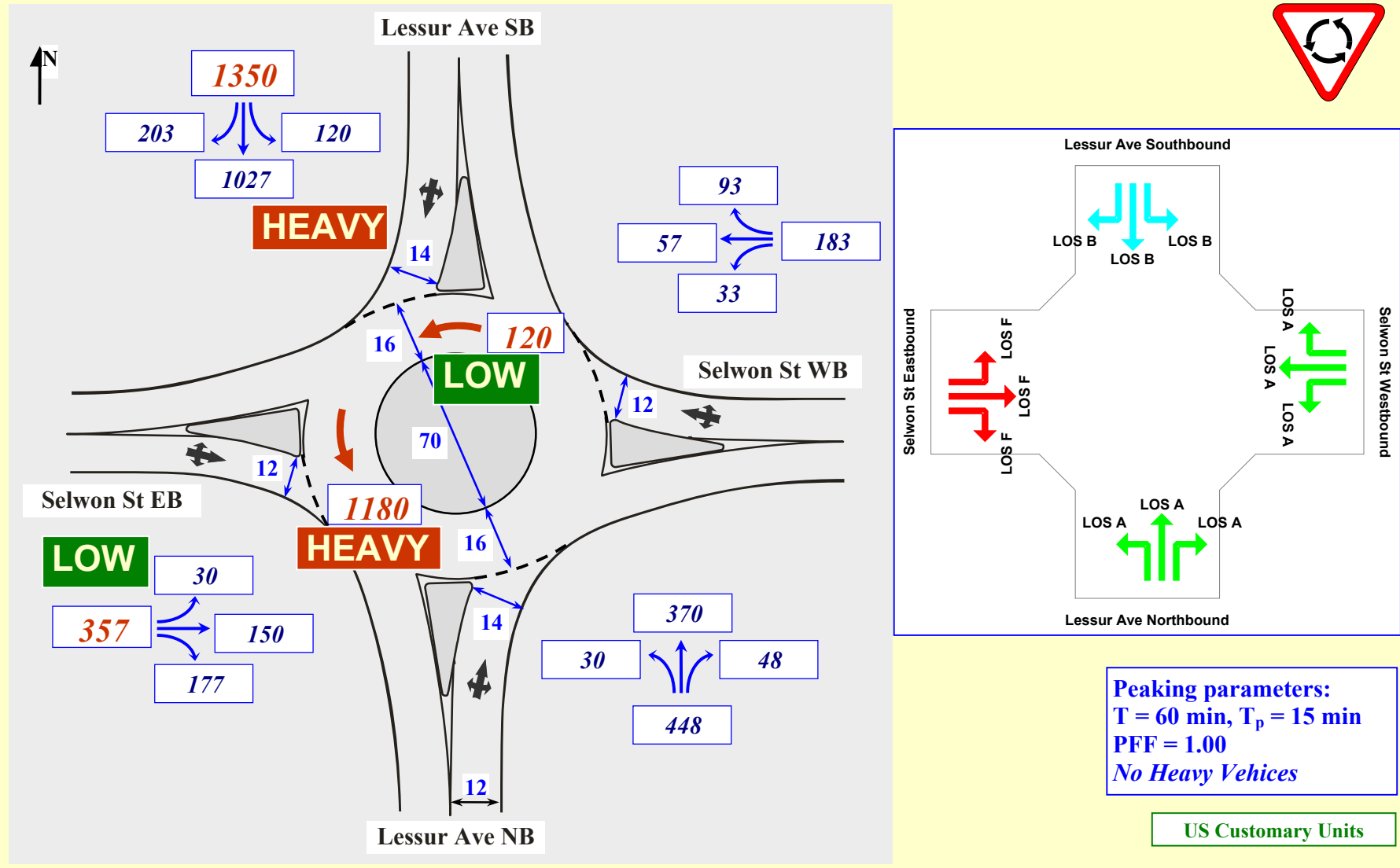
- ♦ 1-lane
- ♦ 2-lane
- ♦ 3-lane

Demand volumes

- ♦ Large
 - ♦ Small
- 1700 to 5300 veh/h**



A Single-Lane Roundabout Case, USA



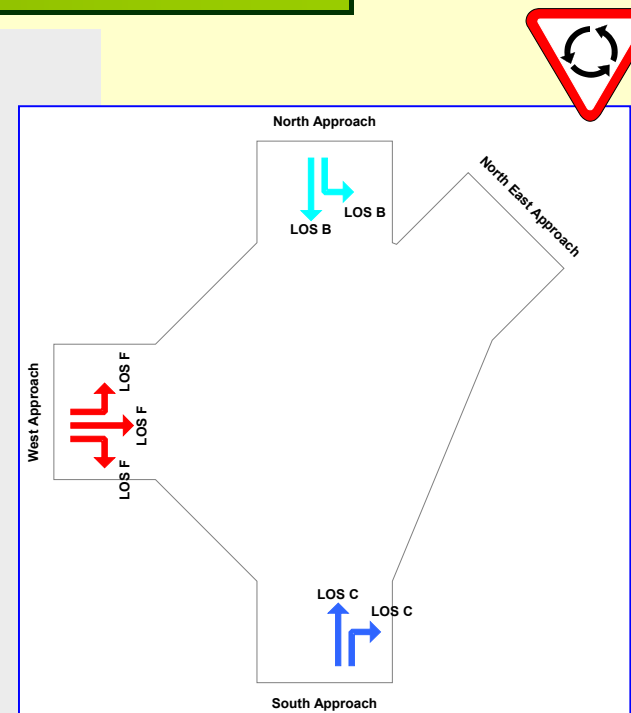
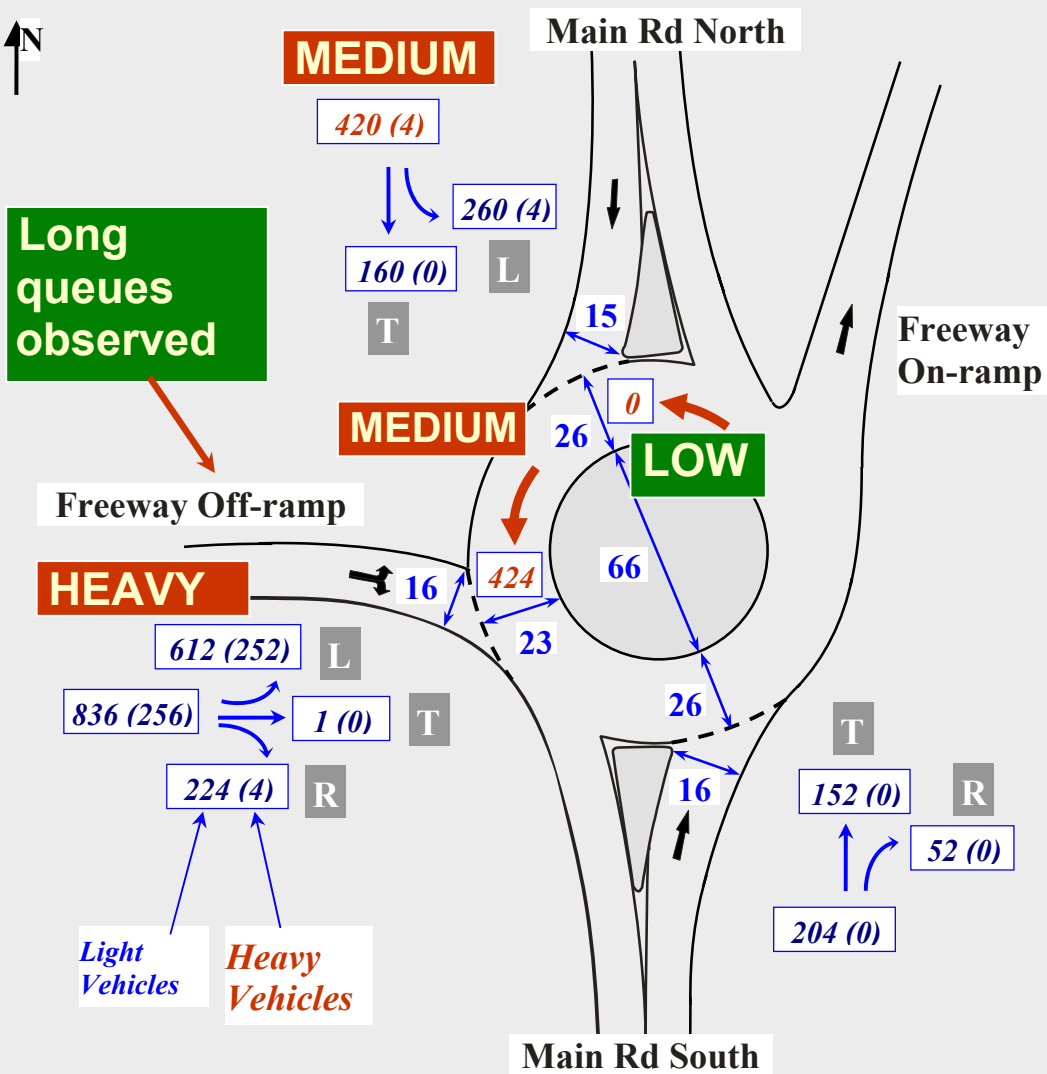
Capacity estimates from various models for the single-lane US roundabout case

App. ID	Approach Name	Approach flow rate (veh/h)	aaSIDRA			TRL (UK) Linear Regression		
			Capacity (veh/h)	Degree of saturation (v/c ratio)	Practical Spare Capacity ($x_p = 0.85$)	Capacity (veh/h)	Degree of saturation (v/c ratio)	Practical Spare Capacity ($x_p = 0.85$)
W	Selwon St EB	357	269	1.325	-36%	533	0.669	27%
S	Lessur Ave NB	448	1112	0.403	111%	1121	0.400	113%
E	Selwon St WB	183	906	0.202	321%	888	0.206	313%
N	Lessur Ave SB	1350	1389	0.972	-13%	1225	1.102	-23%
App. ID	Approach Name	Approach flow rate (veh/h)	NAASRA 1986			HCM 2000 Average		
			Capacity (veh/h)	Degree of saturation (v/c ratio)	Practical Spare Capacity ($x_p = 0.85$)	Capacity (veh/h)	Degree of saturation (v/c ratio)	Practical Spare Capacity ($x_p = 0.85$)
W	Selwon St EB	357	439	0.813	5%	544	0.656	30%
S	Lessur Ave NB	448	1378	0.325	161%	1010	0.444	92%
E	Selwon St WB	183	1213	0.151	463%	895	0.205	315%
N	Lessur Ave SB	1350	1625	0.831	2%	1155	1.169	-27%

