Capacity and Performance Analysis of Roundabout Metering Signals

TRB National Roundabout Conference
Vail, Colorado, USA, 22-25 May 2005

Pictures modified to show driving on the right-hand side of the road

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

Metering Signals

- Cost-effective measure to avoid the need for a fully-signalized intersection treatment when low capacity conditions occur during peak demand flow periods, for example due to unbalanced flow patterns.
- Often installed on selected roundabout approaches and used on a part-time basis since they are required only when heavy demand conditions occur during peak periods.
- Used in Australia, UK and USA to alleviate the problem of excessive delay and queuing by creating gaps in the circulating stream.
- The Australian roundabout and traffic signal guides acknowledge the problem and discuss the use of metering signals.

Roundabout Problems? - Australia

Liberal Party
SOUTH AUSTRALIA

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7 May 2005

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ROUNDABOUT DELAY UPHOLDS GOVT INABILITY TO DELIVER
Thursday, 17 March 2005

Liberal Infrastructure spokesperson Wayne Matthew said today's announcement of added delays in the reconstruction of the Britannia Roundabout was further evidence of the Rann Government's inability to deliver on major projects.

Mr Matthew described the setback as yet another example of the government's failure to invest in the State's transport infrastructure.

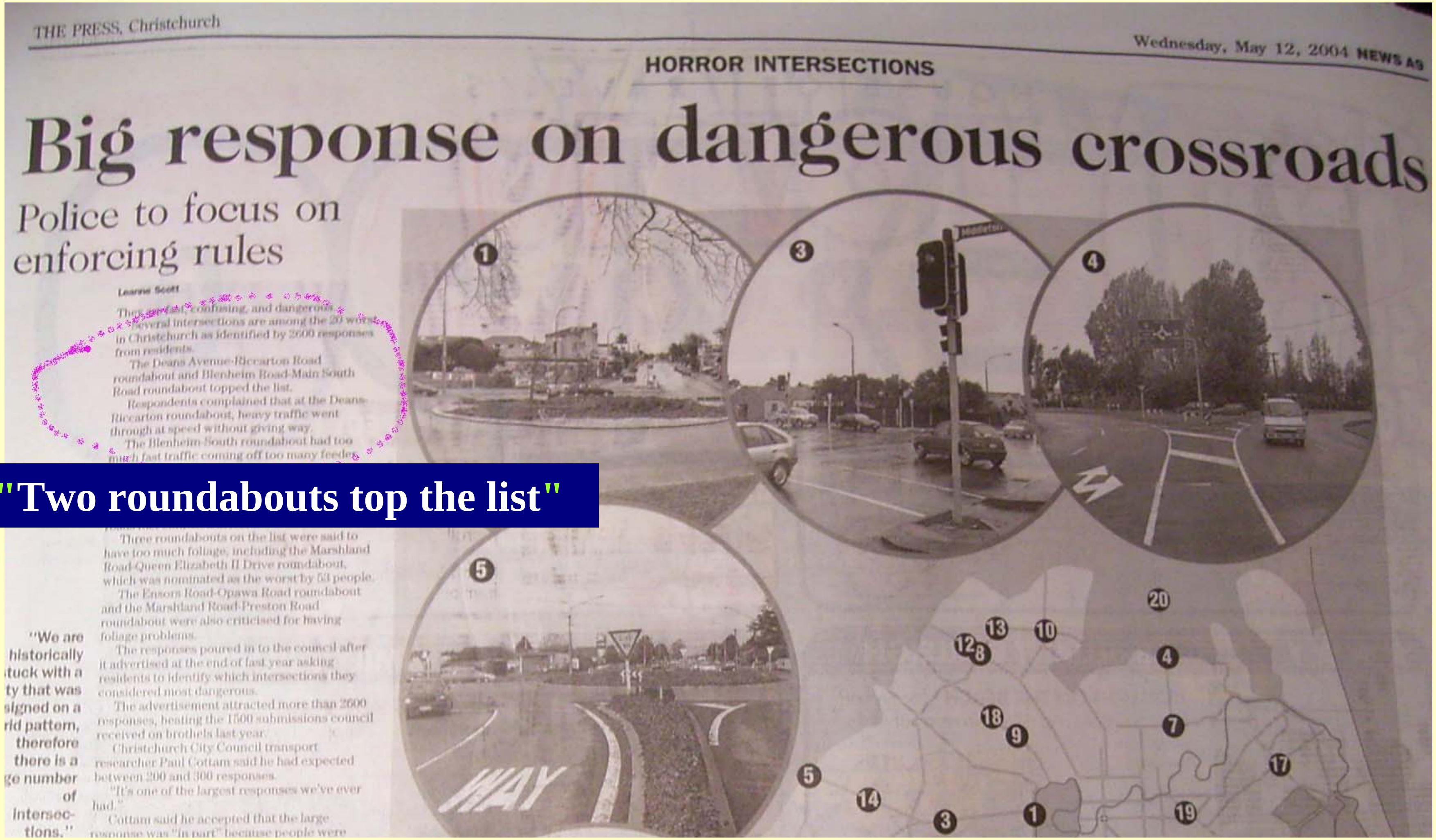
"The Britannia Roundabout is one of South Australia's most notorious traffic blackspots," Mr Matthew said.

"Transport SA figures show it is the site of around 115 accidents per year, making it one of the most hazardous traffic locations in the state.

"The roundabout capacity is now approaching saturation point with 41,000 drivers using the intersection each day and another 10,000 believed to avoid it because of congestion.

"It is long overdue for an overhaul and now the Rann Government

Roundabout Problems? - New Zealand



THE PRESS, Christchurch

Wednesday, May 12, 2004 NEWS A9

HORROR INTERSECTIONS

Big response on dangerous crossroads

Police to focus on enforcing rules

Leanne Scott

... confusing, and dangerous ... several intersections are among the 20 worst in Christchurch as identified by 2600 responses from residents.

The Deans Avenue-Riccarton Road roundabout and Blenheim Road-Main South Road roundabout topped the list.

Respondents complained that at the Deans-Riccarton roundabout, heavy traffic went through at speed without giving way.

The Blenheim-South roundabout had too much fast traffic coming off too many feeder ...

Three roundabouts on the list were said to have too much foliage, including the Marshland Road-Queen Elizabeth II Drive roundabout, which was nominated as the worst by 53 people.

The Ensors Road-Opawa Road roundabout and the Marshland Road-Preston Road roundabout were also criticised for having foliage problems.

The responses poured in to the council after it advertised at the end of last year asking residents to identify which intersections they considered most dangerous.

The advertisement attracted more than 2600 responses, beating the 1500 submissions council received on brothels last year.

Christchurch City Council transport researcher Paul Cottam said he had expected between 200 and 300 responses.

"It's one of the largest responses we've ever had."

Cottam said he accepted that the large response was "in part" because people were ...

"We are historically ... tuck with a ... ty that was ... signed on a ... rid pattern, therefore there is a ... ge number of intersections."

"Two roundabouts top the list"

Roundabout Problems? - UK

thisisoxfordshire.co.uk

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First published on Wednesday 06 February 2002:

Drivers see red over roundabout delays

Drivers on Oxford's Barton estate are being forced to wait 20 minutes during rush-hour to get on to the city's busiest roundabout.

Now Oxford City Council's Headington councillor, Alex Hollingsworth, says installing traffic lights at the five-exit Green Road roundabout has become an urgent priority.

Funeral directors are among those backing his appeal.

Residents in Headington and Barton have campaigned for ye roundabout.

Traffic is always busy because the roundabout is the gatewa to the M40 and London, and the nearby Sandhills park-and-r

Cllr Hollingsworth said: "Drivers living on the Barton estate c every morning to get on to the roundabout.

