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Recalibration of a Vehicle Power Model for Fuel and Emission Estimation and its Effect on Assessment of Alternative Intersection Treatments

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The first and third authors are the developers of the SIDRA INTERSECTION and SIDRA TRIP software

SIDRA SOLUTIONS

This paper …

- The power-based fuel consumption and emission model used in the SIDRA INTERSECTION and SIDRA TRIP software is described.
- The recent work on recalibration of light and heavy vehicle parameters used by this model using a large empirical database for a modern vehicle fleet is described.
- The model recalibration results are presented for a number of vehicles.
- The implications of the change in fuel and emission model parameters on intersection assessment are considered.

This paper …

A **roundabout evaluation case** is presented assessing the effectiveness of **roundabout metering signals** using the fuel consumption and emission (CO_2, HC, CO, NO_x) and operating cost models with

- the **older vehicle parameter values** and
- the **recalibrated parameter values**

to investigate whether the changes in vehicle parameters change the **evaluation results** significantly.

The model provided in the SIDRA INTERSECTION software package is used for this purpose.

Fuel Consumption and Emission Models

Fuel consumption and emission (CO_2, CO, HC, NO_x) models of four levels of aggregation were developed by the first author and his colleagues at the Australian Road Research Board in the 1980s:

- Instantaneous (second-by-second) << SIDRA TRIP
- Four-mode elemental (modal) << SIDRA INTERSECTION
- Running speed & PKE (Positive Kinetic Energy))
- Average speed

HISTORY

KEY DOCUMENTS
available on sidrasolutions.com

AKÇELIK, R. (1983). ARRB Research Report ARR No. 124.

BOWYER, D.P., AKÇELIK, R. and BIGGS, D.C. (1985). ARRB Special Report SR No. 32.

US AWARD

ITE (USA) 1986 Transportation Energy Conservation Award
in Memory of Frederick A. Wagner
for research into energy savings from urban traffic management.

Vehicle Paths for Four-Mode Elemental Model

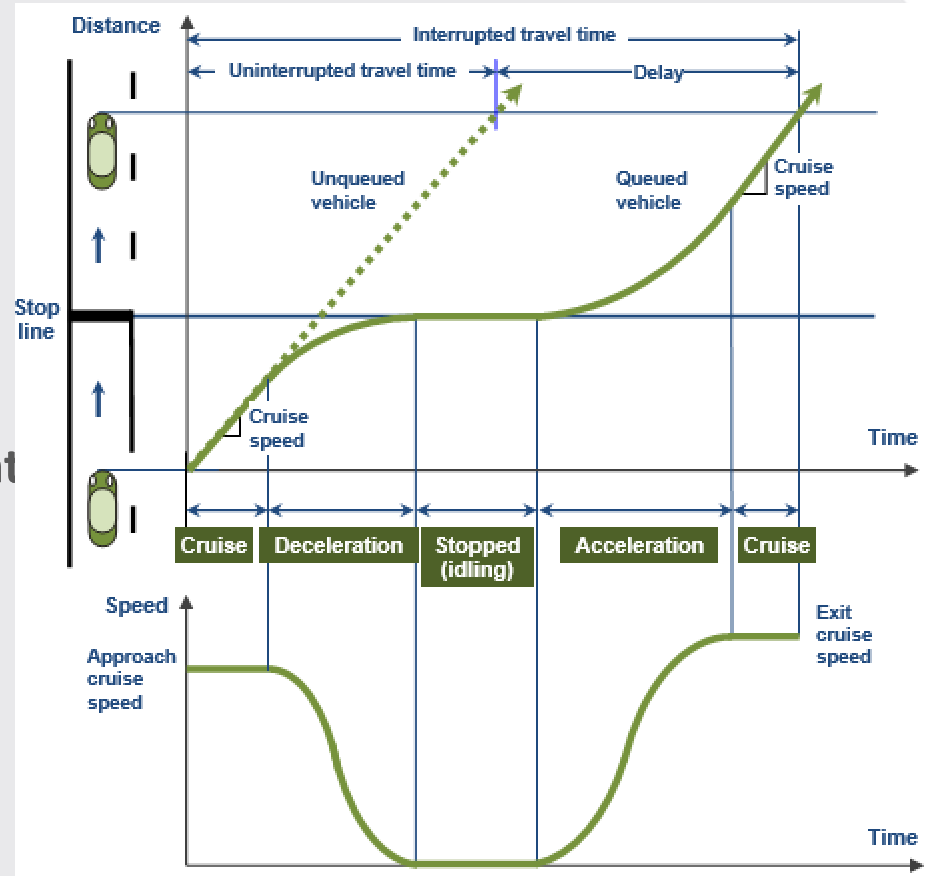
Vehicle path model needed for

- Fuel Consumption
- Emissions: CO_2 / CO / HC / NO_x
- Operating COST

Applied separately to queued and unqueued vehicles for every movement class in very lane