Capacity constraint applies to all models (different circulating flows used as a result)



An interchange roundabout case from Sydney, Australia (Modified for driving on the right-hand side of the road)



TRL (UK) regression model:
use **Grade-Separated** option

Traffic volumes (veh/h) for the 15-min pm peak hour period shown.
Peaking parameters:
 $T = 60$ min, $T_p = 15$ min
PFF = 1.00
Separate LV & HV

US Customary Units

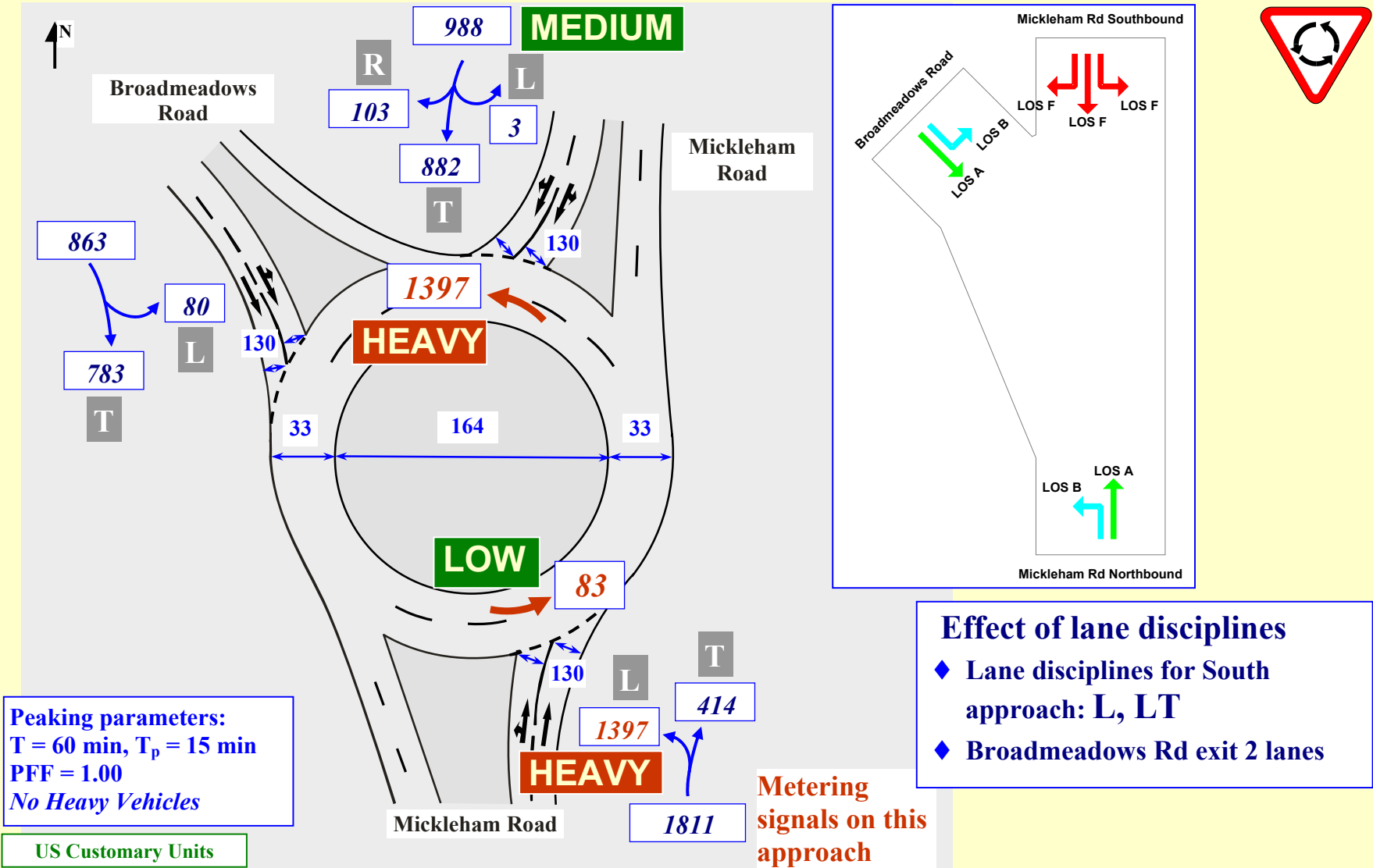
Capacity results for the interchange roundabout in Sydney, Australia
(For driving on the right-hand side of the road using US customary units)

App. ID	Approach Name	Total App. Flow (veh/h)	Circul. Flow (1) (pcu/h)	Total App. Capacity (veh/h)	Degree of saturation (v/c ratio)	Practical Spare Capacity ($x_p = 0.85$)
			aaSIDRA Model			
S	Main Rd South	204	1135	416	0.491	73%
W	Freeway Off-ramp	1092	424	896	1.219	-30%
N	Main Rd North	424	0	1750	0.242	251%
			TRL (UK) Linear Regression Model (2)			
S	Main Rd South	204	1328	534	0.382	123%
W	Freeway Off-ramp	1092	424	1099	0.994	-14%
N	Main Rd North	424	0	1621	0.262	224%

- (1) The aaSIDRA circulating flow rate for the South approach includes capacity constraint effect due to oversaturation on West approach ($x > 1.0$). Circulating flows for the TRL (UK) model are without any capacity constraint since all approach lanes are estimated to be undersaturated ($x < 1.0$). All circulating flows include heavy vehicle effects (in pcu/h).
- (2) The grade-separated roundabout option used for the TRL (UK) model.



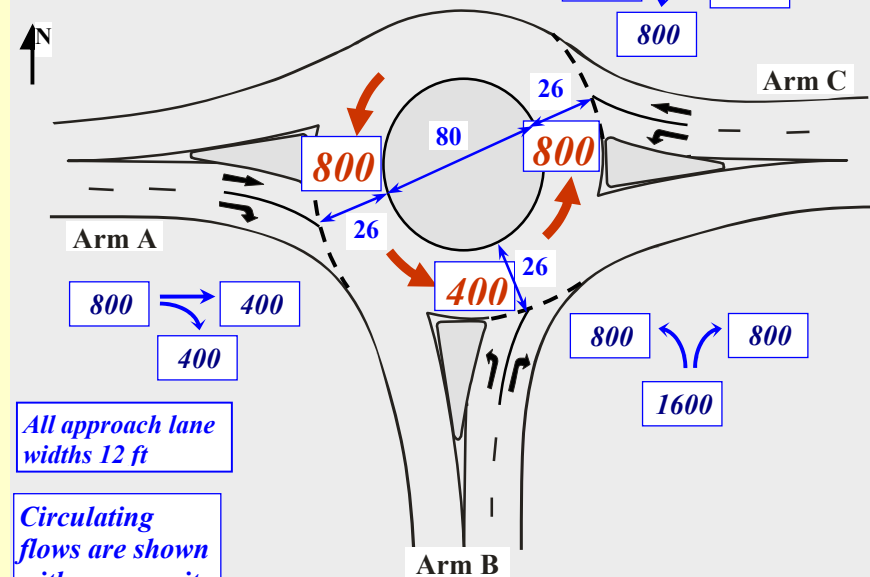
(Modified for driving on the right-hand side of the road)



T-intersection roundabout case (based on article by CHARD, UK)

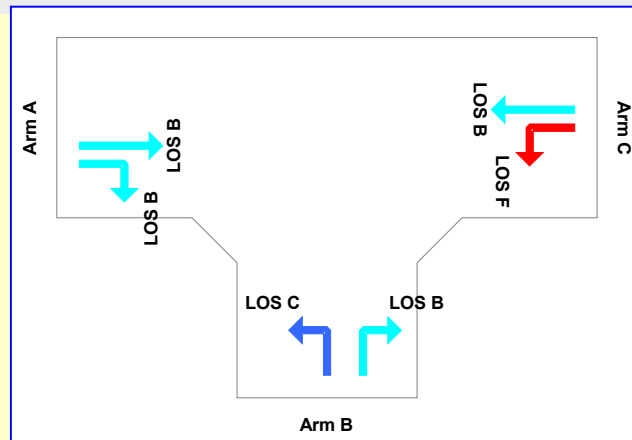
(Modified for driving on the right-hand side of the road)