"It is unreasonable to expect them to have to wait so long to get out onto the ring road, particularly if they have a long journey ahead of them.

"The bus companies in Oxford are also experiencing problems because drivers are finding it so hard to get off the estate."

Funeral services, whose corteges have to go round the roundabout to get to the crematorium in Bayswater Road, backed the call for traffic signals. Sandra Homewood, partner at S&R Childs Funeral Services in London Road, Headington, said: "If you have a cortege with a hearse and following cars, there is no way you can stick together, and the sooner traffic lights are brought in, the better.

"Councilor A.H. says installing traffic lights at the five-exit Green Road roundabout has become urgent priority. Funeral directors are among those backing his appeal"

This paper

- The basic principles of the operation of roundabout metering signals explained
- Results of analysis of a case study of a roundabout operating with metering signals presented

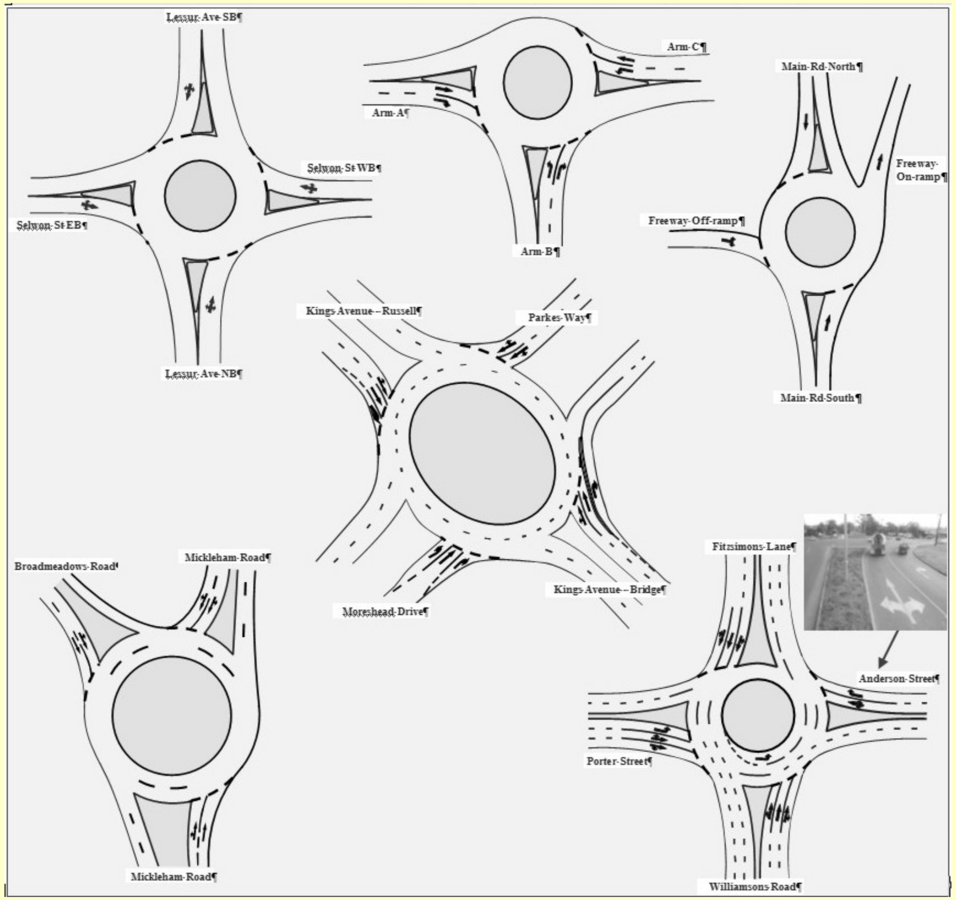
Other case studies published
(see the ITE 2004 paper by the author)

Country
- Australia
- UK
- USA

Roundabout size
- 1-lane
- 2-lane
- 3-lane

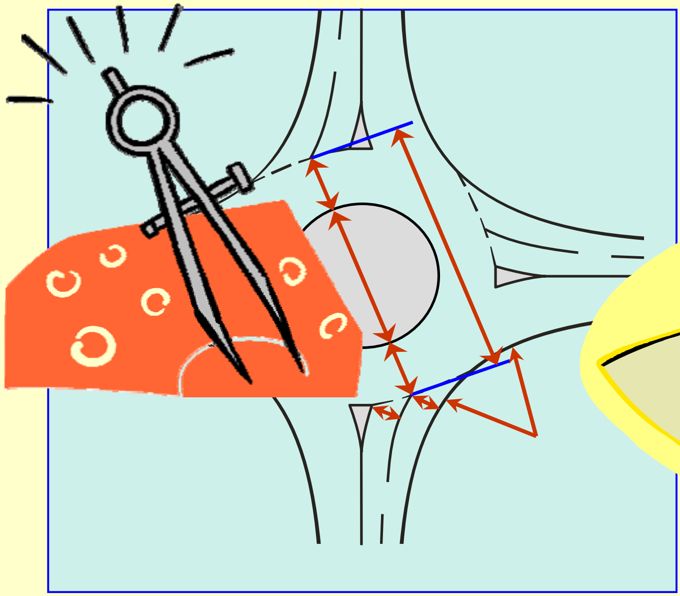
Demand volumes
- Large
- Small

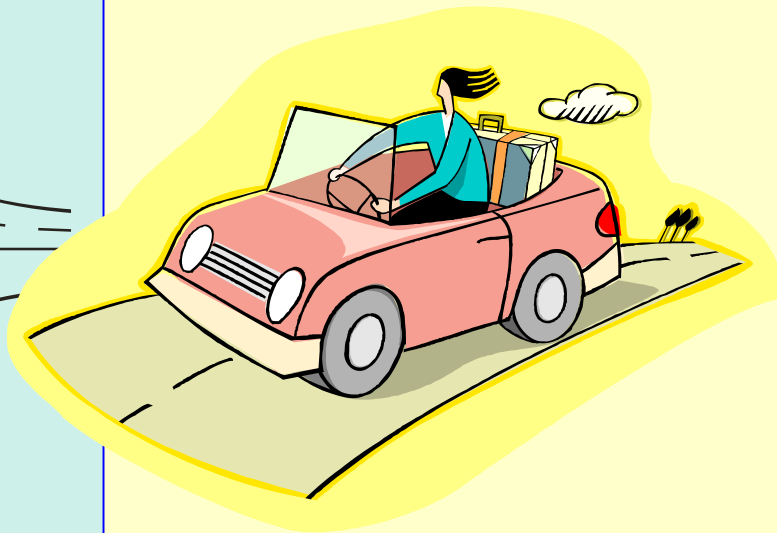
1700 to 5300 veh/h



Roundabout capacity and performance

- 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.