Integral functions are used for each element (mode) of vehicle path:

- Cruise
- Deceleration
- Idling
- Acceleration



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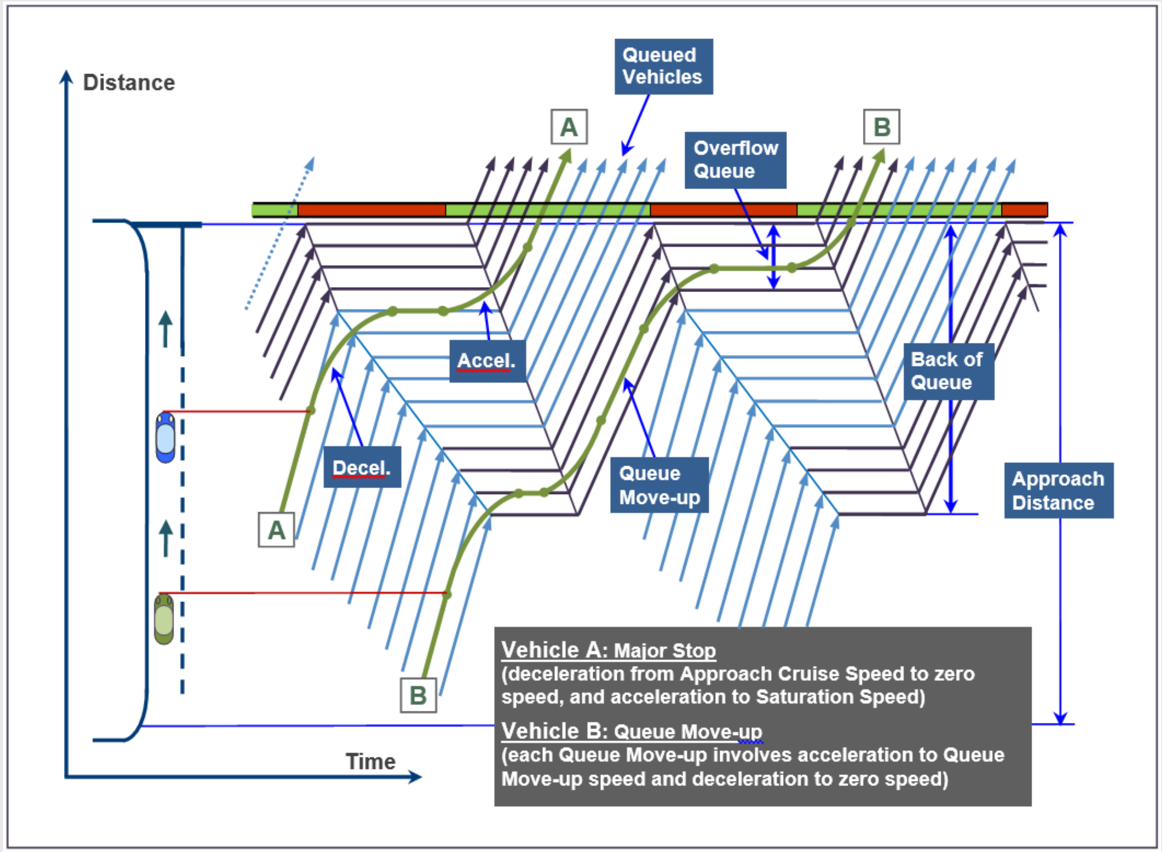
Vehicle Path Model: with queue move-ups

- The basis of this is the modeling of not only delays and queues but also stop-starts (major stops and queue move-ups).
- Queue move-ups occur at roundabouts and TWSC as a result of the gap-acceptance process.
- NO STOPS MODELLING in the HCM.

Example for queues at traffic signals



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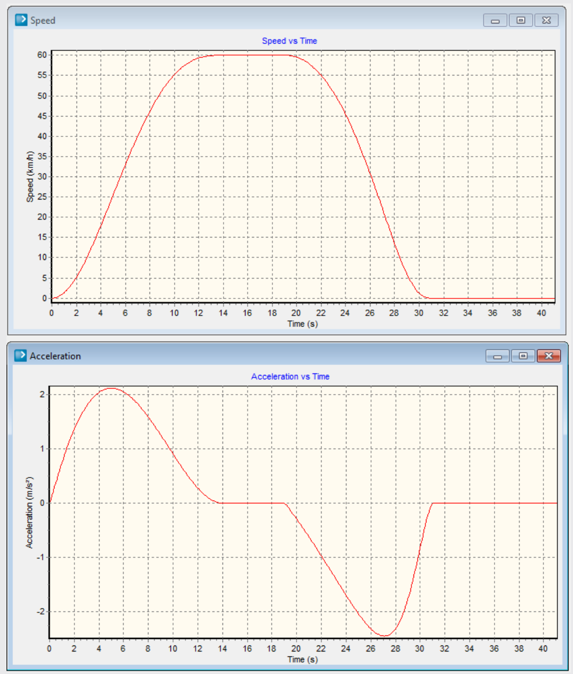
Acceleration – Deceleration models