Exclusive approach lanes and single-lane circulating road

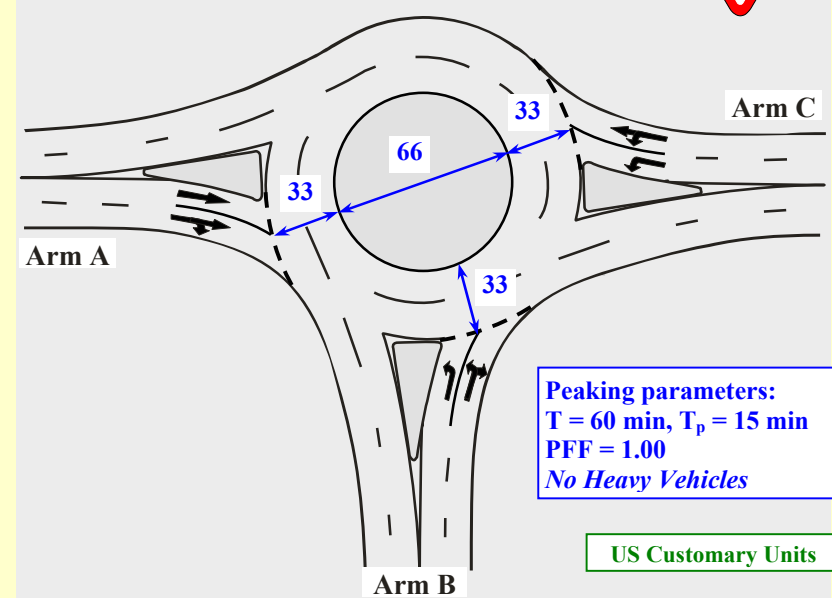


All approach lane widths 12 ft

Circulating flows are shown with no capacity constraint

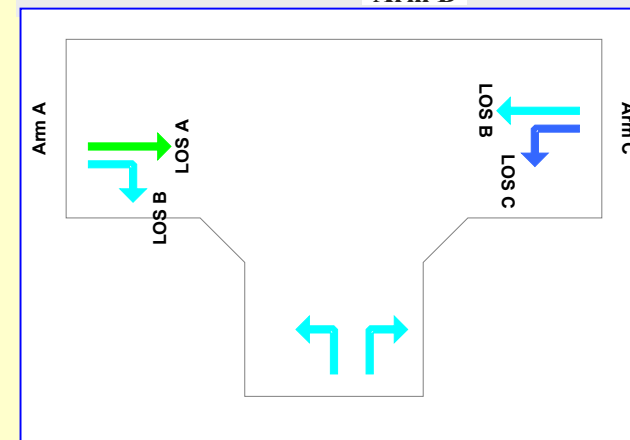


Shared approach lanes and two-lane circulating road



Peaking parameters:
T = 60 min, $T_p = 15$ min
PFF = 1.00
No Heavy Vehicles

US Customary Units



Capacity results for the T-intersection roundabout
(For driving on the right-hand side of the road using US customary units)

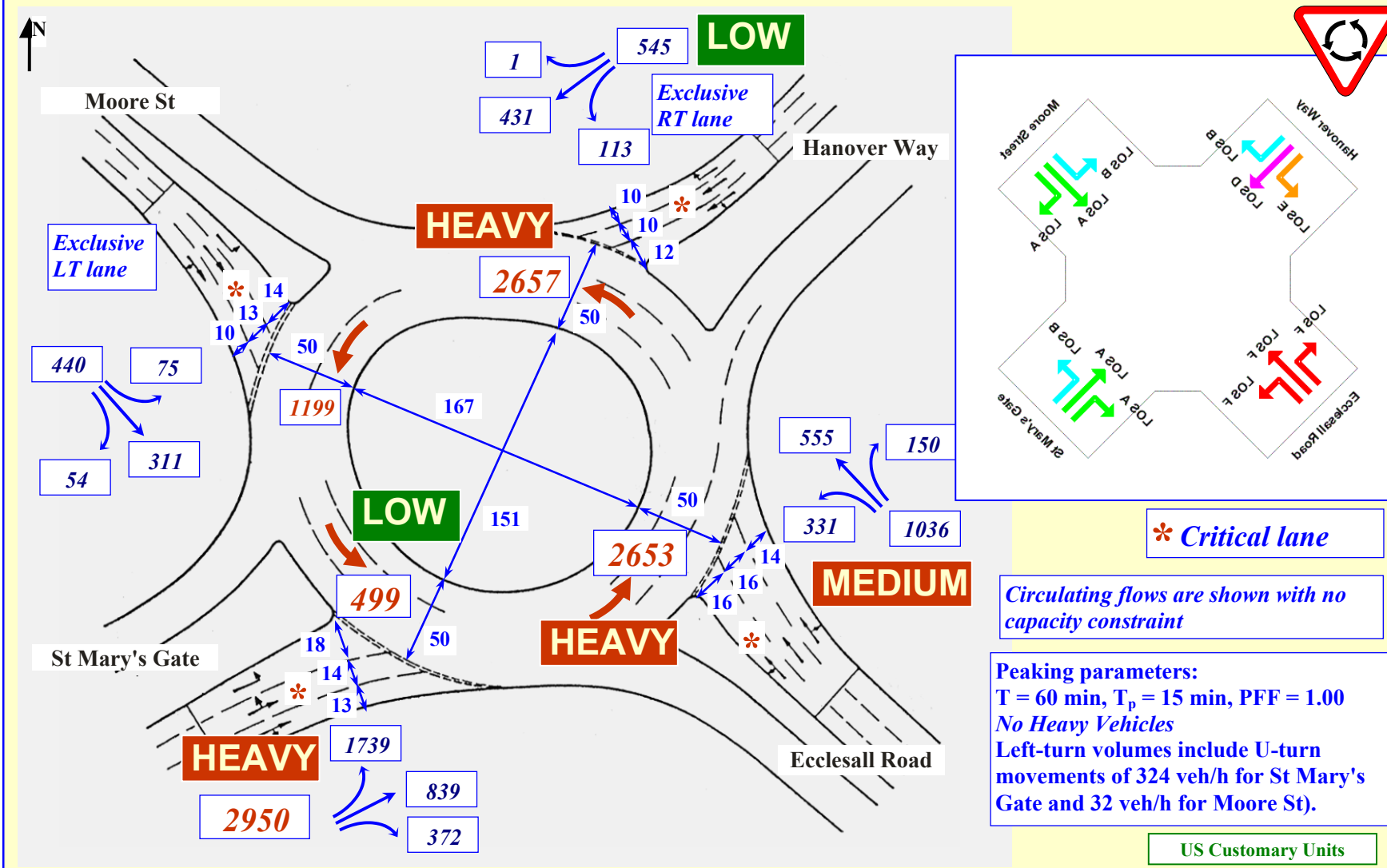
App. ID	Approach Name	Total App. Flow (veh/h)	Circul. Flow (1) (pcu/h)	Critical Lane (2)	Critical Lane Flow (veh/h)	Total App. Capacity (veh/h)	Critical Lane capacity (veh/h)	Degree of saturation (v/c ratio)	Practical Spare Capacity ($x_p = 0.85$)
			aaSIDRA: Single-lane circulating road and exclusive approach lanes						
W	Arm A	800	749	1 (T)	400	1433	628	0.637	33%
S	Arm B	1600	400	1 (L)	800	2199	999	0.801	6%
E	Arm C	1000	800	1 (L)	800	1255	749	1.068	-20%
			aaSIDRA: Two-lane circulating road and shared approach lanes						
W	Arm A	800	800	2 (TR)	430	1569	842	0.511	66%
S	Arm B	1600	400	2 (LR)	841	2091	1099	0.765	11%
E	Arm C	1000	800	2 (LT)	537	1471	789	0.680	25%
			TRL (UK) Linear Regression Model: Same results for both lane arrangements						
W	Arm A	800	800	-	-	1654	-	0.484	76%
S	Arm B	1600	400	-	-	1950	-	0.820	4%
E	Arm C	1000	800	-	-	1654	-	0.605	41%

- (1) The aaSIDRA circulating flow rate for the West approach includes capacity constraint effect due to oversaturation on East approach ($x > 1.0$) in the case of single-lane circulating road. Circulating flows for the TRL (UK) model, as well as the aaSIDRA model for two-lane circulating road, are without any capacity constraint since all approach lanes are estimated to be undersaturated ($x < 1.0$).
- (2) aaSIDRA approach degrees of saturation represent the critical lane degrees of saturation (L: Left, T: Through, R: Right). The TRL capacity model combines exclusive and shared lanes to obtain an average approach degree of saturation, and therefore cannot identify unequal lane utilization and cannot distinguish between different lane use arrangements.



Moore Street Roundabout, Sheffield, UK

(Modified for driving on the right-hand side of the road)



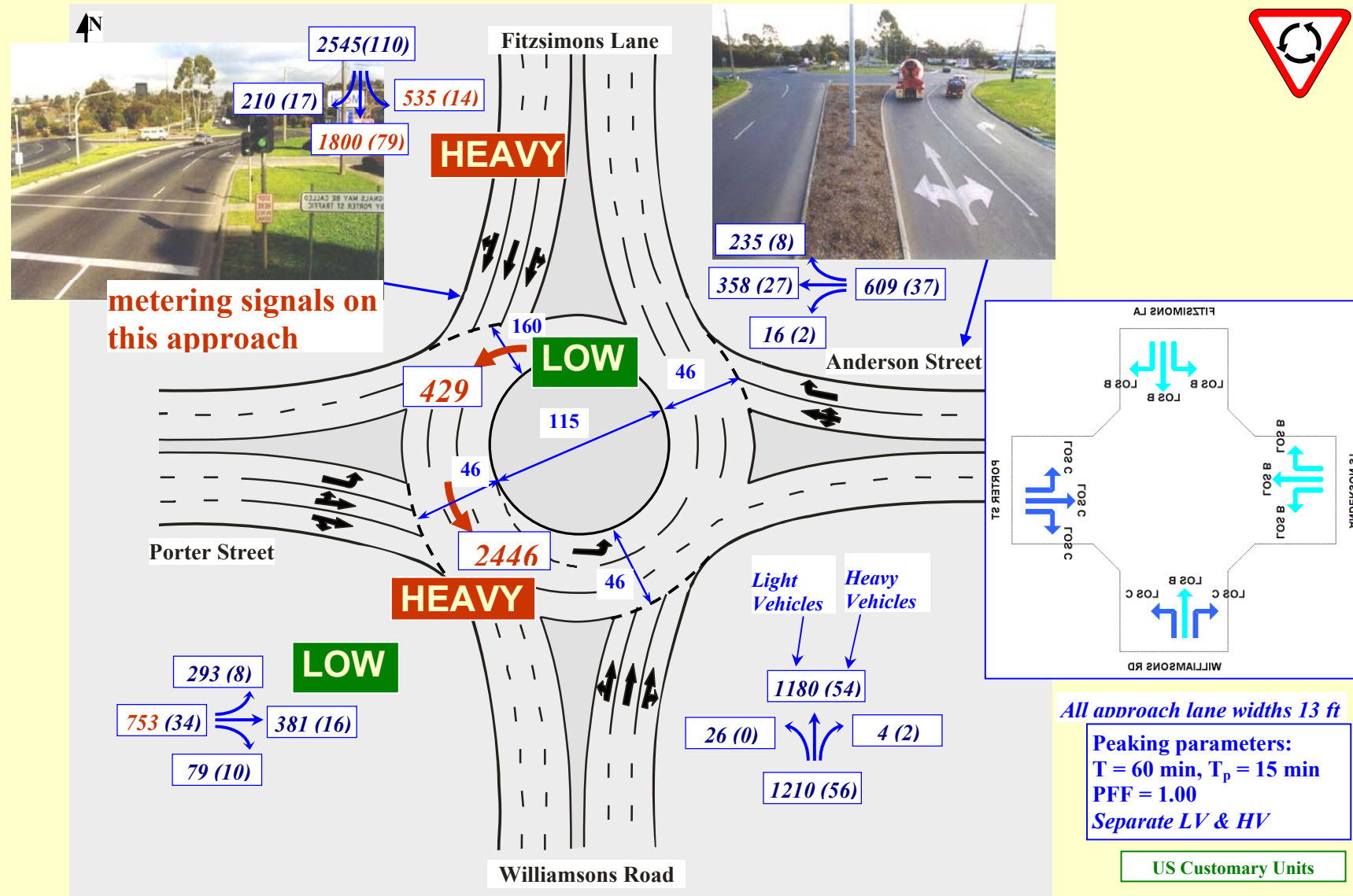
Moore Street Roundabout, Sheffield, UK (Morning 15-min Peak Period)

