

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

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ABSTRACT

Estimation of fuel consumption and pollutant emissions for evaluating road traffic conditions is useful for environmental assessment in traffic design, operations and planning. This also forms the basis of operating cost modeling. Fuel consumption and emission (CO₂, CO, HC, NO_x) models with four levels of aggregation for traffic engineering and transport planning purposes were developed by the first author and his colleagues at the Australian Road Research Board in the 1980s. These models are based on vehicle power requirements, and the four-mode elemental (modal) and the more detailed instantaneous forms of the model are implemented in the SIDRA INTERSECTION and SIDRA TRIP software packages.

This paper describes 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. Implications of the change in fuel and emission model parameters on intersection assessment are considered. A roundabout evaluation case is presented assessing the effectiveness of roundabout metering signals using the fuel consumption and emission models with (i) older vehicle parameter values and (ii) the recalibrated parameter values to investigate whether the changes in vehicle parameters change the results significantly. The model provided in the SIDRA INTERSECTION software package is used for this purpose.

INTRODUCTION

Environmental assessment in traffic design, operations and planning can be conducted using models to estimate fuel consumption and pollutant emissions as a function of traffic conditions. This also forms the basis of operating cost modeling.

Fuel consumption and emission (CO₂, CO, HC, NO_x) models with four levels of aggregation for traffic engineering and transport planning purposes were developed by the first author and his colleagues based on extensive research at the Australian Road Research Board in the 1980s (1-19). These models are based on vehicle power requirements, and the four-mode elemental (modal) and the more detailed instantaneous forms of the model are implemented in the SIDRA INTERSECTION and SIDRA TRIP software packages (20-23).

Studies of fuel consumption and emission using SIDRA software were reported in the past (24, 26). In more recent years, an application of the model to investigate of fuel consumption, pollutant emission and operating cost savings at a roundabout with metering signals was reported by the first author (27).

This model provides highly accurate fuel consumption estimates for traffic analysis since there is no simplification of traffic information into such aggregate variables as average travel speed, average running speed and number of stops. However, it has been recognized that it is necessary to update the vehicle parameters used by the model, especially for emission estimates, in order to reflect more recent changes in vehicle characteristics (rated engine power, catalyst loading and composition, engine management system, etc.) and fleet composition (28).

Research was undertaken recently to calibrate the light and heavy vehicle parameters used by the fuel consumption and emission models in SIDRA INTERSECTION and SIDRA TRIP based on a large empirical database for a modern vehicle fleet. The preliminary results of this effort were reported by the authors previously (29).

The research involved the use of an empirical database (NISE 2) incorporating a large range of fuel consumption and emission data for about 400 vehicles representing a cross section of typical vehicles on Australian metropolitan roads (30-32). 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. This drive cycle consists of four phases representing *Residential*, *Arterial*, *Freeway* and *Congested* driving conditions.

This paper describes the instantaneous form of the fuel consumption and CO₂ models, presents the model recalibration results for a number of vehicles, and compares the default vehicle parameters for the composite "Light Vehicle" in SIDRA INTERSECTION before and after recalibration.

Implications of the change in fuel and emission model parameters on intersection assessment are considered. A roundabout evaluation case is presented assessing the effectiveness of roundabout metering signals using fuel consumption and emissions (CO₂, HC, CO, NO_x) as well as operating costs (including vehicle operating cost and value of time) with (i) older vehicle parameter values and (ii) the recalibrated parameter values, to investigate whether changes in vehicle parameters change the results significantly. The model provided in the SIDRA INTERSECTION software package is used for this purpose.

MODEL PARAMETERS

The fuel consumption and emission models use two groups of parameters, namely vehicle parameters, and traffic and road parameters.

Vehicle parameters include loaded mass, idle fuel or emission rates, and fuel or emission efficiency rates. The vehicle parameters used in the fuel consumption and emission models are derived considering fleet composition (percentage of vehicle kilometres for each vehicle type) with more detailed vehicle data including fuel type (% diesel), maximum engine power, power to weight ratio, number of wheels and tyre diameter, rolling resistance factor, frontal area and the aerodynamic drag coefficient.