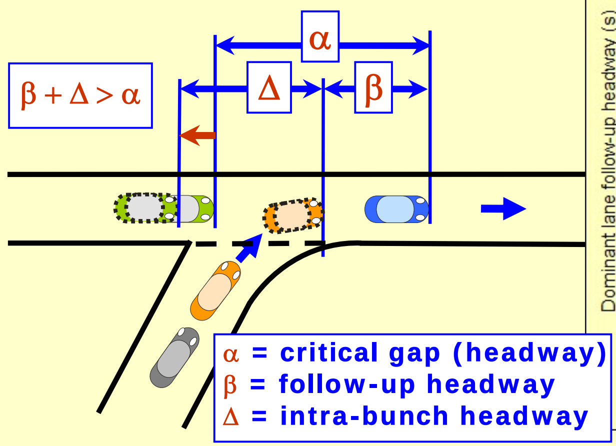


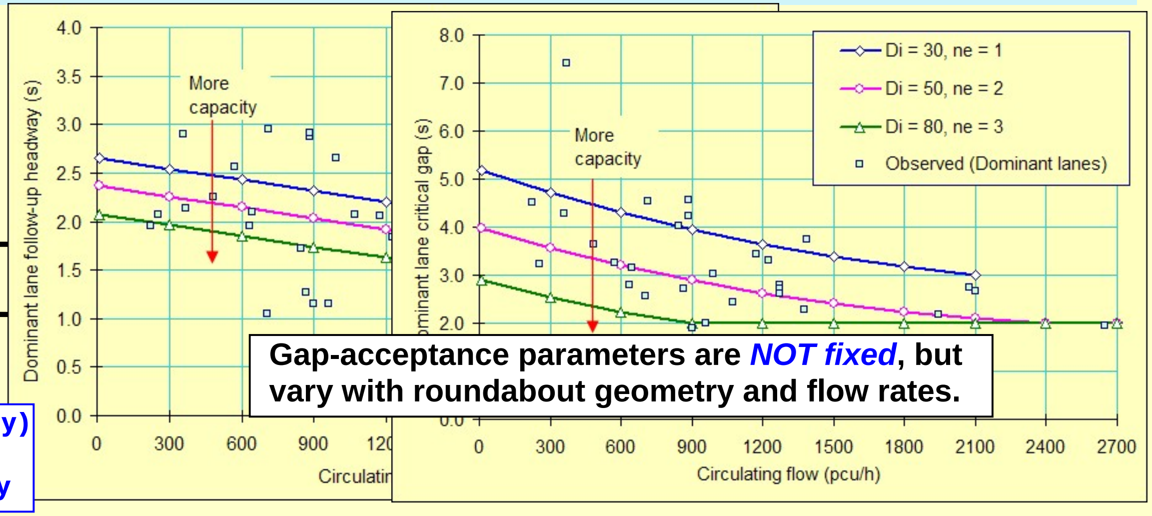


Roundabout capacity and performance

aaSIDRA used in the analyses reported in this paper employs an *empirical gap-acceptance method* to model roundabout capacity and performance. The model allows for the effects of *both roundabout geometry and driver behaviour*, and it incorporates effects of *priority reversal* (low critical gaps at high circulating flows), *priority emphasis* (unbalanced O-D patterns), and *unequal lane use* (both approach and circulating lanes).

CAPACITY can be measured as a *service rate* for each traffic *lane* in *undersaturated conditions* (v/c ratios less than 1) according to the HCM definition of capacity to represent "*prevailing conditions*". This is in contrast with measuring *approach* capacity in *oversaturated conditions*.





Gap-acceptance parameters are *NOT fixed*, but vary with roundabout geometry and flow rates.

Origin-destination demand flow pattern

The operation of a roundabout is a closed-loop system where the conditions of traffic streams entering from approach roads affect traffic on other approaches (not just the circulating flow rate).

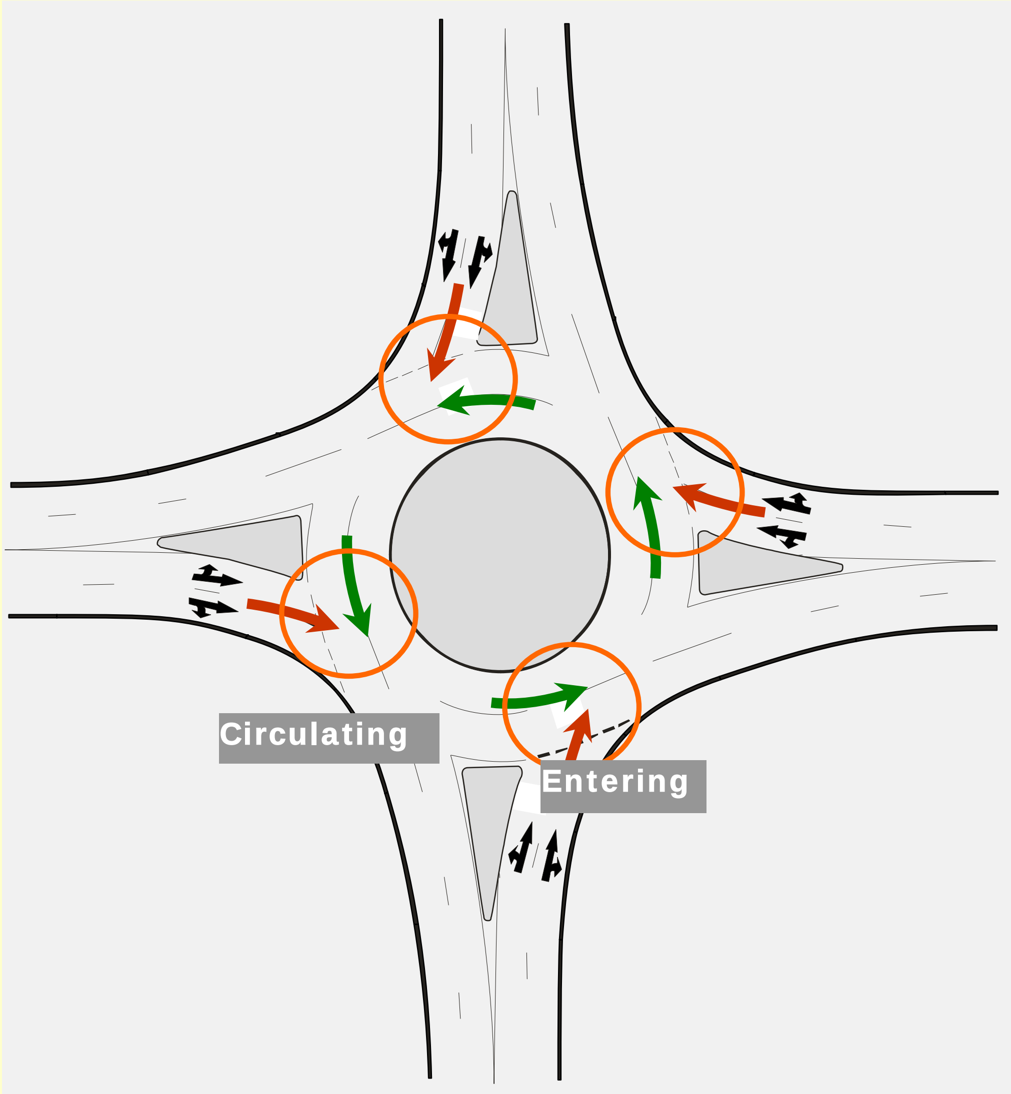
As a result, important factors that influence the capacity and performance of traffic on roundabout approach roads:

- **Origin-Destination pattern of arrival (demand) flows**
- **Approach and circulating lane use**

Related issues discussed in the paper:

- ***priority reversal* and**
- ***priority emphasis***

O-D factor method (aaSIDRA)



- Treating the roundabout as *a series of* ***independent T-junctions*** is not good enough (**capacity constraint** on circulating flows is not sufficient).
- Model **interactions among approach flows**

O-D factor method (aaSIDRA)

- Traditional methods may be adequate for low flow conditions, the O-D factor improves the prediction of capacities under medium to heavy flow conditions, especially with unbalanced demand flows.
- The O-D factor helps to avoid capacity overestimation under such conditions as observed at many real-life intersections.
- Overoptimistic results without the O-D factor method. This represents a substantial change to the method described in the Australian Roundabout Guide from which aaSIDRA originated. Same with other methods (HCM, TRL).

