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Evaluating Roundabout Capacity, Level of Service and Performance

Presenter:

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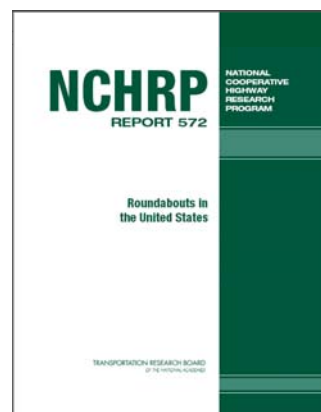
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Roundabout Capacity, Level of Service and Performance

NCHRP Report 572

- Research on US roundabouts (NCHRP Project 3-65)
- Basis for 2010 Highway Capacity Manual (after revisions)
- Highly important for US practice
- Implemented in SIDRA INTERSECTION Version 4 released July 2009



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Examples

- Compare
 - NCHRP Report 572 capacity model and
 - Standard SIDRA INTERSECTION capacity model (calibrated using Environment Factor for US conditions)
- Single-lane and multi-lane roundabouts selected to demonstrate various issues
- Roundabout Metering signals (example)



Discussions of related issues

- Importance of the basic findings of NCHRP Report 572 research on US roundabouts
- Lower capacity of roundabouts in the USA compared with Australian and UK roundabouts
- NCHRP 572 model implementation and extensions in SIDRA INTERSECTION (further issues raised)
- Possible increases in roundabout capacities in the USA over time
- Choice of Level of Service (LOS) thresholds for roundabouts



Disclaimer

The author is the developer of the
SIDRA INTERSECTION model used in the
study presented in this paper.



Importance of the basic findings of NCHRP Report 572 research on US roundabouts



Driver Behavior and Roundabout Geometry

- NCHRP Report 572 confirmed that roundabout **geometry** alone is not sufficient for modeling capacity of roundabouts, and **driver behavior** parameters are most important:
 - ... the fine details of geometric design appear to be secondary and less significant than variations in driver behavior at a given site and between sites.
 - (the driver behavior is) the largest variable affecting roundabout performance (although) geometry in the aggregate sense (number of lanes) has a clear effect on the capacity of a roundabout entry ...



Driver Behavior and Roundabout Geometry

- NCHRP Report 572 recognized importance of **lane-by-lane** modeling of roundabouts

These conclusions confirm the basic premises of the Australian method, and is in sharp contrast with the UK TRL method.



Regression (empirical) and gap-acceptance models

- NCHRP Report 572 proposed **Exponential** models of capacity for single-lane and two-lane roundabouts
- The NCHRP 572 exponential **regression** model is in fact a **gap-acceptance** model which uses the form of **Siegloch M1** gap-acceptance model (random arrivals)!
- NCHRP Report 572 showed that the capacity model using **exponential regression** and using the model derived using **average field values of the gap-acceptance parameters** are very close.



Regression (empirical) and gap-acceptance models

- Thus modeling capacity by a gap-acceptance method (**using critical gap and follow-up headway parameters determined in the field in a "theoretical" gap-acceptance equation**) and modeling capacity by **direct regression** using field capacities give very close results.

This confirms the validity of gap-acceptance methodology for roundabout capacity modeling.



Lower capacity of roundabouts in the USA compared with Australian and UK roundabouts

- The NCHRP Report 572 raised the question
How appropriate are some international research and practices are for the United States?...
- and found that
Drivers in the United States appear to use roundabouts less efficiently than models suggest is the case in other countries around the world (Australia and UK).



NCHRP 572 model implementation in SIDRA INTERSECTION

- NCHRP Report 572 recognized and assessed the SIDRA INTERSECTION model
- Original SIDRA INTERSECTION roundabout capacity model is based on research on Australian roundabouts thus reflecting **Australian driver characteristics.**
- After early results of NCHRP 3-65 research, SIDRA INTERSECTION capacity model was calibrated for **US versions of SIDRA INTERSECTION** to provide lower capacity estimates as observed in the USA: **Environment Factor = 1.2** as the default . For this paper, this is referred to as the **SIDRA Standard Model.**



NCHRP 572 model implementation in SIDRA INTERSECTION

- In SIDRA INTERSECTION Version 4 released recently, roundabout capacity models proposed in NCHRP Report 572 report have been implemented as an alternative model. This model is referred to as the **NCHRP 572 Model**.