In SIDRA INTERSECTION, fuel consumption, emissions and cost are calculated for different *movement classes* including *Light Vehicles, Heavy Vehicles, Buses, Bicycles, Large Trucks, Light Rail / Trams* and two *user-defined classes*. Traditionally, a more aggregate "heavy vehicle" designation is used for traffic modeling as well as fuel and emission modeling, where a heavy vehicle is defined as any vehicle with more than two axles or with dual tyres on the rear axle. The US Highway Capacity Manual (33) defines a heavy vehicle as "a vehicle with more than four wheels touching the pavement during normal operation". Thus, buses, trucks, semi-trailers (articulated vehicles), cars towing trailers or caravans, tractors and other slow-moving vehicles are classified as heavy vehicles. All other vehicles are defined as light vehicles (cars, vans, small trucks).

Traffic and road parameters used directly in the SIDRA INTERSECTION model for fuel and emission estimation include speed, acceleration rate and grade parameters. A detailed description of the polynomial acceleration model used for this purpose is available (16, 20).

SIDRA INTERSECTION uses a macroscopic four-mode elemental (modal) model. For each lane of traffic, the traffic model derives vehicle paths (drive cycles) consisting of a series of *cruise, acceleration, deceleration* and *idling (stopped) time* elements (Figure 1) for specific traffic conditions represented by intersection geometry, traffic control and demand flows based on data supplied by the user. Thus, the vehicle paths (drive cycles) generated by SIDRA INTERSECTION are very different for different intersection types (signalized, roundabout, sign-controlled), for different signal phasing arrangements, for different signal timings for a given phasing arrangement, for give-way (yield) and stop control (two-way or all-way), and for different congestion levels.

Vehicle paths (drive cycles) are derived and the fuel consumption and emission models are applied to queued (stopped) and unqueued (unstopped) vehicles belonging to different *movement classes* in each lane separately, and then the total values are calculated for all traffic using the lane.

Vehicle paths for *unqueued vehicles* are constructed taking into account (i) cruise on entry to the approach, (ii) slow-down to a safe negotiation speed or full stop on the approach, and (iii) negotiation of the intersection departure area at the safe negotiation speed.