Unbalanced demand flows reduce capacity

Total Circulating Flow = 1000

Pattern A:
BALANCED
$Flow_1$ = 500
$Flow_2$ = 500

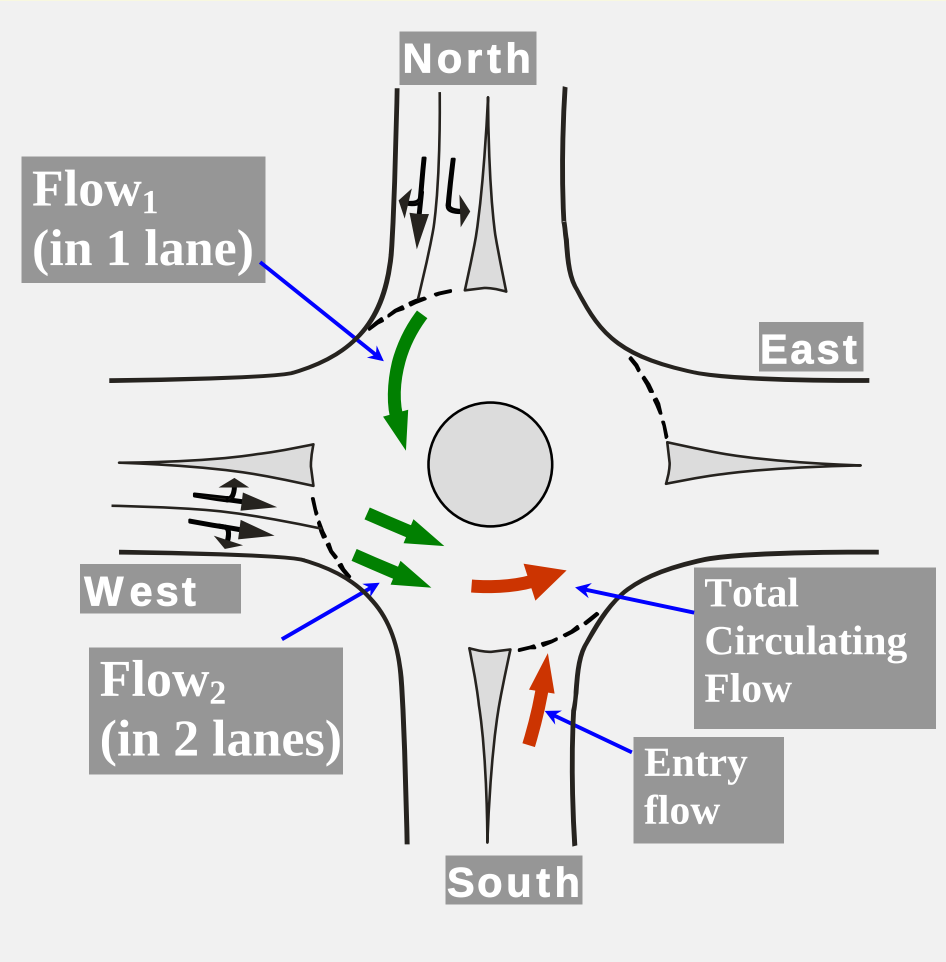
Pattern B:
WEST Dominant
$Flow_1$ = 100
$Flow_2$ = 900

Pattern C:
NORTH Dominant
$Flow_1$ = 900
$Flow_2$ = 100

LESS capacity

Dominant flow in 2 lanes

Dominant flow in 1 lane



Effect of the O-D pattern

- **Different capacities and levels of performance may be estimated for the same circulating flow rate depending on the conditions of the component streams.**
- **The lowest capacity is obtained when:**
  - **main opposing stream is a very large proportion of the total circulating flow (unbalanced),**
  - **it is in a single lane, and**
  - **is highly queued on the approach lane it originates from.**

Priority Emphasis - What is it?

Grange Rd, St Georges Rd and Alexandra Avenue in Toorak, Melbourne, Australia
(photo modified for driving on the right-hand side of the road)

Huddart, UK (1983)

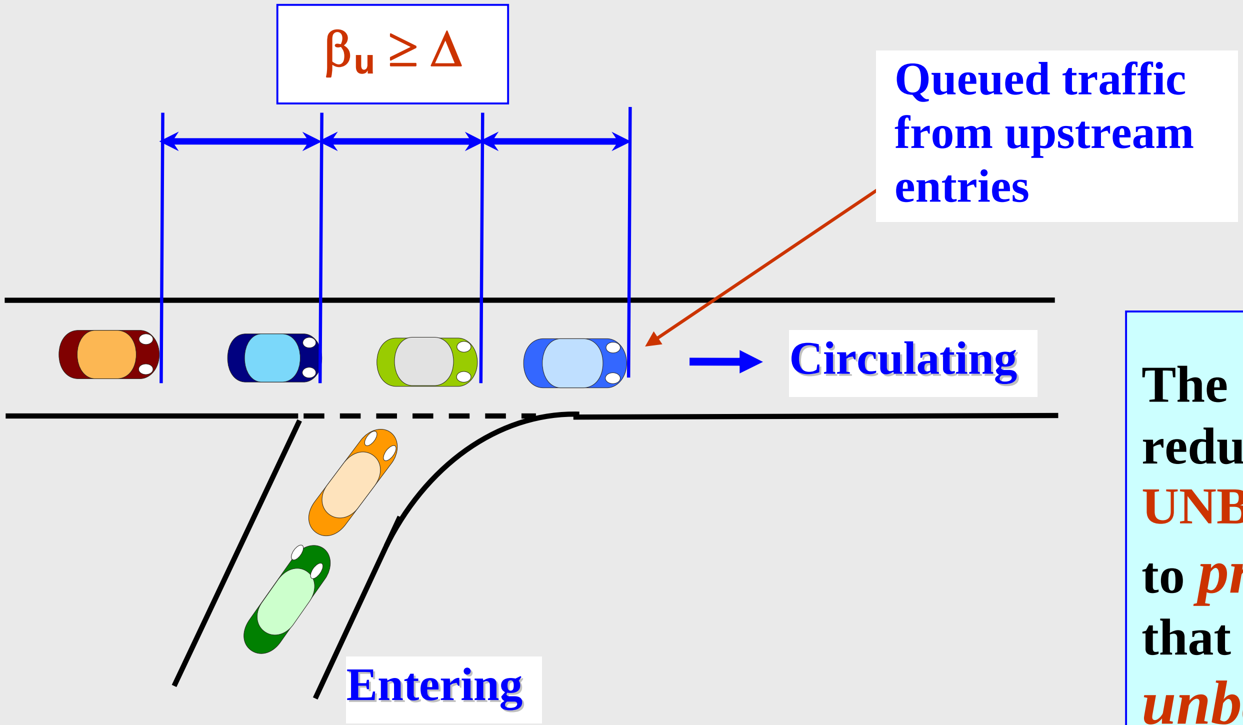
"… the proper operation of a roundabout depends on there being a reasonable balance between the entry flows. … an uninterrupted but not very intense stream of circulating traffic can effectively prevent much traffic from entering at a particular approach."

"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."