Comparison of aaSIDRA and TRL (UK) models

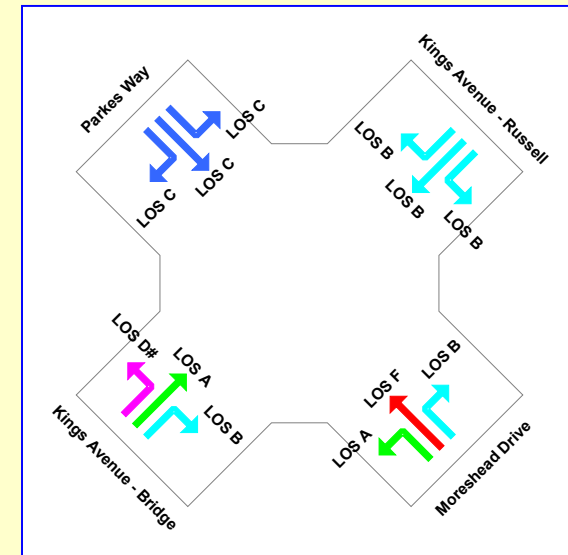
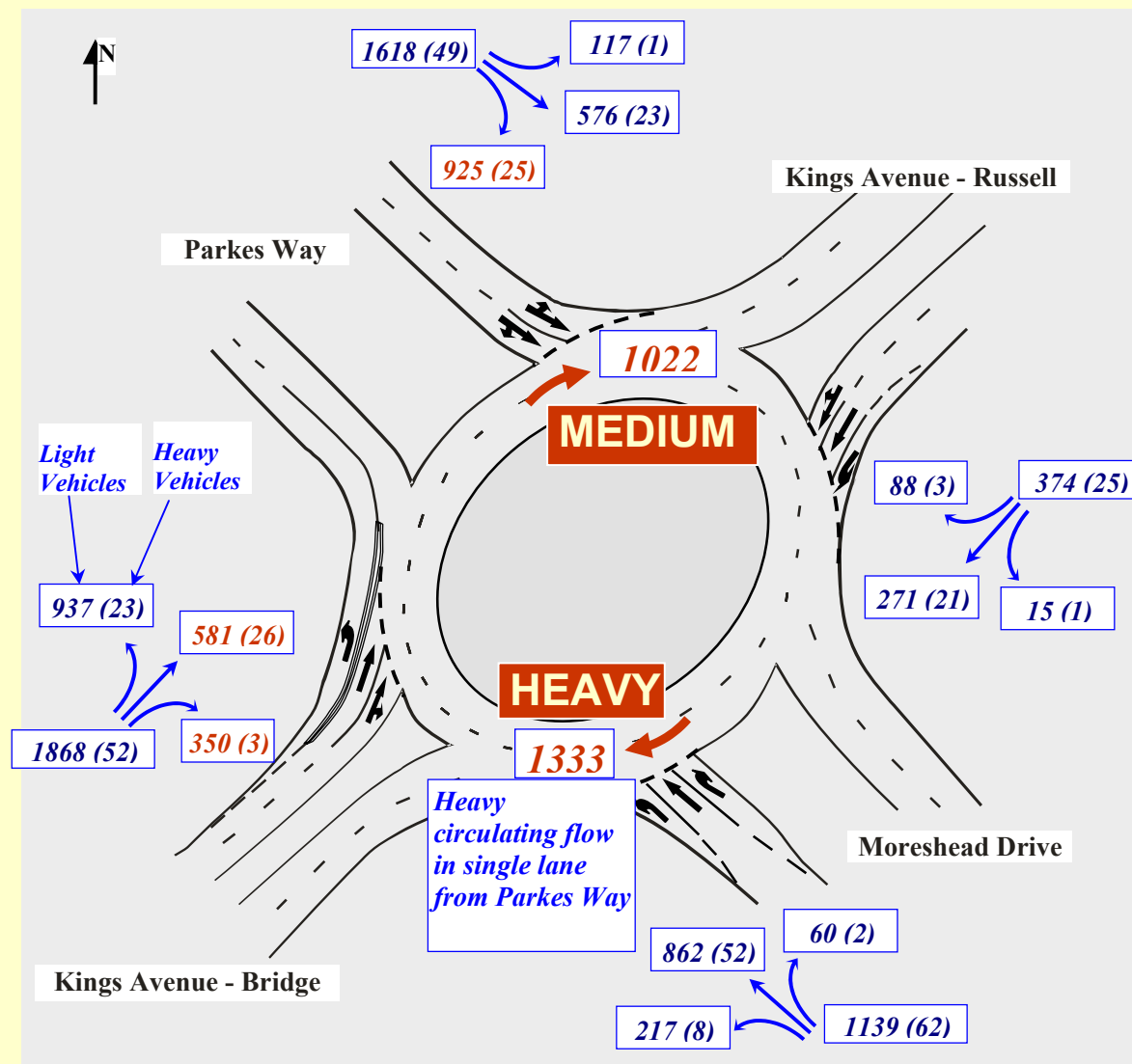
App. ID	Approach Name	Total App. Flow (veh/h)	Circul. Flow (1) (pcu/h)	Critical Lane (2)	Critical Lane Flow (veh/h)	Total App. Capacity (veh/h)	Critical Lane capacity (veh/h)	Degree of satn, x (v/c ratio)	Practical Spare Capacity ($x_p = 0.85$)
			aaSIDRA Model						
SW	St Mary's Gate	3206	542	2 (TR)	1223	3755	1433	0.854	0%
NW	Moore St	479	1207	1 (LT)	240	3205	1286	0.187	355%
NE	Hanover Way	592	2716	2 (T)	357	1152	434	0.823	3%
SE	Ecclesall Rd	1126	2884	3 (R)	360 (3)	934	263	1.367	-38%
			TRL (UK) Linear Regression Model						
SW	St Mary's Gate	3206	542	-	-	3842	-	0.834	2%
NW	Moore St	479	1303	-	-	2343	-	0.204	325%
NE	Hanover Way	592	2888	-	-	999	-	0.592	44%
SE	Ecclesall Rd	1126	2884	-	-	1714	-	0.657	29%



Fitzsimons Lane - Porter St Roundabout, Melbourne, Australia



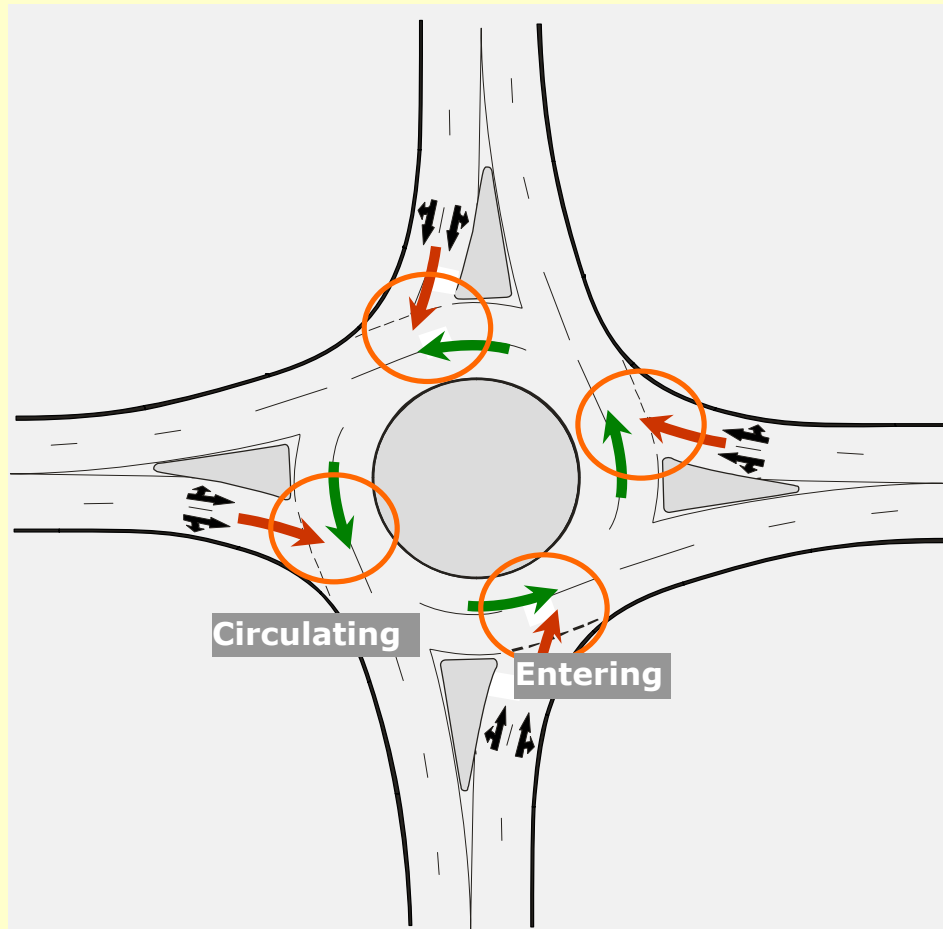
Parkes Way - Kings Avenue Roundabout, Canberra, Australia