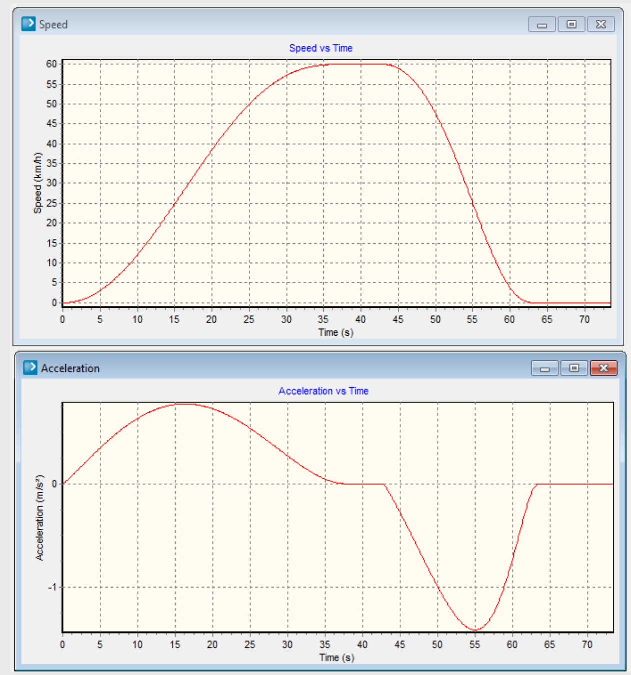
Polynomial acceleration profile model used for **acceleration distance and acceleration time** calculations

AKÇELIK, R. and BIGGS, D.C. (1987). **Acceleration profile models for vehicles in road traffic.** *Transportation Science*, 21 (1), pp. 36-54

Light Vehicles



Heavy Vehicles



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Instantaneous Model of Fuel Consumption

$$f_t = \alpha + \beta_1 P_T + [\beta_2\, a\, P_I]_{a>0} \qquad \text{for } P_T > 0$$
$$= \alpha \qquad \text{for } P_T \leq 0$$

f_t = fuel consumption rate (mL/s),
P_T = total tractive power (kilowatts, kW),
P_I = inertia component of total power (kW),
α = idle fuel consumption rate (mL/s)
β_1, β_2 = efficiency parameters

Simpler Model

$$f_t = \alpha + \beta_1 P_T \qquad \text{for } P_T > 0$$
$$= \alpha \qquad \text{for } P_T \leq 0$$

Model Calibration

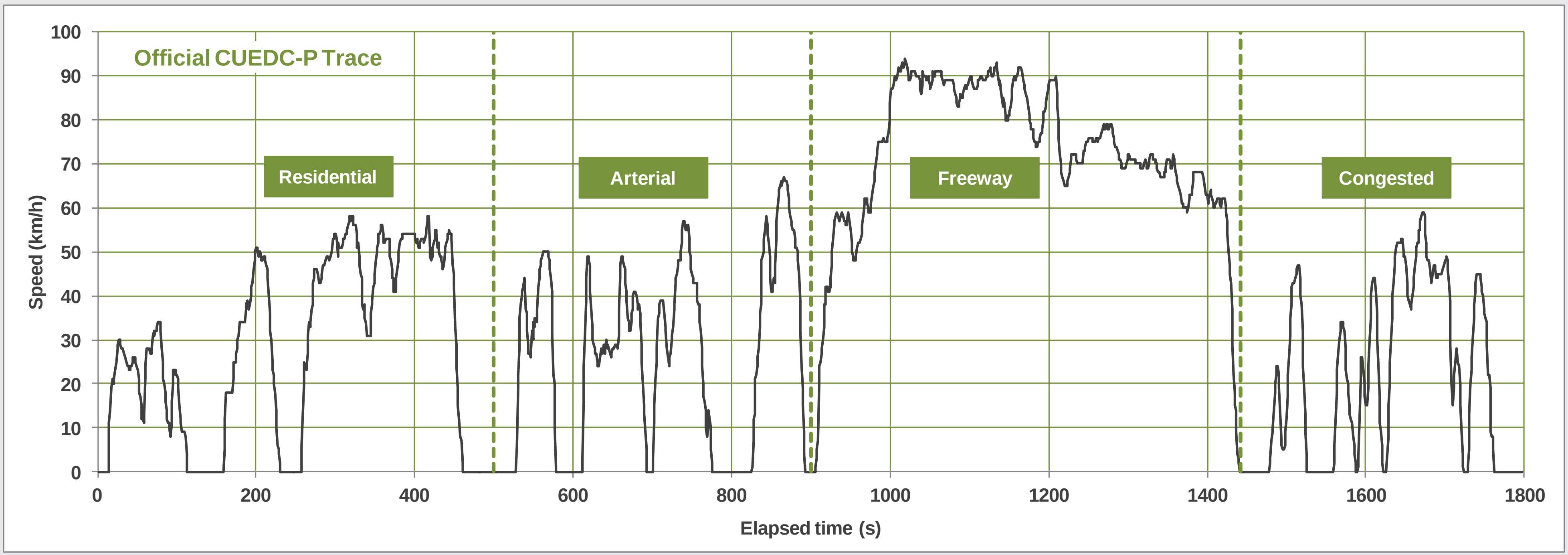
Vehicle parameters were calibrated using data for a modern vehicle fleet.