Priority Emphasis

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

Priority Emphasis

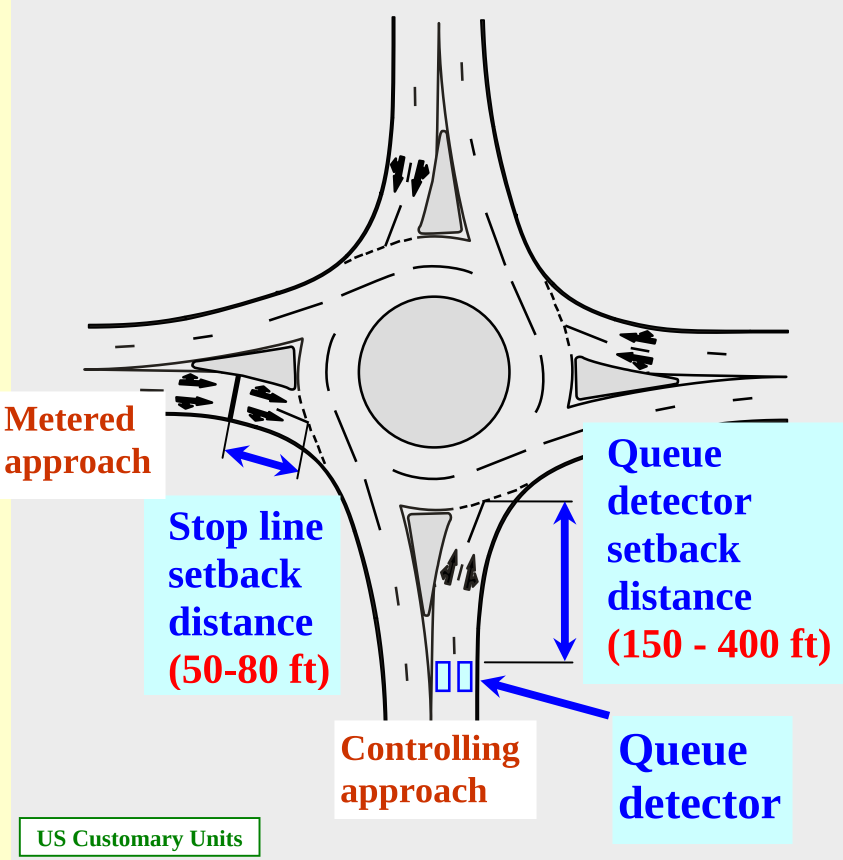


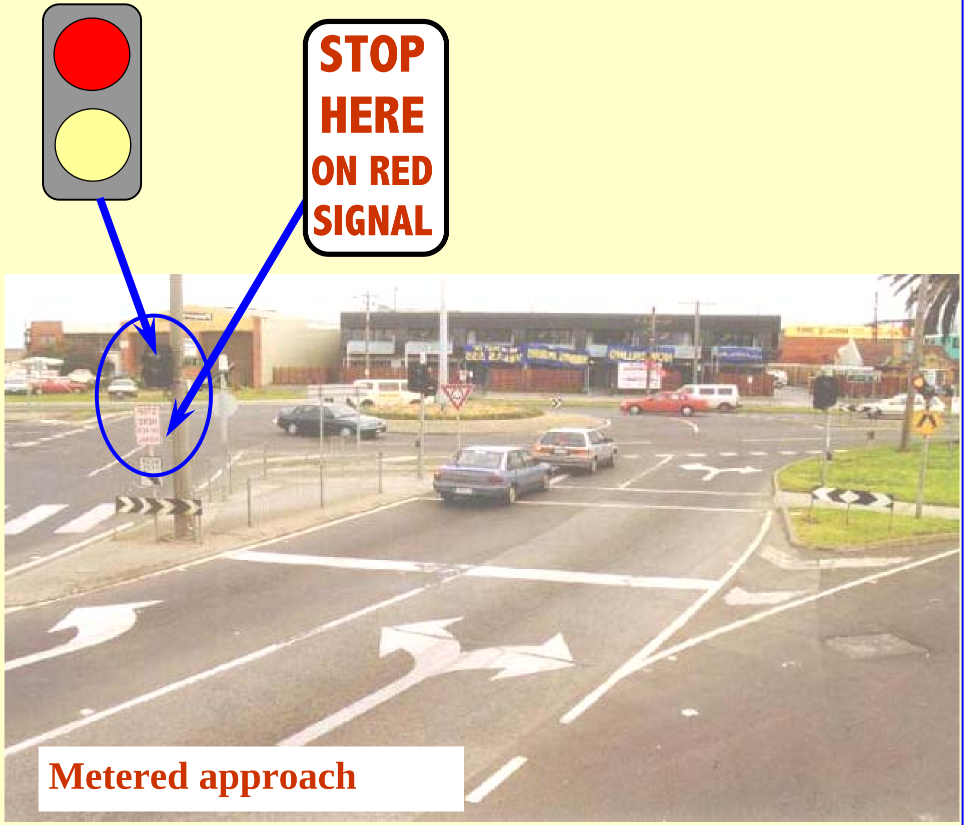
β_u = upstream entry follow-up headway
Δ = intra-bunch headway

The *O-D Factor* reduces the UNBLOCK TIME due to *priority emphasis* that occurs with *unbalanced flow* conditions.

Roundabout Part-time Metering Signals

Typical arrangements with metering signals with an example from Melbourne, Australia





Use of pedestrian-actuated signals for roundabout metering (Fitzsimons Lane - Porter St Roundabout, Melbourne, Australia)

Use metering signals at the Clearwater roundabout, Florida, USA

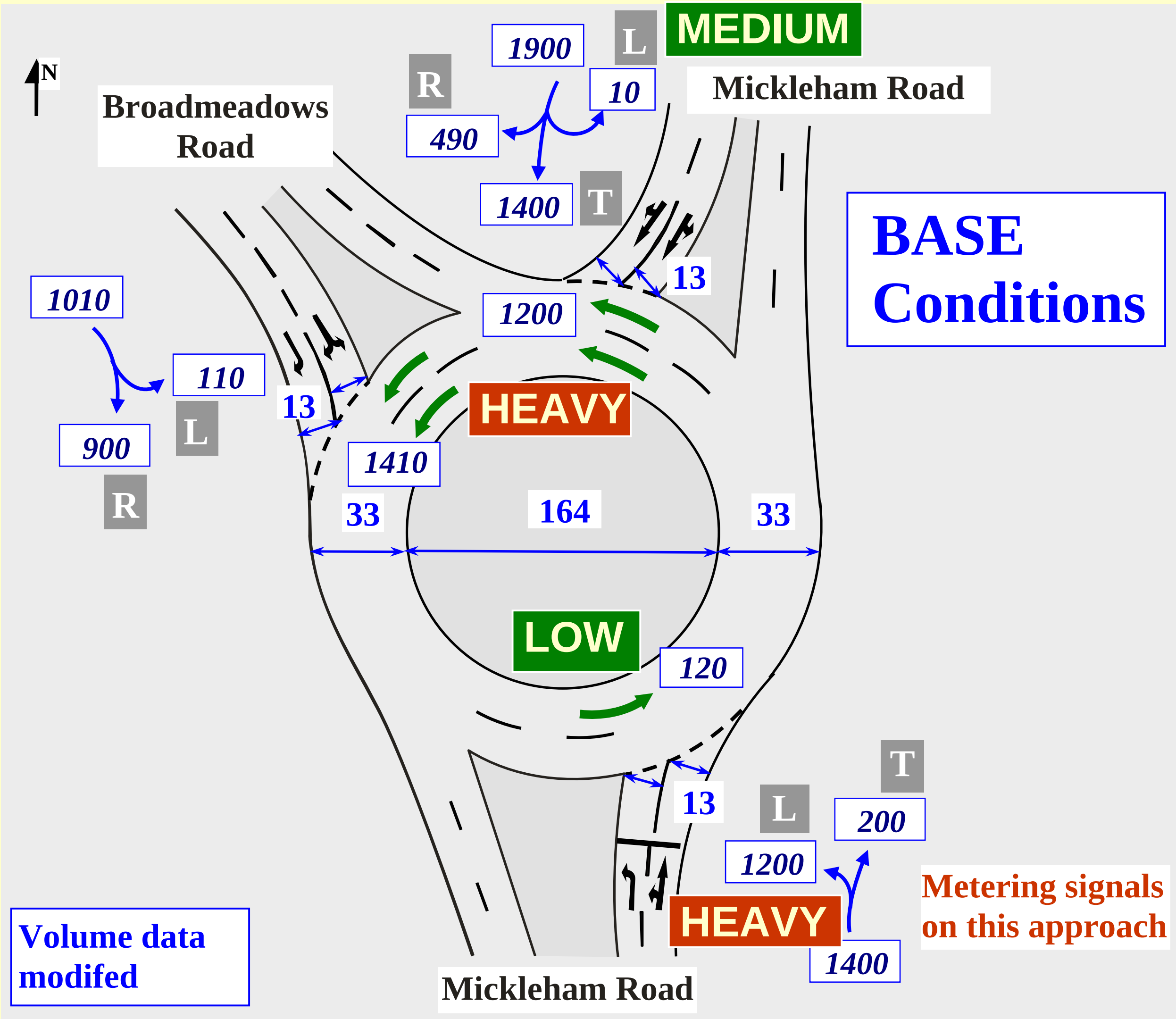
Typical design and control parameters used for roundabout metering signals