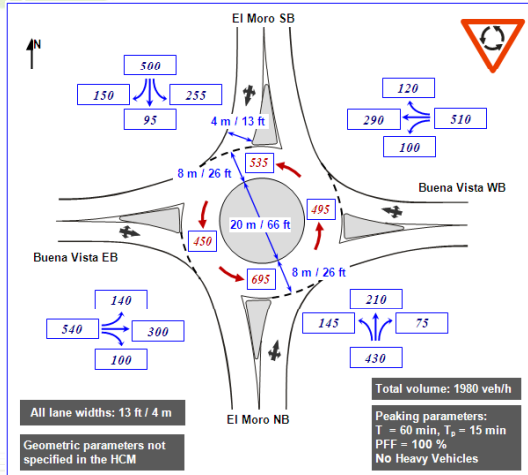


Two examples to compare the SIDRA Standard and the NCHRP 572 capacity models



Roundabout Capacity, Level of Service and Performance

Example 1: Single-Lane Roundabout



- Based on the example described in Highway Capacity Manual 2000, Chapter 17.
- A fairly balanced origin-destination flow pattern.

Roundabout Capacity, Level of Service and Performance

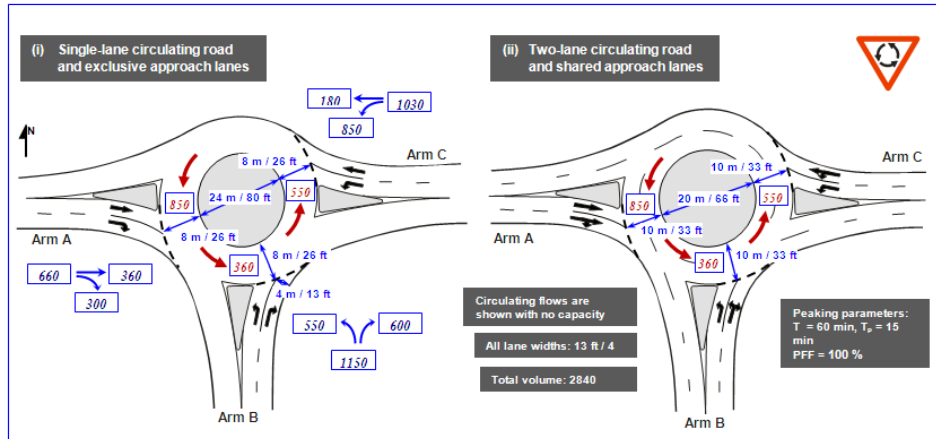
Example 1: Single-Lane Roundabout

| App. ID | Approach Name | Approach Flow (veh/h) | Circulating Flow (pcu/h) | Capacity (veh/h) | Degree of saturation (v/c ratio) |
|--|----------------|-----------------------|--------------------------|------------------|----------------------------------|
| SIDRA Standard Capacity Model (Environment Factor = 1.2) | | | | | |
| S | El Moro NB | 430 | 695 | 543 | 0.79 |
| E | Buena Vista WB | 510 | 495 | 671 | 0.76 |
| N | El Moro SB | 500 | 535 | 643 | 0.78 |
| W | Buena Vista EB | 540 | 450 | 703 | 0.77 |
| NCHRP 572 Capacity Model | | | | | |
| S | El Moro NB | 430 | 695 | 564 | 0.76 |
| E | Buena Vista WB | 510 | 495 | 689 | 0.74 |
| N | El Moro SB | 500 | 535 | 662 | 0.76 |
| W | Buena Vista EB | 540 | 450 | 721 | 0.75 |

- Capacities are very close (about 3-4 % difference).
- Environment Factor = 1.2 approximates NCHRP 572 model closely.
- Environment Factor = 1.0 gives capacities about 30 per cent higher.

Example 2: Two-Lane Roundabout Cases

Based on an example published by Chard who demonstrated the lack of sensitivity of the UK TRL model to different approach lane use arrangements.