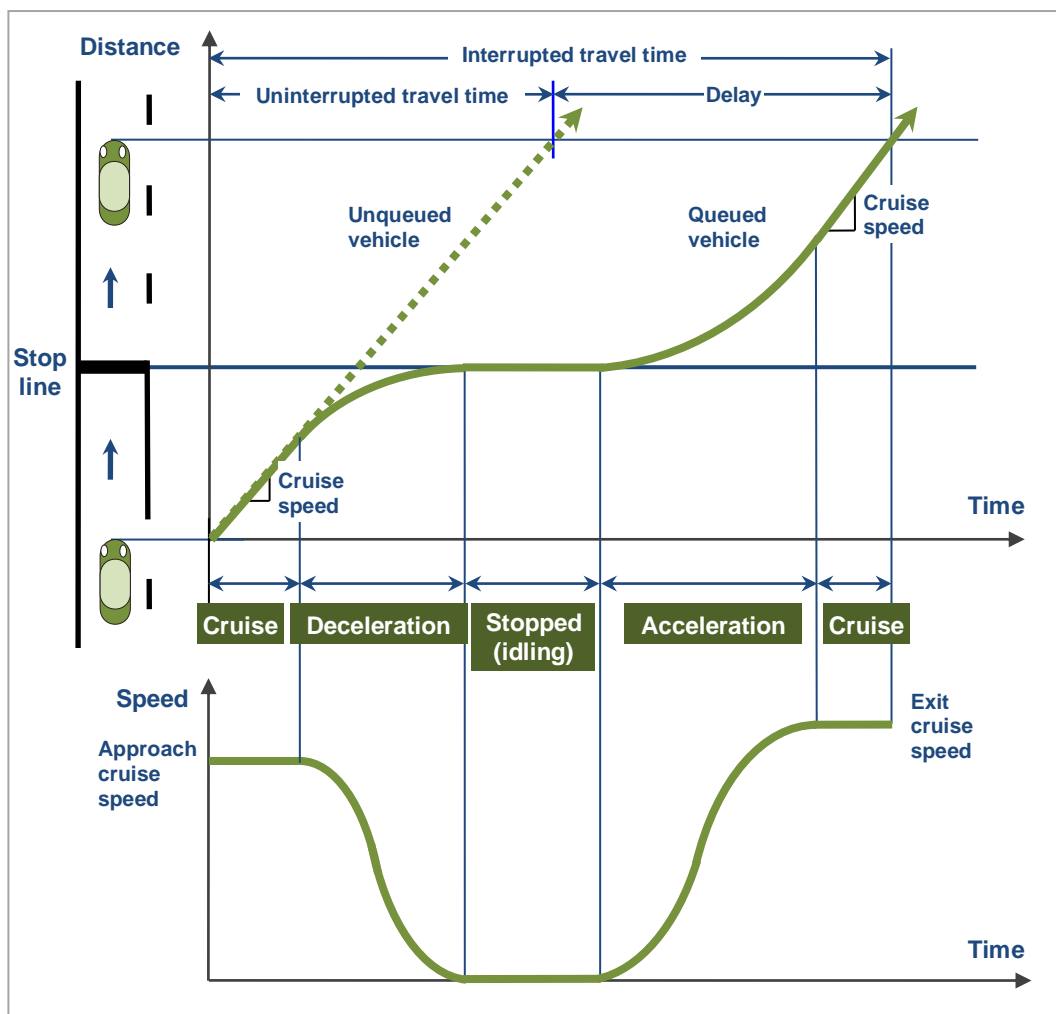


Figure 1 - Vehicle path (drive cycle) during a stop - start manoeuvre (example)

Vehicle paths for *queued vehicles* (Figures 1 and 2) are constructed taking into account (i) cruise on entry to the approach, (ii) major stop (stop or slow down from approach cruise speed), (iii) queue move-ups (repeated stops and starts in the queue) and (iv) negotiation of the intersection departure area at the safe negotiation speed.

Once the vehicle travel paths are determined, the fuel consumption and emission values are calculated for each of the four driving elements (modes) for each vehicle path, the results are added together for the entire vehicle path, and aggregate values for lanes and origin-destination (turning) movements are determined according to flow proportions of queued and unqueued vehicles and movement classes.

Thus, the key to the estimation of fuel consumption and emissions is detailed modelling of stop-starts in addition to delays and queues. The stop-start model is strongly related to the modelling of back of queue and delay at all types of intersection. This is depicted in Figure 2 where *queue move-ups* are seen to be related to *overflow queues*. Stop - start modeling is not included in the HCM for intersections (33). In SIDRA INTERSECTION, a gap-acceptance model by signal analogy is used as a basis of modeling stop-starts for roundabouts and two-way sign control (34, 35).

The instantaneous models of fuel consumption and CO₂ are described in the following section. Other emission models have the same structure as the fuel consumption model.