Fuel consumption and emission data were used for vehicles selected from an empirical database (NISE 2) incorporating a large range of data for about 400 vehicles representing a cross section of typical vehicles on Australian metropolitan roads were used.

Data were collected in a vehicle emissions test laboratory using a real-world driving cycle called CUEDC-P (Composite Urban Emission Drive Cycle for Petrol vehicles) developed from Australian driving pattern data collected in the field.

Official CUEDC-P Speed-Time Profile

The drive cycle includes four sections representing residential, arterial, freeway and congested traffic.



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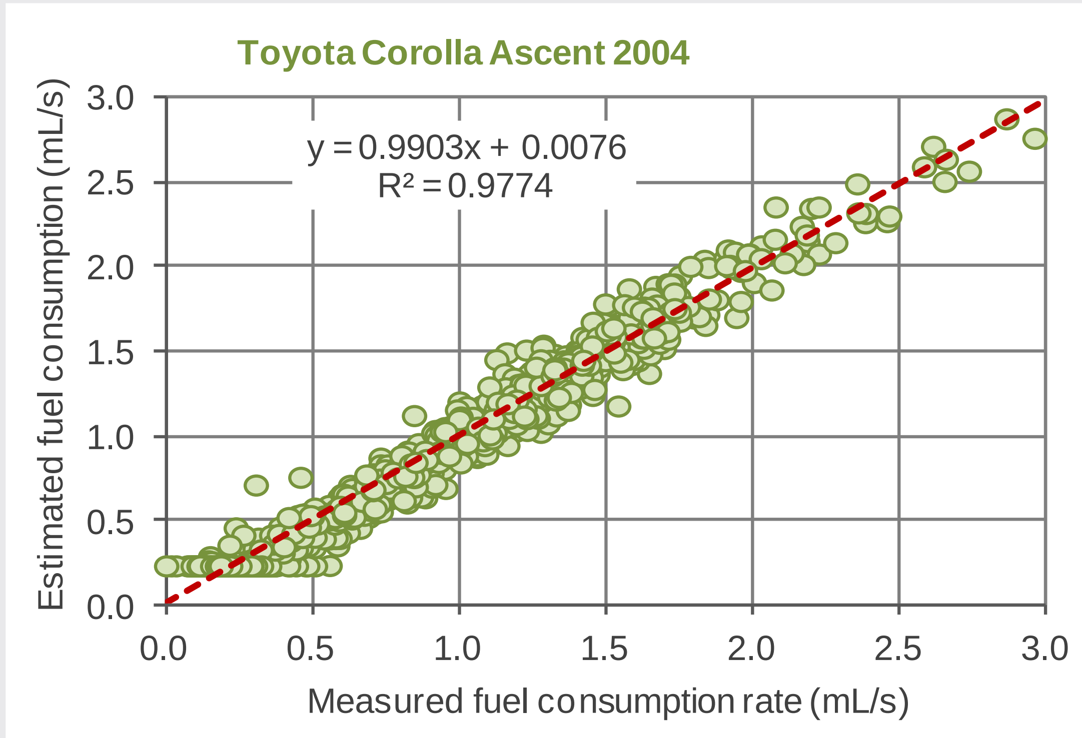
Test Vehicles