Example 2: Two-Lane Roundabout Cases

- Two alternative approach and circulating lane arrangements:
 - Case (i) - Unbalanced lane use: Two entry lanes and a single-lane circulating road
 - Case (ii) - Balanced lane use: Two-lane approach roads with shared lanes and two circulating lanes

Example 2: Two-Lane Roundabout Cases

| App. ID | Approach Name | Total Approach Flow (veh/h) | Circulating Flow (pcu/h) [1] | Critical Lane [2] | Critical Lane Flow (veh/h) | Total Approach Capacity (veh/h) | Critical Lane Capacity (veh/h) | Degree of saturation (v/c ratio) |
|--|---------------|-----------------------------|------------------------------|-------------------|----------------------------|---------------------------------|--------------------------------|----------------------------------|
| Case (i): Single-lane circulating road and exclusive approach lanes SIDRA Standard Capacity Model (Environment Factor = 1.2) | | | | | | | | |
| W | Arm A | 660 | 825 | 1 (T) | 360 | 1006 | 539 | 0.67 |
| S | Arm B | 1150 | 360 | 2 (R) | 600 | 1905 | 988 | 0.61 |
| E | Arm C | 1030 | 550 | 1 (L) | 850 | 1286 | 825 | 1.03 |
| Case (i): Single-lane circulating road and exclusive approach lanes NCHRP 572 Capacity Model | | | | | | | | |
| W | Arm A | 660 | 850 | 1 (T) | 360 | 1178 | 589 | 0.61 |
| S | Arm B | 1150 | 360 | 2 (R) | 600 | 1576 | 788 | 0.76 |
| E | Arm C | 1030 | 550 | 1 (L) | 850 | 1304 | 652 | 1.30 |
| Case (ii): Two-lane circulating road and shared approach lanes SIDRA Standard Capacity Model (Environment Factor = 1.2) | | | | | | | | |
| W | Arm A | 660 | 850 | 2 (TR) | 330 | 1210 | 605 | 0.55 |
| S | Arm B | 1150 | 360 | 2 (R) [3] | 600 | 1768 | 887 | 0.68 |
| E | Arm C | 1030 | 550 | 2 (LT) | 515 | 1438 | 719 | 0.72 |
| Case (ii): Two-lane circulating road and shared approach lanes NCHRP 572 Capacity Model | | | | | | | | |
| W | Arm A | 660 | 850 | 2 (TR) | 337 | 1220 | 623 | 0.54 |
| S | Arm B | 1150 | 360 | 2 (R) [3] | 600 | 1741 | 878 | 0.68 |
| E | Arm C | 1030 | 550 | 2 (LT) | 552 | 1517 | 769 | 0.68 |



Example 2: Two-Lane Roundabout Cases

- Both the SIDRA Standard and NCHRP 572 models identify the problem of **unbalanced lane flows** on the East approach (oversaturated).
- UK TRL model was shown to fail to indicate the problem for this approach as originally demonstrated by Chard. UK TRL model capacity estimates for the two cases are the same (due to the "**approach-based**" method).



Example 2: Two-Lane Roundabout Cases

- Both the SIDRA Standard and NCHRP 572 models give **capacity estimates which differ significantly between Cases (i) and (ii)**.
- Using a **lane-by-lane** method, the SIDRA Standard and NCHRP 572 models identify **critical lanes** distinguishing between exclusive and shared lane cases and allowing for any unequal lane utilization, thus identifying **oversaturation on the East approach** in the case of a single-lane circulating road with exclusive lanes.



Example 2: Two-Lane Roundabout Cases

- Considering the annual values of one hour of traffic operation only, the difference between the two cases amount to approximately:
 - **5,600 person-hours** of delay
 - **US\$57,000** in operating cost
 - **2,500 gal** of fuel consumption
 - **24,000 kg** of CO2 emission per year



NCHRP 572 model extensions in SIDRA INTERSECTION

- More than 2 lanes
- Short lanes (flares)
- Bypass lanes (slip lanes and continuous lanes)
- Closely-spaced or multiple intersections
 - Capacity Adjustment parameter
 - Probability of blockage
- Upstream signal effects: Extra Bunching parameter allows for platooning created by signals. This cannot be applied to the NCHRP 572 model based on random arrivals.



NCHRP 572 model extensions in SIDRA INTERSECTION

- A model for average conditions (regression) vs special situations (unbalanced lane use, unbalanced Origin-Destination pattern, high entry flow / low circulating flow)
- Lane flows according to the equal degree of saturation principle
 - Equal lane volume principle allocates too much volume into low-capacity lanes
 - Critical lane definition: highest degree of saturation
- Capacity constraint