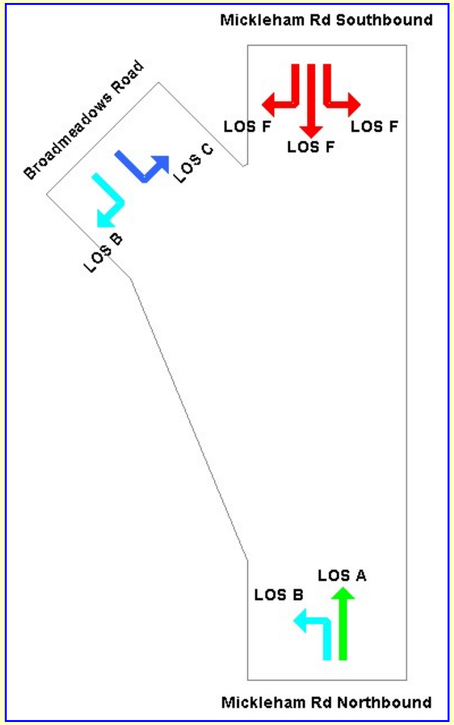
Metered approach	
Signal stop-line setback distance	14 -24 m (46 - 79 ft)
Detector setback distance (if detector is used)	2.5 m (8 ft)
Loop length (if detector is used)	4.5 m (15 ft)
Minimum blank time setting	20 - 50 s
Maximum blank extension time settings	30 s
Blank signal gap setting	3.5 s
Yellow time	4.0 s
All-red time	1.0 - 2.0 s

Typical design and control parameters used for roundabout metering signals

Controlling approach	
Queue detector setback distance	50 - 120 m (164 - 394 ft)
Loop length for the queue detector	4.5 m (15 ft)
Minimum red time setting	10 - 20 s
Maximum red extension time settings	20 - 60 s
Queue detector gap setting	3.0 - 3.5 s
Queue detector occupancy setting: t_{oq}	4.0 - 5.0 s
Yellow time: t_{yR}	3.0 - 4.0 s
All-red time: t_{arR}	1.0 - 2.0 s