Metric Units



Independent T-intersections vs interactions among roundabout approaches



aaSIDRA **O-D FACTOR**
allows for effects of

- **PRIORITY EMPHASIS**
- **PRIORITY SHARING**
- **PROPORTION QUEUED**
on each approach road
- **Approach and circulating**
LANE USE

Unbalanced demand flows reduce capacity

Total Circulating Flow = 1000

Pattern A:

BALANCED

Flow₁ = 500

Flow₂ = 500

Pattern B:

WEST Dominant

Flow₁ = 100

Flow₂ = 900

Pattern C:

NORTH Dominant

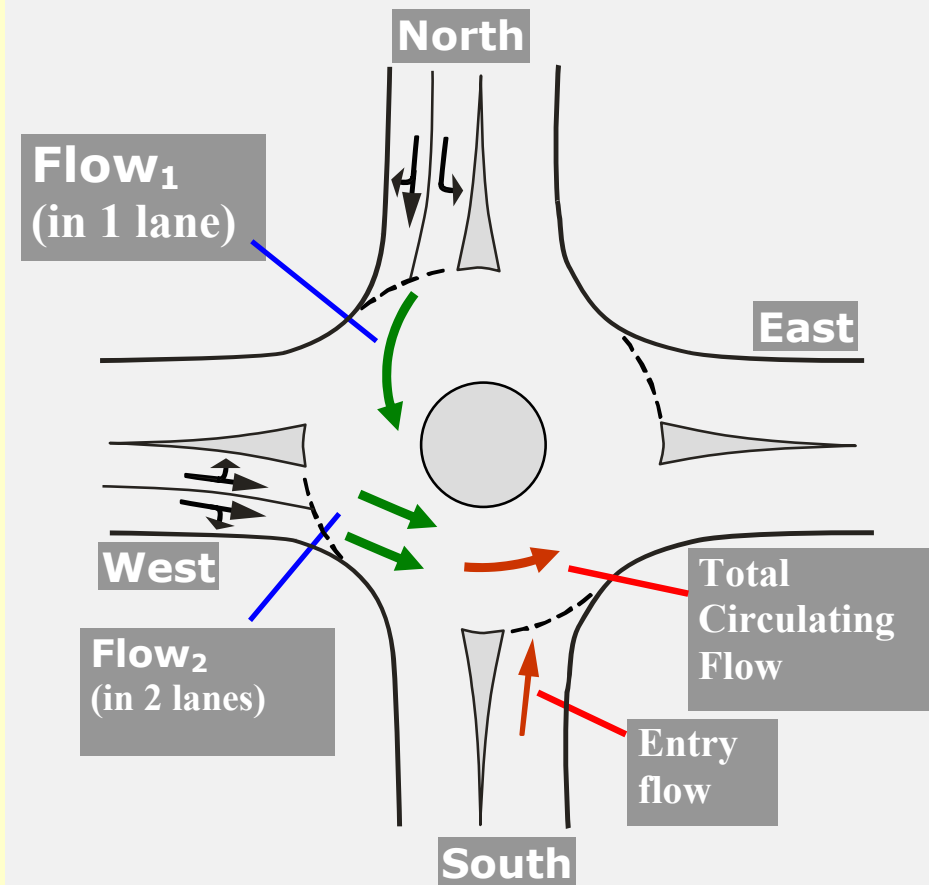
Flow₁ = 900

Flow₂ = 100

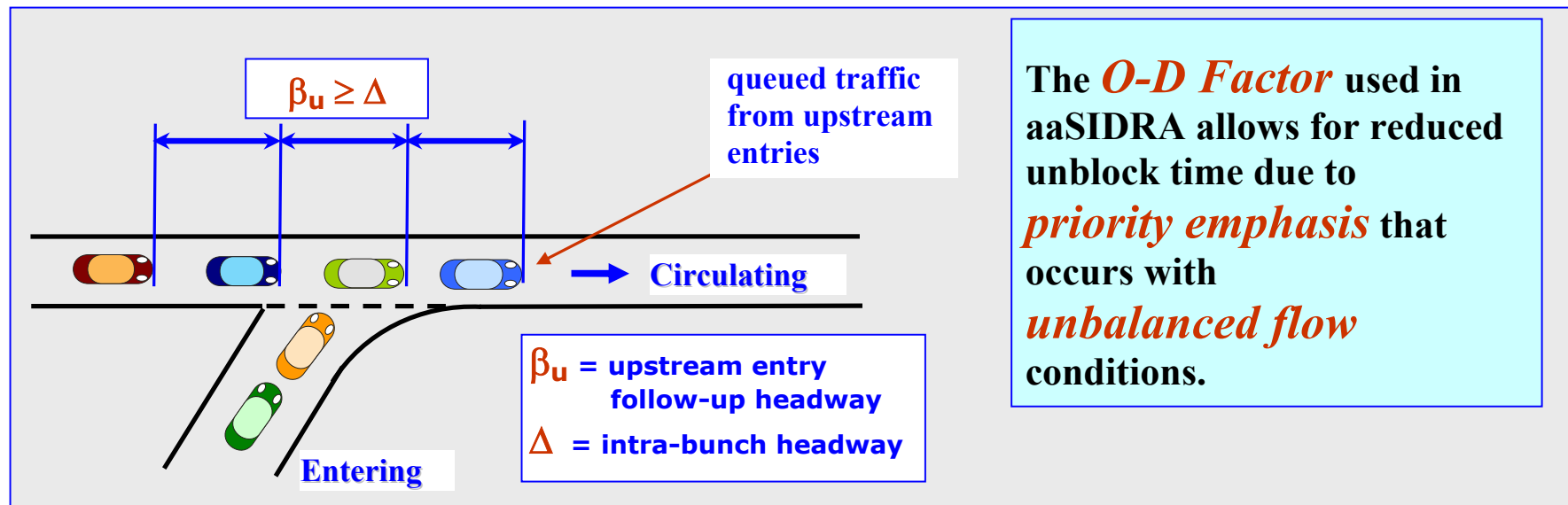
LESS
capacity

Dominant
flow in
TWO LANES

Dominant
flow in
ONE LANE

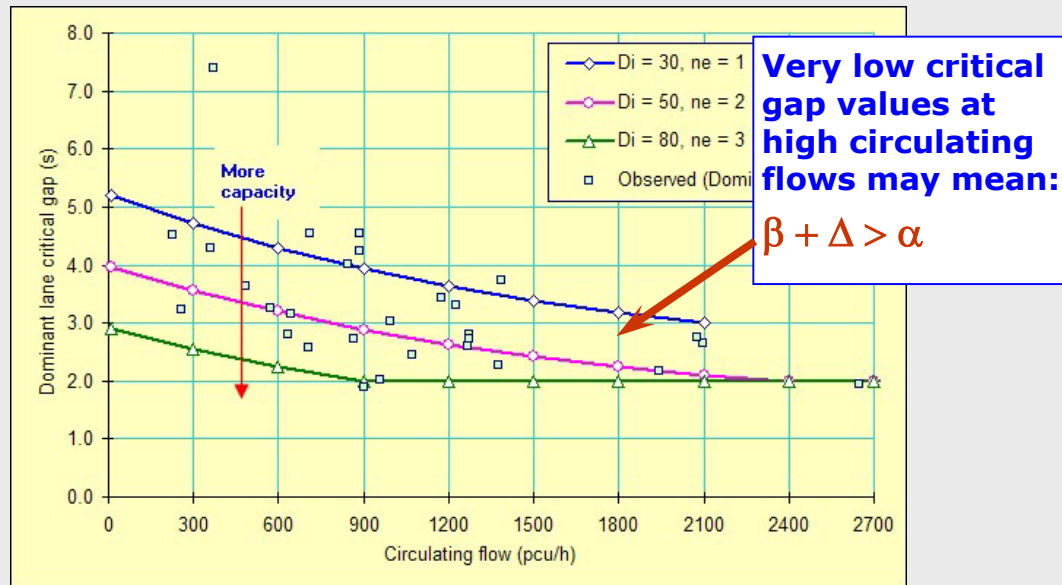
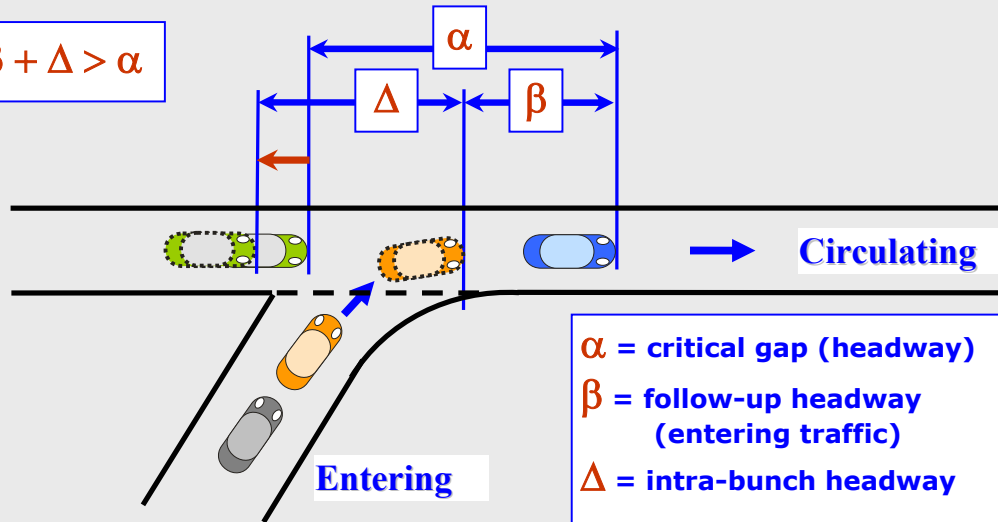