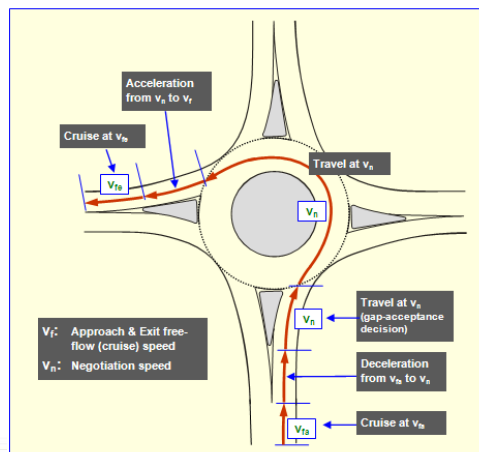
NCHRP 572 model extensions in SIDRA INTERSECTION

- Pedestrian effects
- Heavy Vehicle (HV) effects:
 - Calculate HV factors for each lane using different HV percentages for individual turning movements
 - Specify heavy vehicle equivalent per movement for model calibration in specific situations where there are large commercial vehicles in particular movements.
- Fuel consumption
- Emissions (including CO2)
- Operating cost



NCHRP 572 model extensions in SIDRA INTERSECTION

- **Geometric delay:**
All vehicles slow down to a safe negotiation speed at roundabouts. Geometric delay depends on approach and exit **cruise speeds** as well as the roundabout **negotiation speeds**, which depend on the **geometric characteristics** of the roundabout



NCHRP 572 model extensions in SIDRA INTERSECTION

- Queue Length and Stop Rate estimates
 - For **unsignalised** intersections, HCM 2000 gives a **cycle-average queue**. This includes the instances with zero queues.
 - For **signalized** intersections HCM 2000 uses the **back of queue** concept.
 - For **consistency**, SIDRA INTERSECTION gives **back of queue** estimates in all output reports for unsignalised intersections as well.

Choice of Level of Service (LOS) thresholds for roundabouts

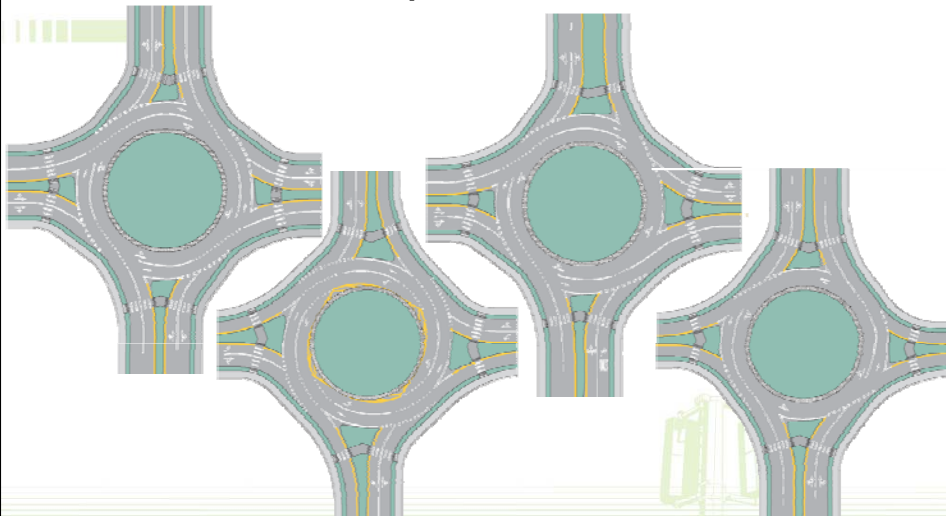
- NCHRP 572 recommended Level of service (LOS) criteria to be the same as those currently used for **unsignalized intersections**.
- SIDRA INTERSECTION offers options for choice of alternative LOS criteria for roundabouts including a **SIDRA Roundabout LOS option** with thresholds between those for signal and stop-sign control.
- The default LOS thresholds in SIDRA INTERSECTION are the **same as signalized intersections**.
- **LOS Target** parameter can be used to specify the acceptable LOS level for particular intersection types.