Case Study: Mickleham Rd and Broadmeadows Rd Roundabout, Melbourne, Australia

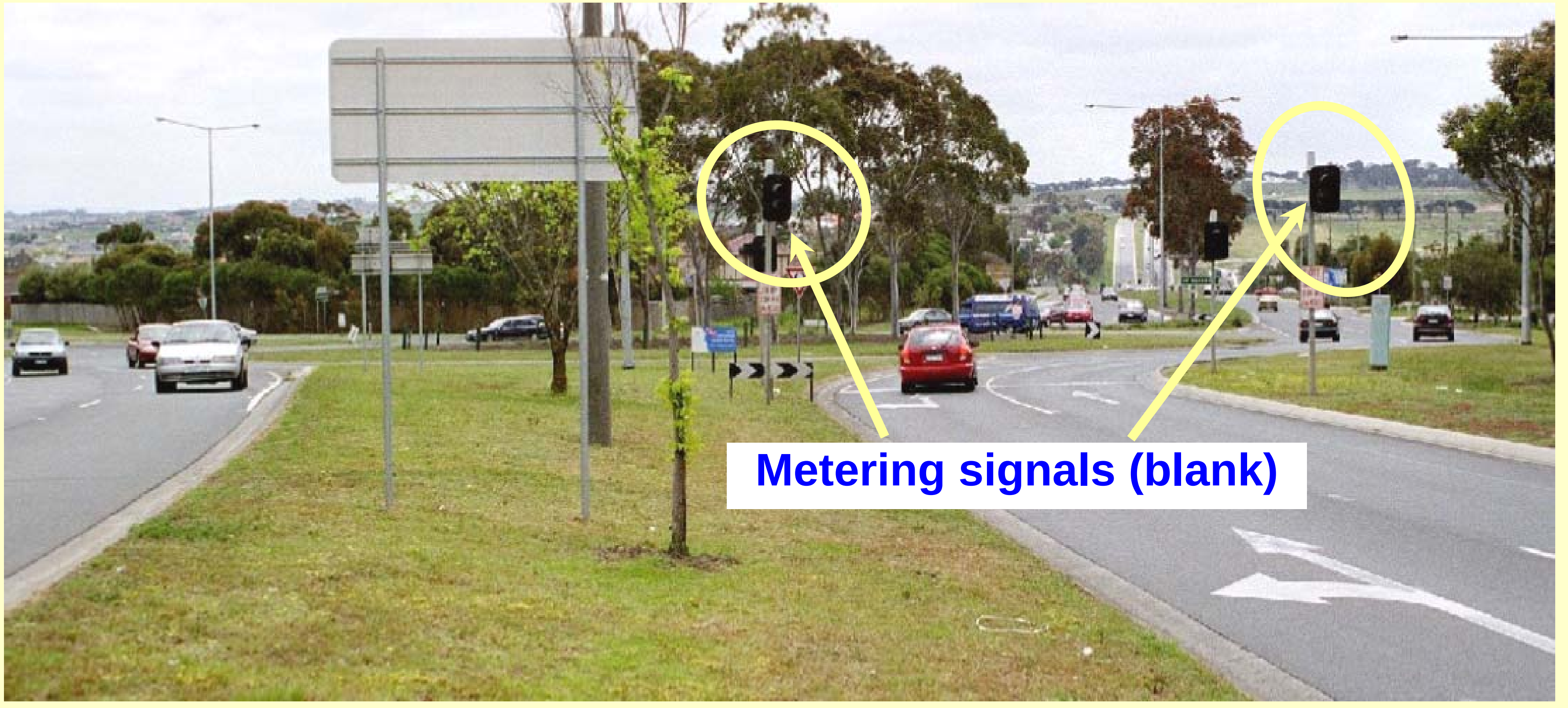




Peaking parameters:
T = 60 min
T_p = 30 min
PFF = 1.00
No Heavy Vehicles

US Customary Units

Mickleham Rd South



Photos during off-peak conditions

Mickleham Rd North

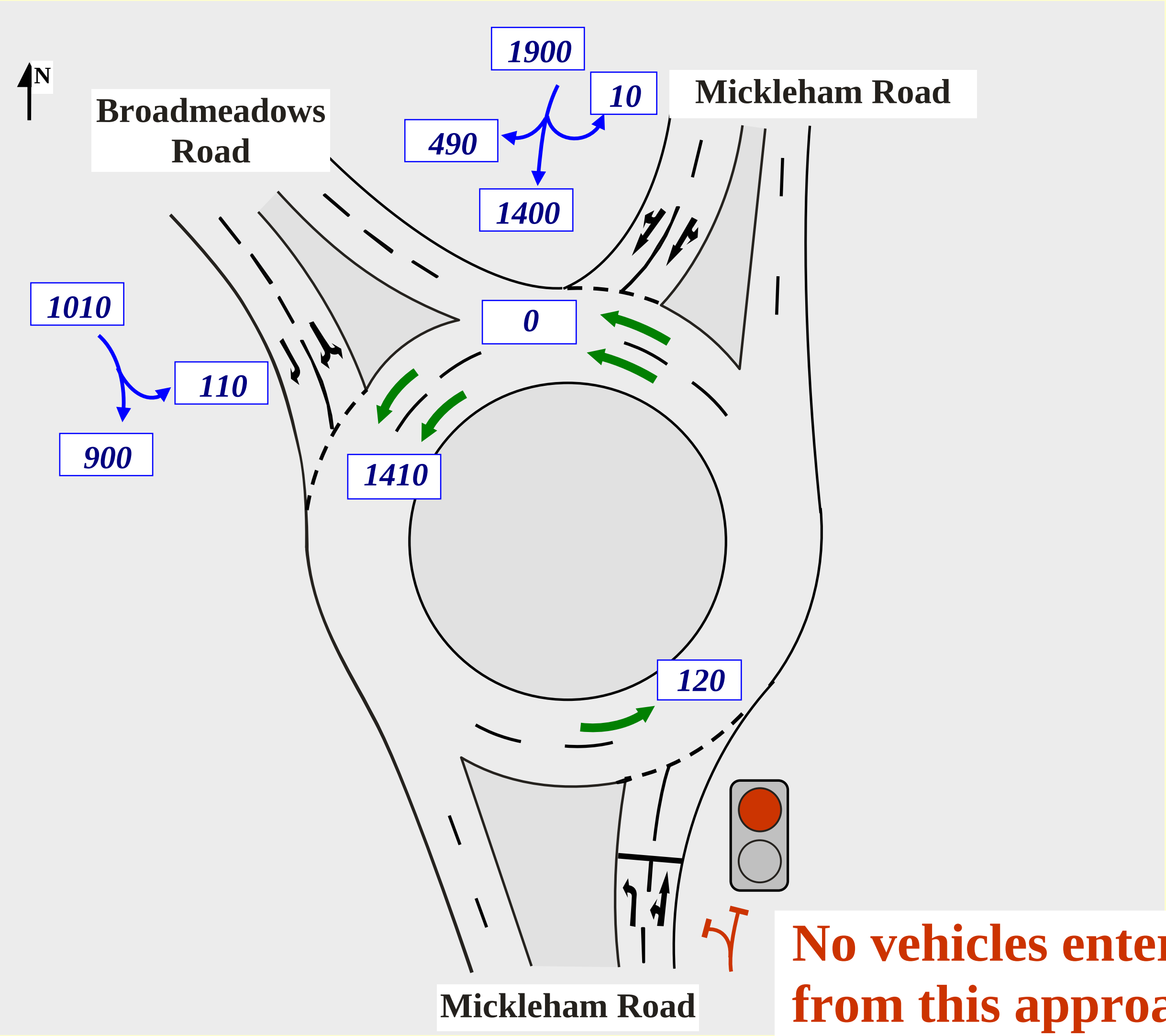
Broadmeadows Road

The Analysis Method (aaSIDRA)

Three operation scenarios:

- **Base Conditions:**
  metering signals BLANK (normal operation)
- **Metering signals RED:**
  metered approach traffic stopped
  the rest of roundabout operates according to normal roundabout rules
- **Signalized intersection scenario**
  to emulate the operation of metered approach signals (phasing information with red and blank phases)

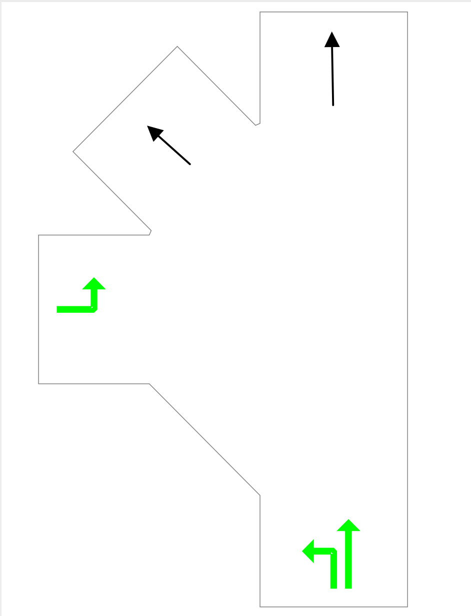
Metering signals RED



No vehicles entering from this approach

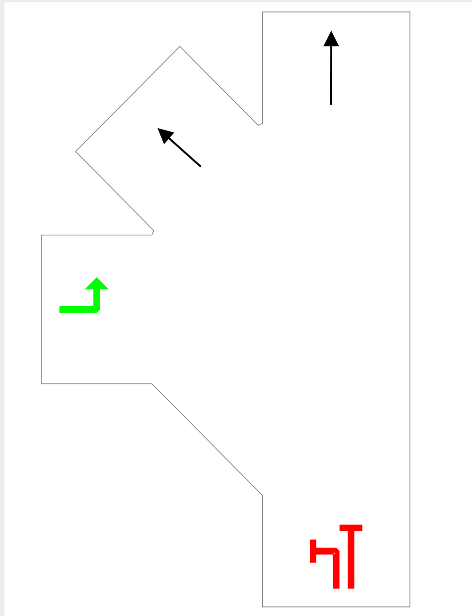
Signalized intersection scenario

Phase A (Blank signals)



Effective blank time = **72** s
Cycle time = **120** s
Blank time ratio = **0.60**

Phase B (Red signals)



Effective red time = **48** s
Cycle time = **120** s
Red time ratio = **0.40**

Without metering signals (Base condition)

App. ID	Approach Name	Dem Flow (veh/h)	Deg. of sat. (v/c ratio)	Aver Delay (sec)	Level of Service	CO2 (kg/h)	Oper. Cost ($/h)
S	Mickleham Rd NB	1400	0.48	12.1	B	373.4	363.52
N	Mickleham Rd SB	1900	1.06	82.8	F	708.8	904.14
NW	Broadmeadows Rd	1010	0.82	17.9	B	284.4	278.92
Intersection		4310	1.06	44.6	D	1366.6	1546.58

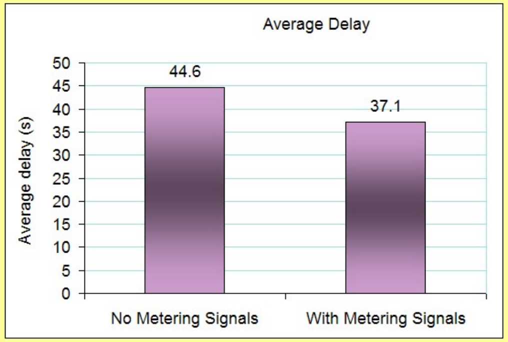
With metering signals (Red Signal 40% of the time)

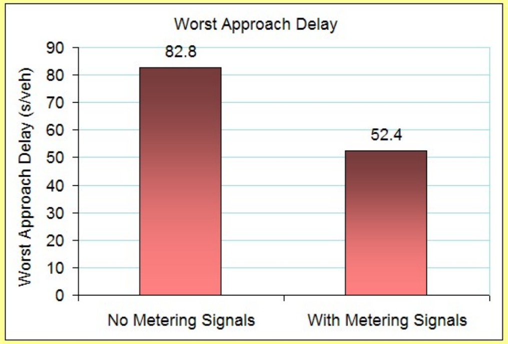
App. ID	Approach Name	Dem Flow (veh/h)	Deg. of sat. (v/c ratio)	Aver Delay (sec)	Level of Service	CO2 (kg/h)	Oper. Cost ($/h)
S	Mickleham Rd NB	1400	0.79	31.7	C	408.80	437.92
N	Mickleham Rd SB	1900	0.77	52.4	D	612.24	720.94
NW	Broadmeadows Rd	1010	0.68	15.7	B	278.48	271.10
Intersection		4310	0.79	37.1	D	1299.52	1429.96