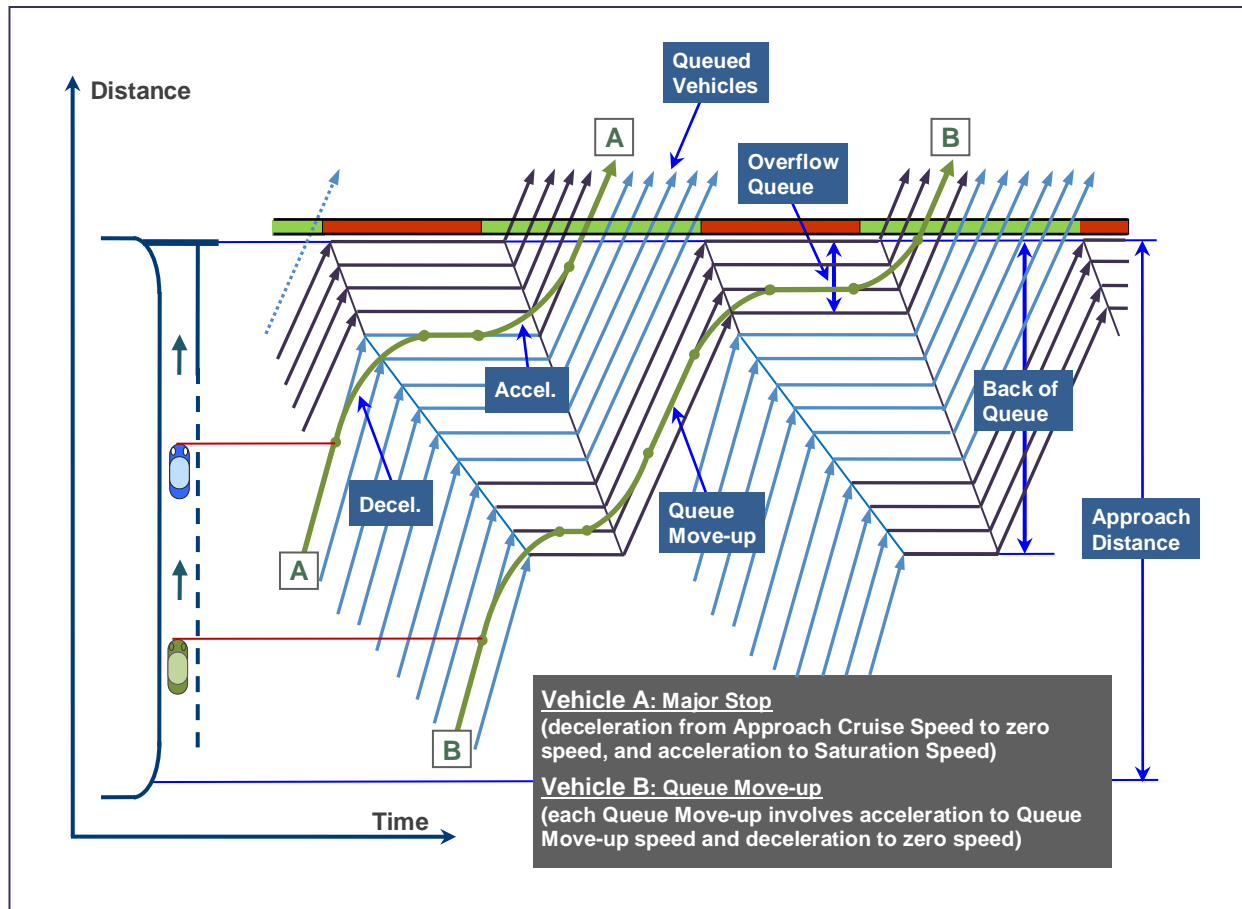


Figure 2 - Relationship between queue move-ups (multiple stops) and back of queue

MODEL FOR FUEL CONSUMPTION AND CO₂

The original fuel consumption model developed in the 1980s can be expressed in terms of the energy, power or tractive force required by the vehicle. The instantaneous model estimates the fuel consumption rate (mL/s) as a value per unit time measured at any instant during the trip and expressed as a function of the tractive power required by the vehicle:

$$f_t = \alpha + \beta_1 P_T + [\beta_2 a P_I]_{a>0} \quad \text{for } P_T > 0 \quad (1)$$

$$= \alpha \quad \text{for } P_T \leq 0$$

$$P_T = \min(P_{\max}, P_C + P_I + P_G) \quad (2)$$

$$P_C = b_1 v + b_2 v^3 \quad (3)$$

$$P_I = M_v a v / 1000 \quad (4)$$

$$P_G = 9.81 M_v (G/100) v / 1000 \quad (5)$$

$$\alpha = f_i / 3600 \quad (6)$$

where

f_t = instantaneous fuel consumption rate (mL/s),

P_T = total tractive power (kilowatts, kW),

P_{\max} = maximum engine power (kW),

P_C = cruise component of total power (kW),

- P_I = inertia component of total power (kW),
 P_G = grade component of total power (kW),
 G = road grade (per cent), negative if downhill,
 M_v = vehicle mass (kg) including occupants and any other load,
 v = instantaneous speed (m/s) = v (km/h) / 3.6
 a = instantaneous acceleration rate (m/s²), negative for deceleration,
 α = constant idle fuel consumption rate (mL/s), which applies during all modes of driving (as an estimate of fuel used to maintain engine operation),
 f_i = constant idle fuel consumption rate in mL/h,
 b_1 = Drag fuel consumption parameter related mainly to the rolling resistance (kN),
 b_2 = Drag fuel consumption parameter related mainly to the aerodynamic drag (kN/(m/s)²),
 β_1 = the efficiency parameter which relates fuel consumed to the total power provided by the engine, it can be shown to be fuel consumption per unit of energy (mL/kJ or g/kJ), and
 β_2 = the efficiency parameter which relates fuel consumed during positive acceleration to the product of acceleration rate and inertia power when $n = 1.0$ (mL/(kJ.m/s²) or g/(kJ.m/s²)).