The paper summarises the **calibration results** for light and heavy vehicles

Calibration Quality

Estimated vs measured instantaneous fuel consumption rates



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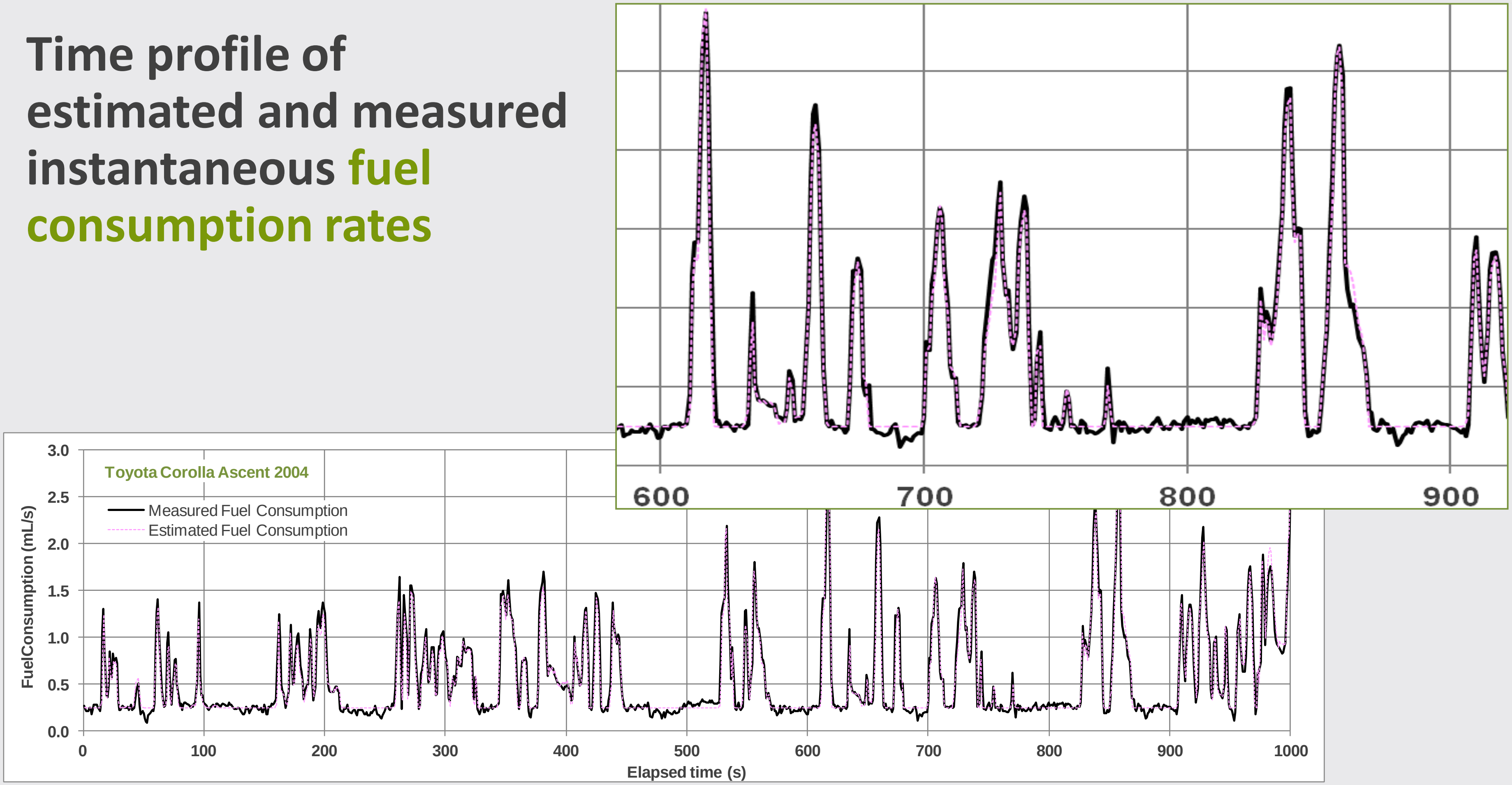
Calibration Quality

Time profile of estimated and measured instantaneous **fuel consumption rates**



Calibration Quality: Estimated vs Measured

Measured and estimated values of fuel consumption and emission rates for individual test vehicles

	Fuel Consumption		CO_2	CO	HC	NO_x
	L/100km	mpg (US)	g/km	g/km	g/km	g/km
Small Car: Toyota Corolla Ascent 2004						
Measured	6.0	39.2	140.1	0.229	0.010	0.068
Estimated	5.9	40.1	137.9	0.234	0.010	0.059
Large Car: Holden Commodore 2006						
Measured	9.4	24.9	220.7	0.095	0.019	0.015
Estimated	9.3	25.4	217.8	0.093	0.016	0.012
Truck: Isuzu FVR900 (T) 2005 (Diesel)						
Measured	32.0	7.3	841.8	0.951	0.083	7.577
Estimated	32.0	7.3	843.7	0.869	0.079	5.880

Calibration Quality: Error levels

The errors in fuel consumption (and CO_2 emission) estimation for the total drive cycle for all vehicles were in the range -3.4 to 0 per cent.

The Accuracy levels were high for all segments of the drive cycle *(Residential, Arterial, Freeway and Congested).*

The error levels in emission (HC, CO, NO_x) estimation were higher (-23.1 to +2.5 per cent for all vehicles).