Priority Emphasis due to Unbalanced Flows



Priority Sharing (Priority Reversal)

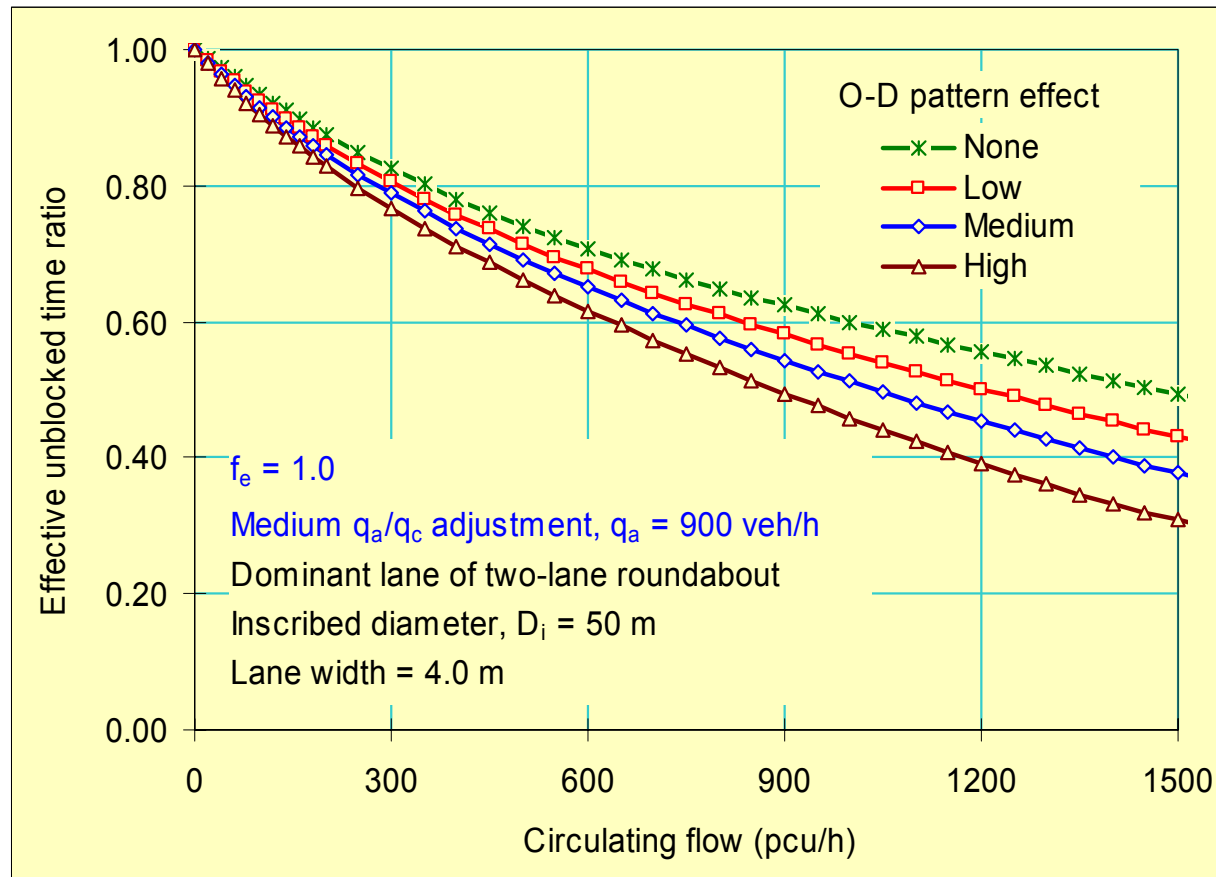
$$\beta + \Delta > \alpha$$



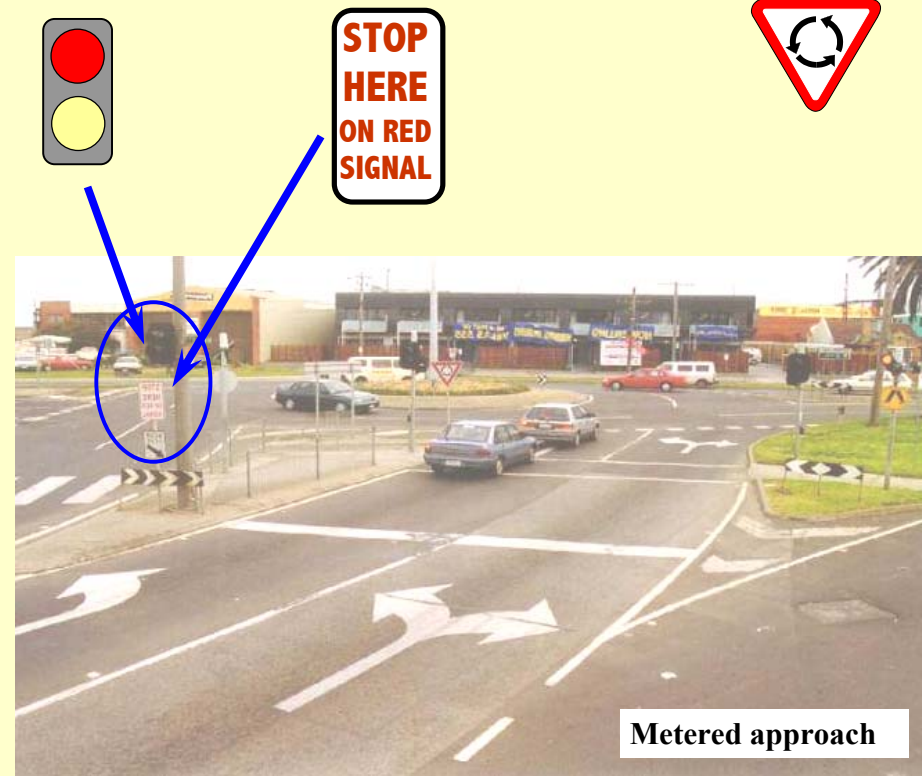
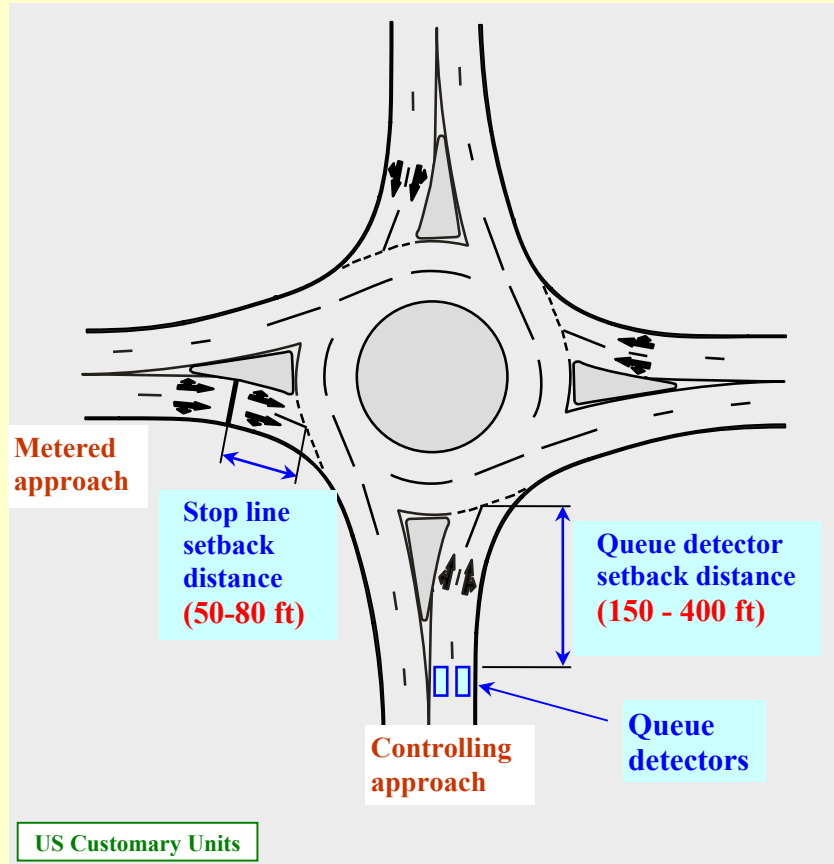
- ◆ The gap-acceptance capacity formula based on **absolute priority** of circulating stream vehicles needs to be adjusted for **PRIORITY SHARING** between entering and circulating vehicles at high circulating flows.
- ◆ The priority-sharing method **reduces** the capacity estimated by the absolute-priority 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 Origin-Destination (O-D) Factor in aaSIDRA

Effective unblocked time ratio for three levels of O-D flow pattern effect (and without the O-D pattern factor)



Roundabout Part-time Metering Signals



Use of metering signals with an example from Melbourne, Australia (picture modified to show driving on the right-hand side of the road)

Case Studies and Model Comparison

Case studies show that roundabout capacity and level of service depend not only on the **circulating flow rate** but also the **characteristics of approach flows** contributing to the circulating flow:

The case studies highlight **systematic differences** between two widely used analytical models:

- ♦ **aaSIDRA gap acceptance** model
- ♦ **TRL (UK) linear regression** model

Possible reasons for the **contradictory results** that may be obtained from these models are discussed.

Such systematic model differences have important practical **design implications**.



Disclaimer

The author is the developer of the **aaSIDRA model**, and comments presented in this paper regarding other models should be read with this in mind.

The comments about the **TRL (UK) linear regression model** are relevant to the original published model and are valid for software packages using that model only to the extent that the original model is used without modification to address the issues raised in this paper.



Modeling issues

A simplistic view of capacity models considers **analytical models only**, and classifies them into two **mutually exclusive** categories!

- ♦ **"theoretical (gap-acceptance) only"**
- ♦ **"empirical only"**.

The issue, while narrowly focused, has been discussed widely among traffic engineering researchers and practitioners.