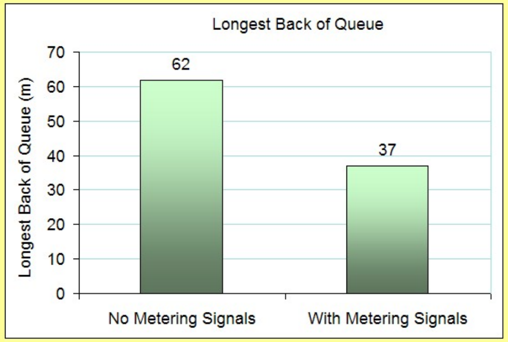
Benefits from metering signals

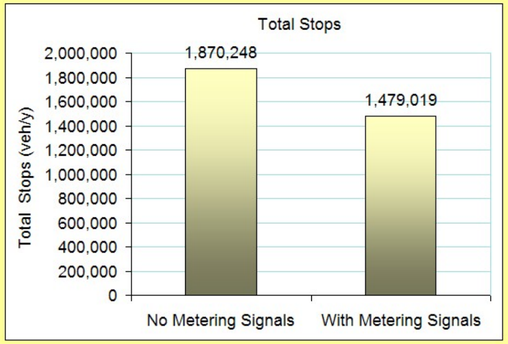
for the Mickleham Rd and Broadmeadows Rd Roundabout

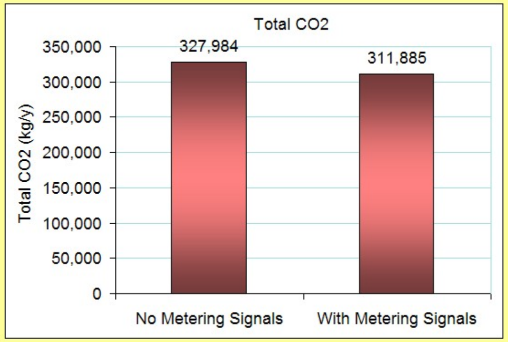
Option	Description	Demand Flow (veh/h)	Average Delay (sec)	Worst Approach Delay (sec/veh)	95% Back of Queue (veh)	Total Stops (veh/y)	CO2 (kg/y)	Operating Cost ($/y)
1	**No Metering Signals**	1,034,400	44.6	82.8	62	1,870,248	327,984	371,179
2	**With Metering Signals**	1,034,400	37.1	52.4	37	1,479,019	311,885	343,190
	Difference	0	-8	-30	-25	-391,229	-16,099	-27,989
	Per cent difference	0.0%	-16.9%	-36.7%	-40.0%	-20.9%	-4.9%	-7.5%

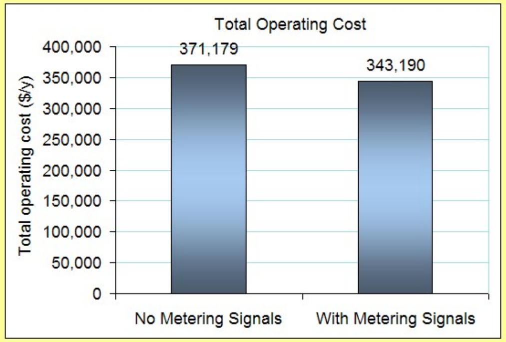












Conclusions for Research & Development

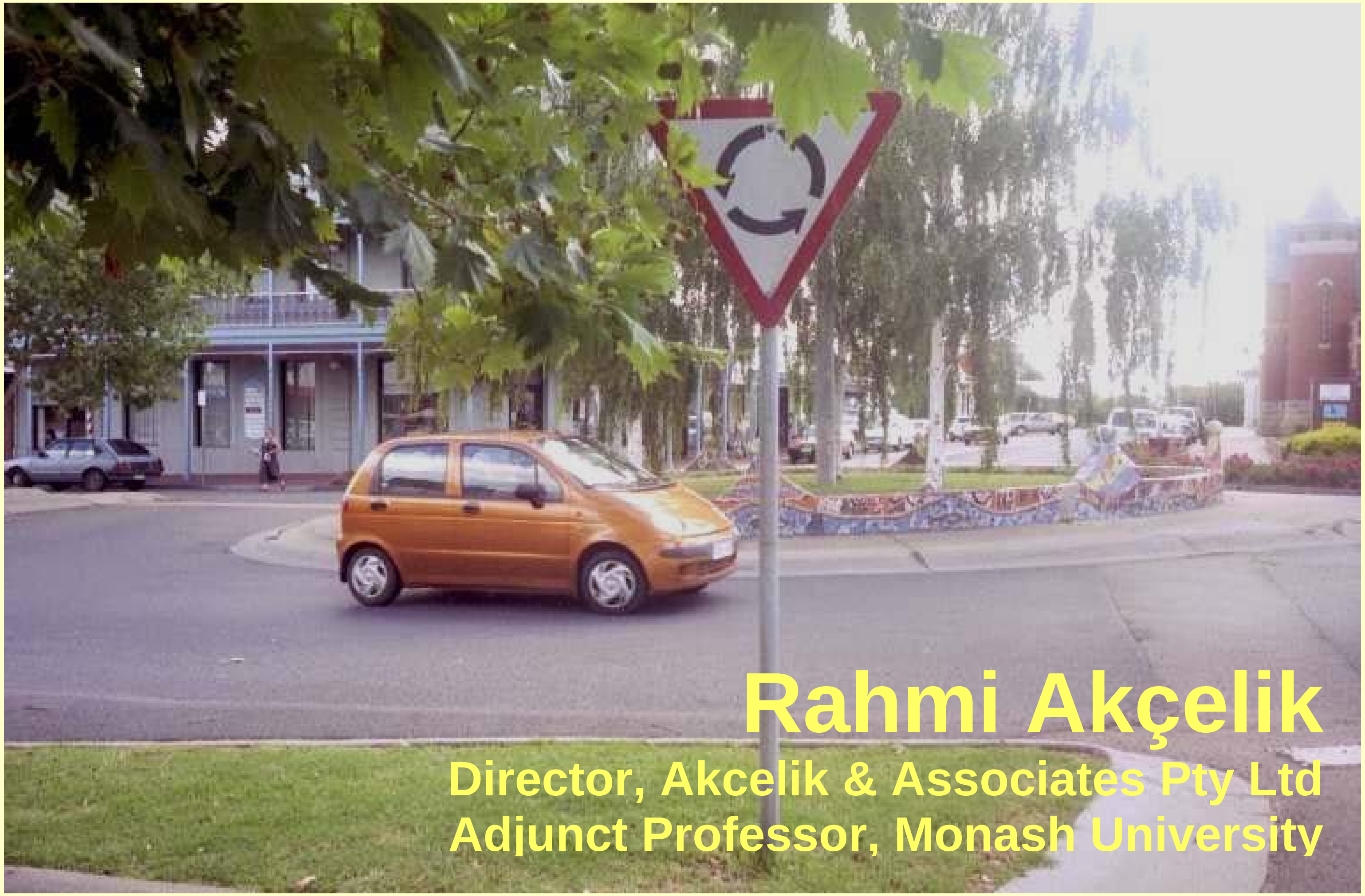
- The analysis method described is an approximate one. It is possible that benefits from the metering signals are higher than indicated in this paper considering dynamic variations in demand flows. A more comprehensive method has been developed and will be included in a future version of aaSIDRA.
- Field observations are recommended on driver behavior at roundabouts subject to metering signal control.

Conclusions for PRACTICE

Improved understanding and MODELING 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)**
- **Unbalanced flows may not be a problem when the overall demand level is low but problem appears with traffic growth even at medium demand levels (DESIGN LIFE analysis important)**
- **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.**

End of presentation



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