Comparison of default parameters for Light Vehicle fuel consumption and CO_2 models before and after recalibration

Param.	Description	Units	OLD Defaults	NEW Defaults	Diff.
M_v	Average vehicle mass	kg	1400	1600	14%
P_{max}	Maximum power	kW	85	120	41%
PWR	Power to Weight ratio	kW / t	60.7	75.0	24%
f_i	Idle fuel consumption rate	mL/h	1350	1200	-11%
A	Drag fuel consumption parameter (rolling resistance)	mL/km	21.0	16.0	-24%
B	Drag fuel consumption parameter (aerodynamic drag)	$(mL/km)/(km/h)^2$	0.00550	0.00400	-27%
β_1	Efficiency parameter	mL/kJ	0.090	0.100	-
β_2	Energy-acceleration eff. parameter	$mL/(kJ.m/s^2)$	0.030	-	NA
f_{CO2}	CO_2 emission rate	g/mL	2.500	2.350	-6%

Comparison of alternative intersection treatments: Metering signals example

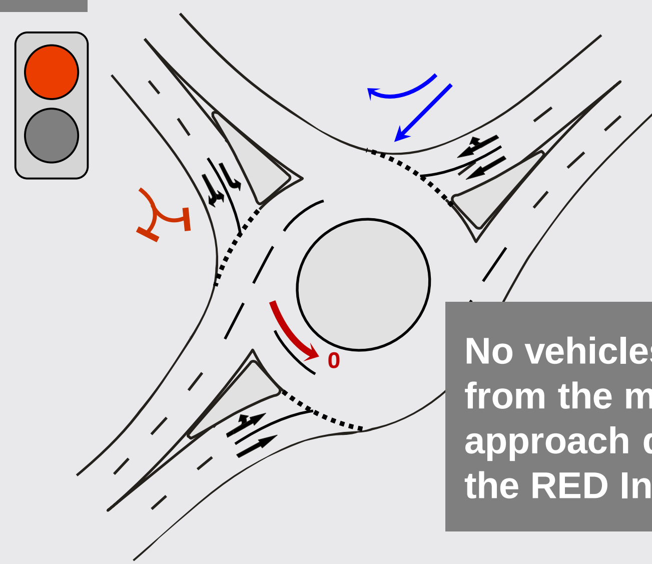
Nepean Highway - McDonald Street roundabout in Melbourne, Australia

AM peak conditions

Mirror-imaged for driving on the right hand side of the road

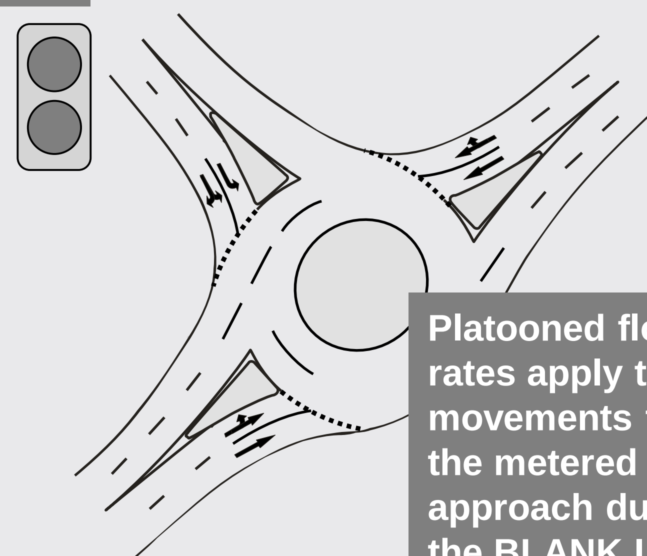
Comparison of alternative intersection treatments: Metering signals example