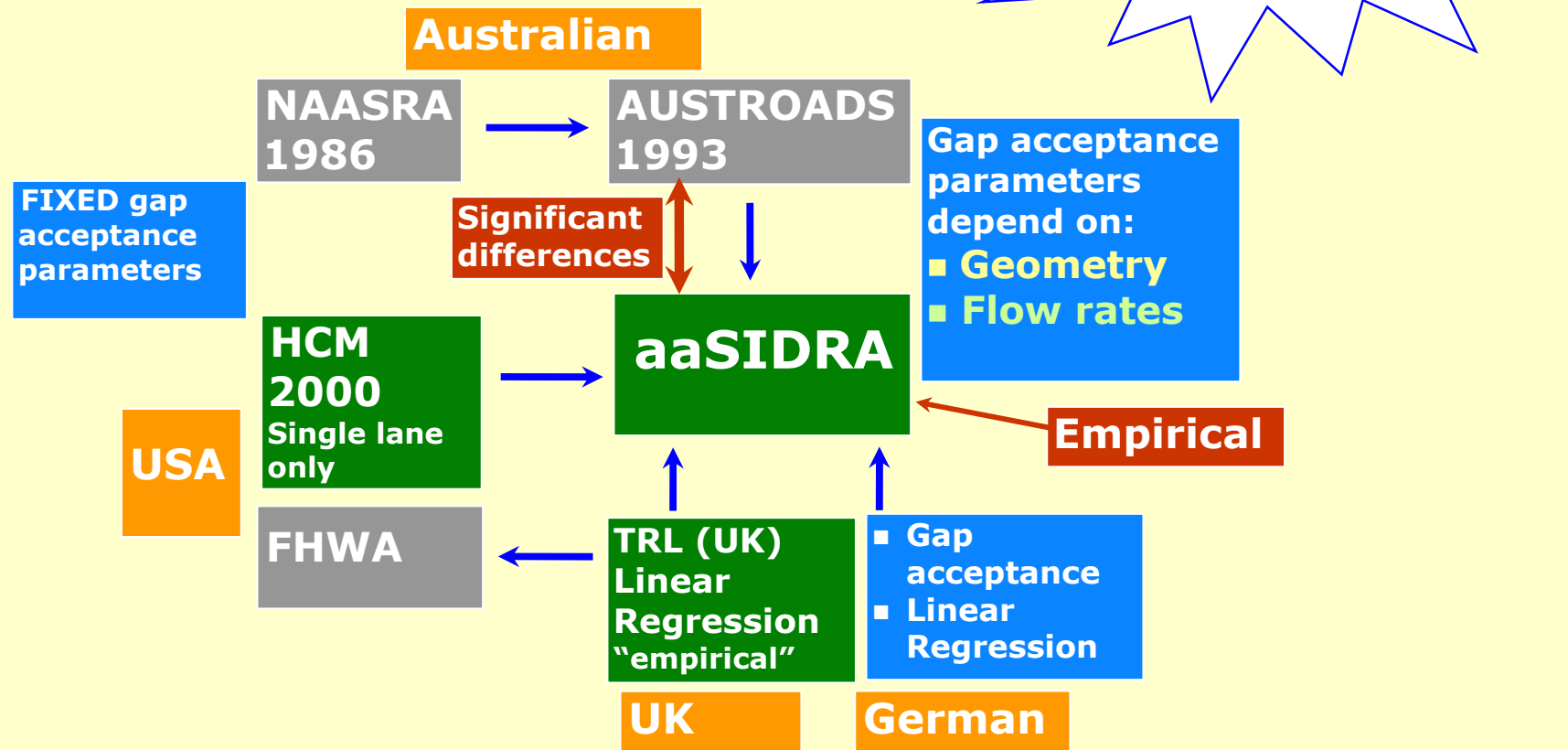
A model can be (and should be) **based on TRAFFIC THEORY but EMPIRICAL at the same time.**

This diverts attention from important methodological issues, e.g.

- ♦ lane-by-lane: **aaSIDRA**
- ♦ by lane group: **HCM - HCS**
- ♦ by approach: **TRL (UK)**



Roundabout capacity models (analytical)



Australian roundabout survey data used for calibrating the Australian gap-acceptance based capacity and performance models

	Total entry width (ft)	No. of entry lanes	Average entry lane width (ft)	Circul. width (ft)	Inscribed Diameter (ft)	Entry radius (ft)	Conflict angle (°)
Minimum	12	1	10	21	52	13	0
Maximum	41	3	18	39	722	∞	80
Average	27	2	13	31	183	128	29
15th percentile	21	2	11	26	93	33	0
85th percentile	34	3	15	39	230	131	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

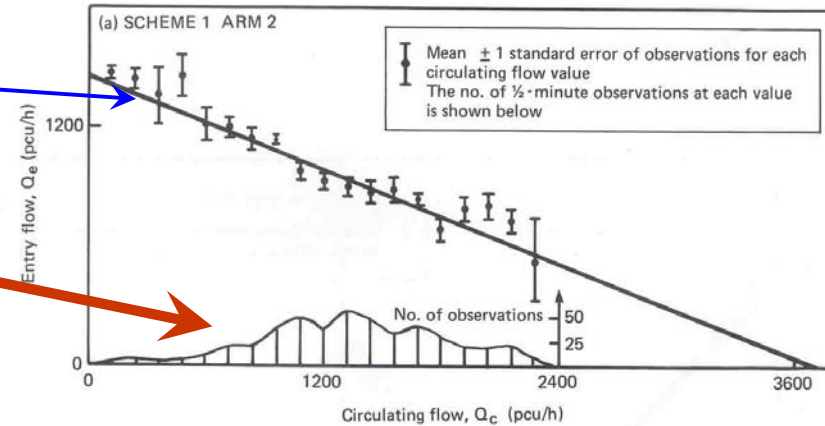


Data from roundabout capacity surveys at UK roundabouts

At-grade roundabout in Wincheap, Canterbury, UK

*Regression
line*

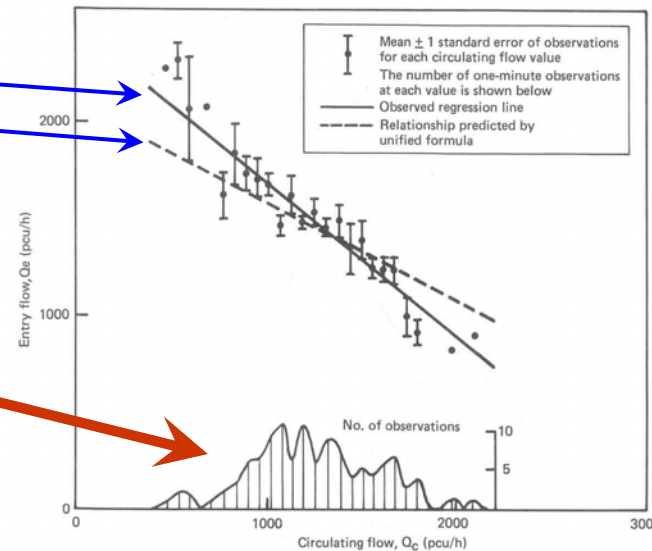
Small number of data
points at low and high
circulating flows