Choice of Level of Service (LOS) thresholds for roundabouts

Default: Same as Signals

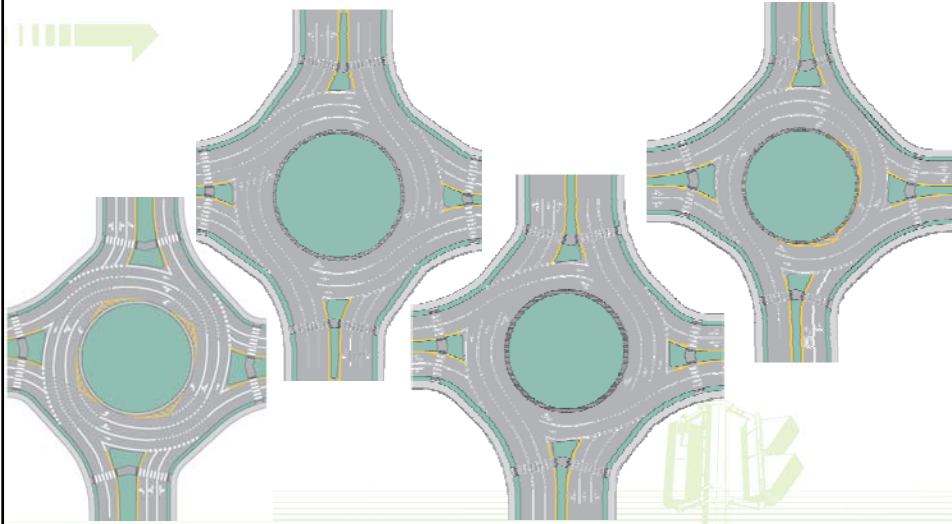
| Level of Service | Control delay per vehicle in seconds (d) | | |
|------------------|--|------------------|------------------|
| | Signals | Roundabouts | Sign Control |
| A | $d \leq 10$ | $d \leq 10$ | $d \leq 10$ |
| B | $10 < d \leq 20$ | $10 < d \leq 20$ | $10 < d \leq 15$ |
| C | $20 < d \leq 35$ | $20 < d \leq 35$ | $15 < d \leq 25$ |
| D | $35 < d \leq 55$ | $35 < d \leq 50$ | $25 < d \leq 35$ |
| E | $55 < d \leq 80$ | $50 < d \leq 70$ | $35 < d \leq 50$ |
| F | $80 < d$ | $70 < d$ | $50 < d$ |

SIDRA INTERSECTION Templates including MUTCD examples



Roundabout Capacity, Level of Service and Performance

SIDRA INTERSECTION Templates including MUTCD examples

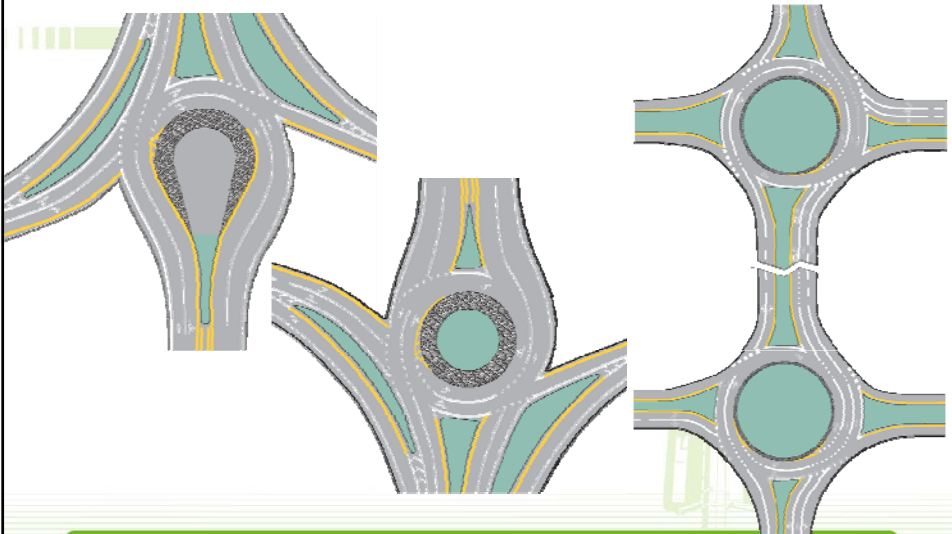


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Roundabout Capacity, Level of Service and Performance