RED Interval



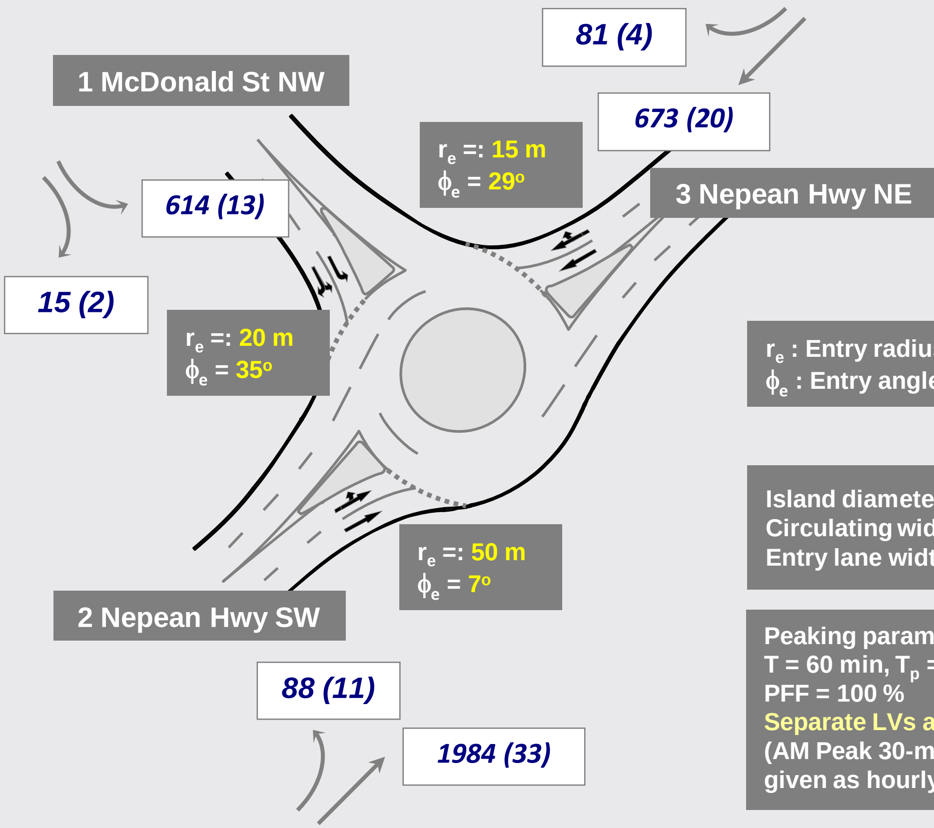
No vehicles enter from the metered approach during the RED Interval

BLANK Interval



Platooned flow rates apply to movements from the metered approach during the BLANK Interval

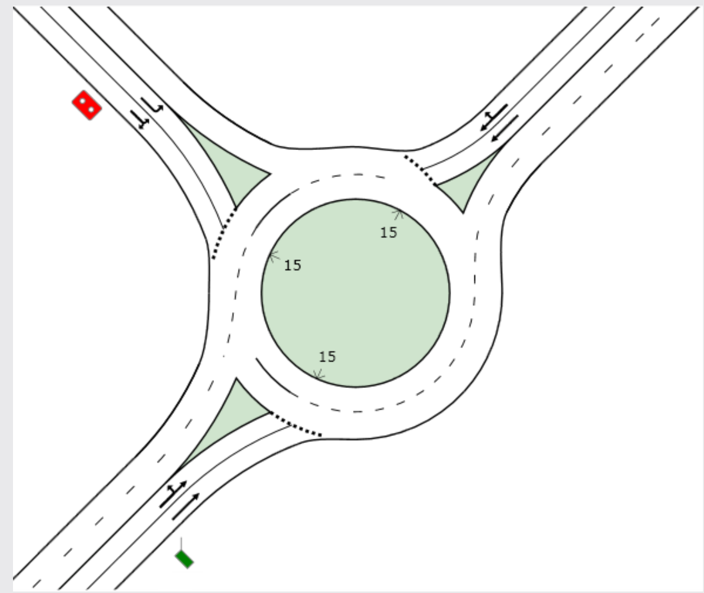
Comparison of alternative intersection treatments: Metering signals example



r_e : Entry radius
ϕ_e : Entry angle

Island diameter = 15 m
Circulating width = 10 m
Entry lane widths = 3.6 m

Peaking parameters:
T = 60 min, T_p = 30 min
PFF = 100 %
Separate LVs and (HVs)
(AM Peak 30-min volumes given as hourly flow rates)



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Comparison of alternative intersection treatments: Metering signals example

Assessment of the effectiveness of roundabout metering signals using old and new default values of vehicle parameters used in the fuel consumption and emission models

Same for OLD and NEW defaults		Unsignalized Roundabout	Metering Signals	Metering Benefit
Degree of Saturation		1.152	0.93	-19.3%
Control Delay (Average)	sec	94.7	29.4	-69.0%
Intersection Level of Service (LOS)		LOS F	LOS C	LOS F to C
95% Back of Queue - Vehicles (Worst Lane)	veh	113.6	35.5	-68.8%
Differences between NEW and OLD defaults		Unsignalized Roundabout	Metering Signals	
Cost	$/y	0.0%	-0.1%	
Fuel Consumption	L/y	-2.8%	-3.9%	
Carbon Dioxide *	kg/y	-8.3%	-9.3%	
Hydrocarbons	kg/y	-92.8%	-92.5%	
Carbon Monoxide	kg/y	-96.6%	-96.2%	
NOx	kg/y	-43.6%	-45.4%	

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Comparison of alternative intersection treatments: Metering signals example

Assessment of the effectiveness of roundabout metering signals using old and new default values of vehicle parameters used in the fuel consumption and emission models