Grade-separated roundabout in Bradford, UK

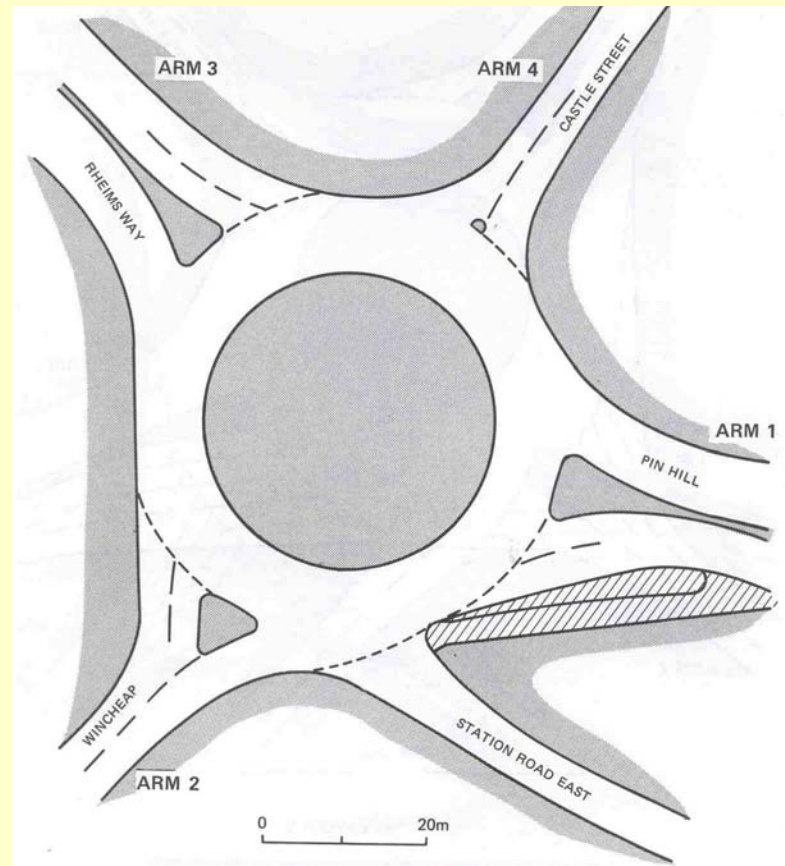
*Regression
lines*

Small number of data
points at low and
high circulating flows

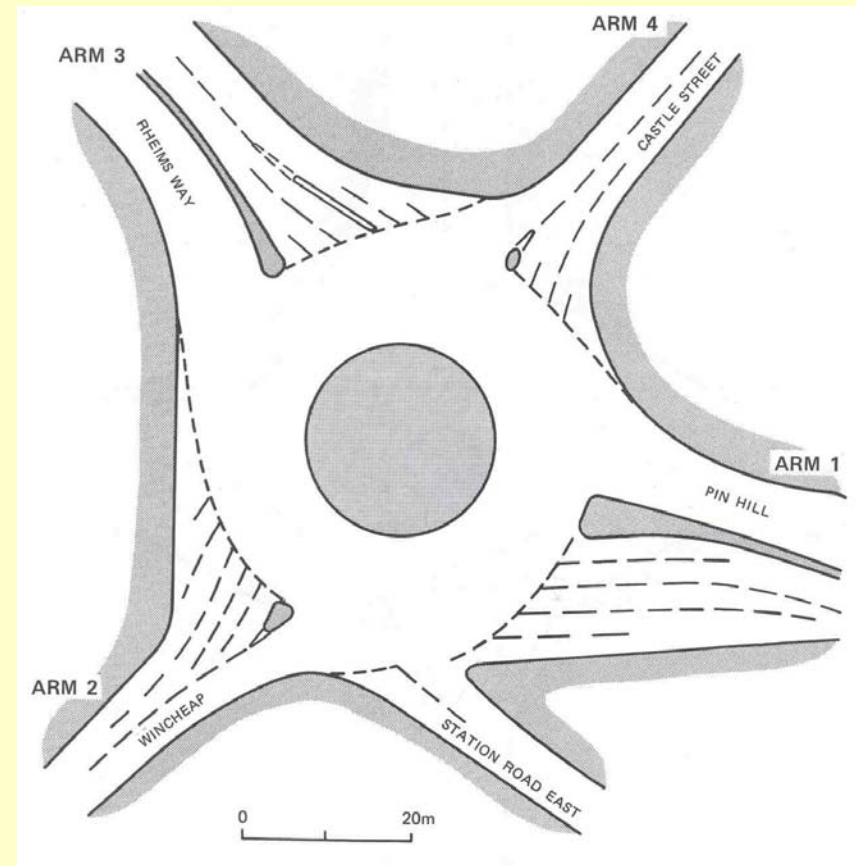


Examples of 'Conventional' and 'Offside Priority' roundabout designs used in capacity measurements for TRL (UK) linear regression model

'Conventional' Design



'Offside Priority' Design



Modeling issues

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.

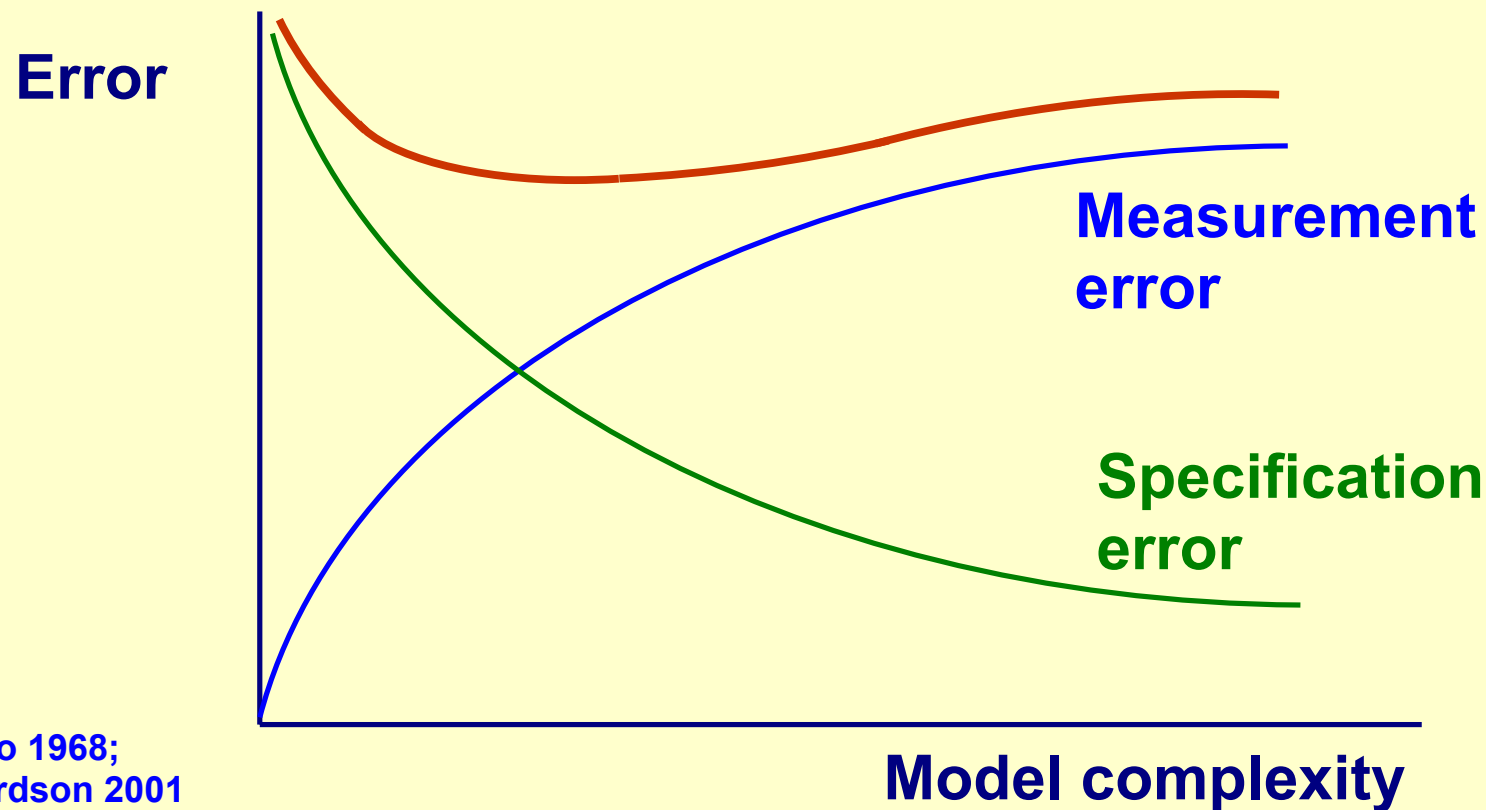
Comparisons of performance estimates from different microsimulation models and between microsimulation and analytical models are recommended.

ANIMATION is useful **BUT the results are not more accurate because it is simulation!**



Estimation Errors

ANIMATION is useful **BUT** the results are not more accurate because it is **simulation!** Question model assumptions !



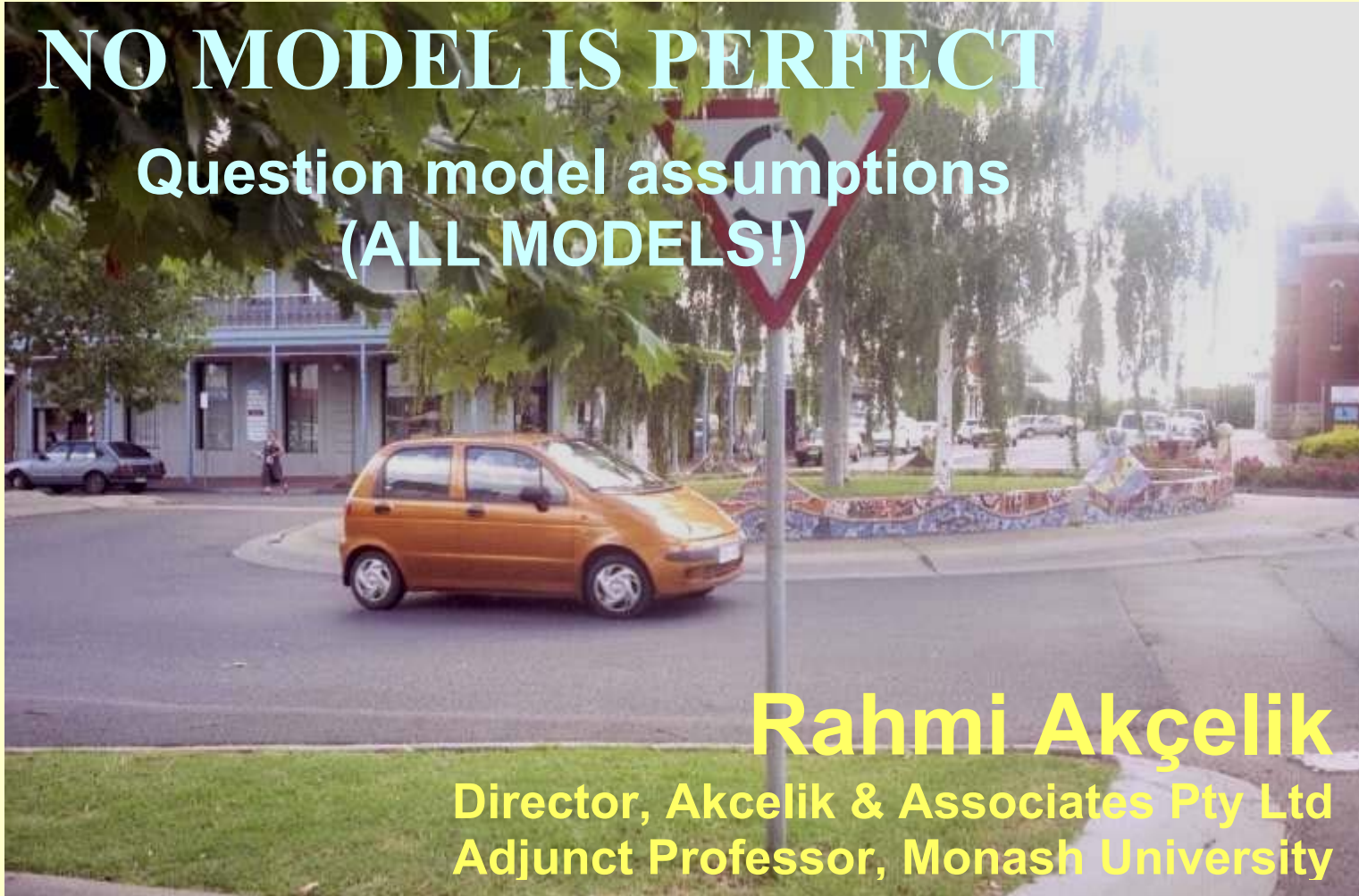
Alonso 1968;
Richardson 2001



End of presentation

NO MODEL IS PERFECT

**Question model assumptions
(ALL MODELS!)**



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Adjunct Professor, Monash University**