The instantaneous cruise fuel consumption rate ($a = 0$, $P_I = 0$) on a on a level road ($G = 0$, $P_G = 0$) is given by:

$$f_{ct} = \alpha + \beta_1 P_C \quad (7a)$$

$$f_{ct} = \alpha + \beta_1 (b_1 v + b_2 v^3) \quad (7b)$$

Parameters A and B specified as input for the software are calculated from:

$$A = 1000 \beta_1 b_1 \quad (8a)$$

$$B = \beta_1 b_2 / 0.01296 \quad (8b)$$

where the parameter units are mL/km for A and (mL/km)/(km/h)² for B.

Parameters A and B (b_1 and b_2) provide a reasonable representation of drag (cruise) power to be provided by the engine so that the model application for fuel consumption is based on a realistic definition of P_C , P_I and P_T . Parameters b_1 and b_2 also reflect some component of drag associated with the engine.

The following simpler model has been developed as part of the recalibration effort and introduced in SIDRA INTERSECTION Version 6. It was obtained as an alternative model by dropping the ($a P_I$) term of Equation (1):

$$f_t = \alpha + \beta P_T \quad \text{for } P_T > 0 \quad (9)$$

$$= \alpha \quad \text{for } P_T \leq 0$$

where parameters are as in Equation (1).

The values of instantaneous Carbon Dioxide (CO_2) emission rate (g/s as a value per unit time) are estimated directly from the instantaneous fuel consumption rate:

$$f_i(CO_2) = f_{CO_2} f_i(fuel) \quad (10)$$

where

$f_i(fuel)$ = fuel consumption rate in mL/s and,

f_{CO_2} = CO_2 to Fuel Consumption Rate in grams per millilitre (kg per litre) of fuel (g/mL or kg/L).

The model for estimating the instantaneous Carbon Monoxide (CO), Hydrocarbons (HC) and Nitrogen Oxides (NO_x) emission rates (mg/s), representing the emission production rate at any instant during the trip determined as a value per unit time, has the same structure as the instantaneous fuel consumption model with different parameters.

The method used to calibrate the fuel consumption and emission models is explained in a previous paper by the authors (29).

MODEL CALIBRATION RESULTS

The calibration confirmed that new vehicles are significantly more efficient with substantially lower fuel consumption and emission (CO₂, CO, HC, NO_x) rates. This result is as expected due to technological improvements in the vehicle fleet since the 1980s.

A comparison of the fuel consumption and CO₂ default parameters used in SIDRA INTERSECTION for light vehicles before and after recalibration is presented in *Table 1*.

Calibration results for individual vehicles of different types are given in *Figure 3* (vehicle characteristics listed include fuel density, D).

Measured and estimated values of fuel consumption and emission rates for some of the individual test vehicles for the CUEDC-P drive cycle are summarized in *Table 2*.

Table 1 - Comparison of default parameters for Light Vehicle fuel consumption and CO₂ models before and after recalibration

Parameter	Description	Units	Old Defaults	New Defaults	Difference
f_i	Idle fuel consumption rate	mL/h	1350	1200	-11%
A	$A = 1000 \beta_1 b_1$	mL/km	21.0	16.0	-24%
B	$B = \beta_1 b_1 / 0.01296$	(mL/km)/ (km/h) ²	0.00550	0.00400	-27%
b₁	Drag fuel consumption parameter, mainly related to rolling resistance	kN	0.233333	0.160000	-31%
b₂	Drag fuel consumption parameter mainly related to aerodynamic drag	kN/(m/s) ²	0.000792	0.000518	-35%
β₁	Efficiency parameter	mL/kJ	0.090	0.100	*
β₂	Energy-acceleration efficiency parameter	mL/(kJ.m/s ²)	0.030	-	-
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_{CO2}	CO ₂ emission rate	g/mL	2.500	2.350	-6%

* The higher value of the efficiency parameter, β₁ compensates for elimination of the second parameter, β₂.