NEW Defaults		Unsignalized Roundabout	Metering Signals	Metering Benefit
Cost	$/y	2,244,932	1,255,306	-44.1%
Fuel Consumption	L/y	232,610	179,855	-22.7%
Carbon Dioxide	kg/y	549,402	425,125	-22.6%
Hydrocarbons	kg/y	54	38	-29.6%
Carbon Monoxide	kg/y	543	460	-15.3%
NOx	kg/y	650	531	-18.3%
OLD Defaults		Unsignalized Roundabout	Metering Signals	Metering Benefit
Cost	$/y	2,245,150	1,257,159	-44.0%
Fuel Consumption	L/y	239,315	187,195	-21.8%
Carbon Dioxide	kg/y	599,091	468,687	-21.8%
Hydrocarbons	kg/y	750	507	-32.4%
Carbon Monoxide	kg/y	15,952	12,099	-24.2%
NOx	kg/y	1,153	972	-15.7%

IN CONCLUSION …

Effects of changes in default vehicle parameters:

- Changes in the default parameters made **little difference to the relative levels of benefits** from metering signals assessed in terms of fuel consumption, emissions and operating cost results.
- **Changes in HC, CO and NO_x emissions were very large** as expected due to the effect of emission control technologies.

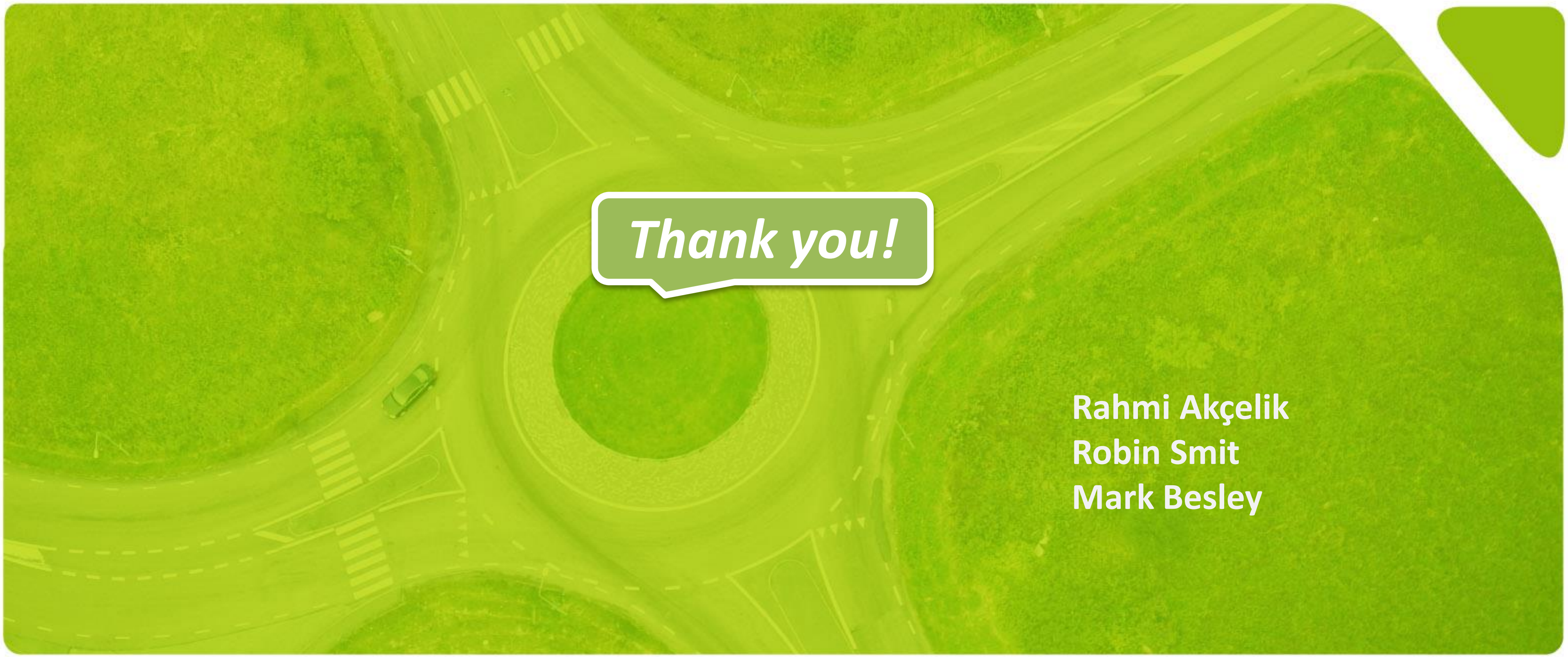
IN CONCLUSION …

- **Changes in fuel consumption and CO_2 emissions were small** in spite of increased vehicle efficiencies.

  The main reason is the **increases in the default vehicle mass values** (composite light vehicle was affected by significant increases in the **SUV and light rigid truck percentages** in vehicle fleet composition).

  This means that while the energy and CO_2 emission efficiencies of modern vehicles are improved, the total fuel consumption and CO_2 emissions of the vehicle fleet are not necessarily decreased due to the **higher percentage of larger vehicles**.

END OF PRESENTATION



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