SIDRA INTERSECTION Templates including MUTCD examples



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Roundabout Metering Signals

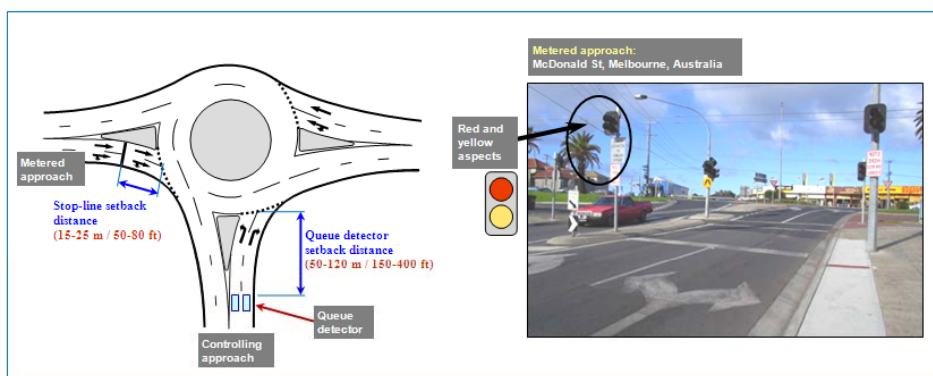
The use of metering signals is a cost-effective measure to avoid the need for a fully-signalized intersection treatment.

Model introduced in **SIDRA INTERSECTION Version 4**

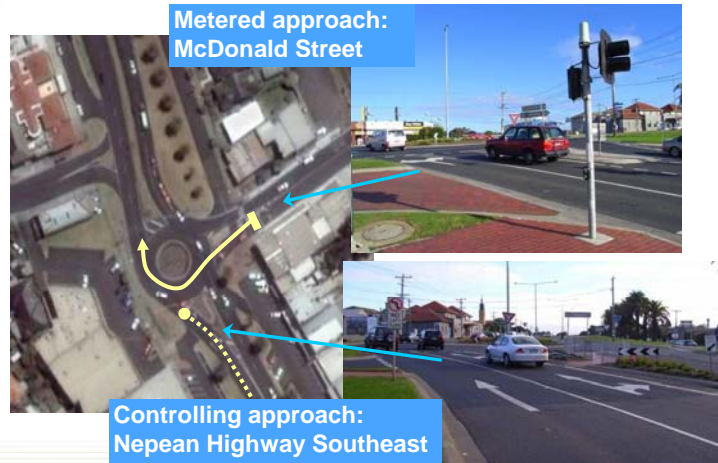
Model can be used with capacities estimated using the NCHRP 572 method as well.



Roundabout Metering Signals Typical Arrangements



Roundabout Metering Signals – Example Melbourne, Australia (driving on the left-hand side of the road)



Possible increases in roundabout capacities in the USA over time

- ❖ The NCHRP Report 572 found **lower capacities at US roundabouts** compared with those in Australia and UK.
- ❖ The question arises about whether capacity of US roundabouts will increase over time due to "**changes in driver experience over time**".
- ❖ Higher capacities from the models derived in Australia and UK might indicate **potential increases** in capacities.



Possible increases in roundabout capacities in the USA over time

- Rodegerdts suggested that possible reasons for lower capacities at US roundabouts include:
 - driver unfamiliarity with roundabouts as a relatively new control device
 - larger vehicles
 - prevalence of stop control, especially use of all-way stop control and lack of use of two-way yield control, and
 - lack of use of turn signals on exits causing driver hesitation during the yield process.



Factors in favor

- Expected increase in efficiency in driver behavior due to increased familiarity
- Increased congestion levels resulting in more aggressive driver behavior
- Reduced vehicle length and better acceleration capabilities



Factors against

- **All-way stop control and two-way yield control:** Practice in Australia is opposite to the US practice, i.e. all-way stop control is almost non-existent, and two-way yield signs are used commonly.
- If this difference is a significant factor, this aspect of US driving culture and traffic control environment would continue to affect roundabout capacities in the future.
- Note that lower gap-acceptance parameters are used in Australia for **two-way sign-control** as well.



Factors against

- Our recent roundabout research in Australia indicated that, the follow-up headway and critical gap values in Australia did not change much since 1980s in spite of significant increases in demand and congestion levels at roundabouts.
- Preference for larger vehicles may not change over time, or changing vehicle population may mean somewhat reduced acceleration capabilities.



Driver response time for relationship between capacity and driver behavior

Queue discharge headway (Follow-up headway) =
Driver response time + Queue space / Queue discharge speed

- Using Environment Factor = 1.2 for US conditions, South approach in Example 1, SIDRA INTERSECTION estimated Driver response time = **1.8 s**
Queue discharge headway = 2.91 s, Queue space = 7.62 m (25 ft), Queue discharge speed = 24.8 km/h (15.4 mph)
- Using Environment Factor = 1.0 for Australian conditions, Driver response time = **1.3 s**
Queue discharge headway = 2.40 s (all other factors same)

Thus small reductions in driver response times could result in significant capacity increases at US roundabouts over time.



End of Presentation