Toyota Corolla Ascent 2004

M_v	P_{max}	f_{CO_2}	D_{fuel}	Eng. Cap.	Auto / Man
kg	kW	g / mL	g / L	L	
1250	100	2.350	738.7	1.8	Auto



f_i	A	B	b_1	b_2	β
mL/h	mL/km	mL/km/(km/h) ²	kN	kN/(m/s) ²	mL/kJ
891	9.60	0.00373	0.0948	0.000478	0.1012

Holden Commodore 2006

M_v	P_{max}	f_{CO_2}	D_{fuel}	Eng. Cap.	Auto / Man
kg	kW	g / mL	g / L	L	
1810	131	2.350	738.7	3.6	Auto



f_i	A	B	b_1	b_2	β
mL/h	mL/km	mL/km/(km/h) ²	kN	kN/(m/s) ²	mL/kJ
1504	19.39	0.00406	0.1779	0.000483	0.1090

Ford Territory 2004

M_v	P_{max}	f_{CO_2}	D_{fuel}	Eng. Cap.	Auto / Man
kg	kW	g / mL	g / L	L	
2150	142	2.350	738.7	4	Auto



f_i	A	B	b_1	b_2	β
mL/h	mL/km	mL/km/(km/h) ²	kN	kN/(m/s) ²	mL/kJ
1479	24.32	0.00375	0.2484	0.000497	0.0979

Isuzu FVR900 (T) 2005 (Diesel)

M_v	P_{max}	f_{CO_2}	D_{fuel}	Eng. Cap.	Auto / Man
kg	kW	g / mL	g / L	L	
12080	164	2.633	830.0	7.8	Manual



f_i	A	B	b_1	b_2	β
mL/h	mL/km	mL/km/(km/h) ²	kN	kN/(m/s) ²	mL/kJ
2274	201.31	0.00818	2.7207	0.001432	0.0740

Hino RB8 2006 (Diesel)

M_v	P_{max}	f_{CO_2}	D_{fuel}	Eng. Cap.	Auto / Man
kg	kW	g / mL	g / L	L	
7180	165	2.633	830.0	4.6	Manual



f_i	A	B	b_1	b_2	β
mL/h	mL/km	mL/km/(km/h) ²	kN	kN/(m/s) ²	mL/kJ
2044	179.32	0.00042	2.0101	0.000062	0.0892

Figure 3 – Fuel consumption model calibration results for individual vehicles

Table 2 - Measured and estimated values of fuel consumption and emission rates for individual test vehicles for the CUEDC-P drive cycle

	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

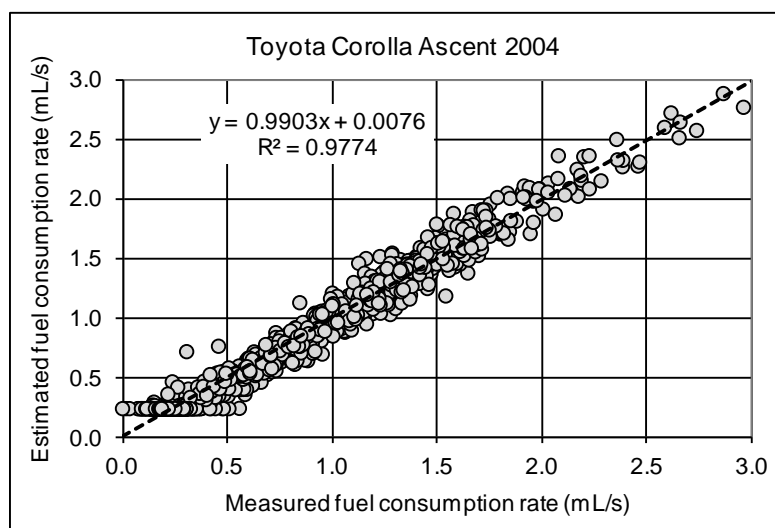


Figure 4 – Estimated fuel consumption vs measured fuel consumption for Toyota Corolla (vehicle details given in Figure 3) for the CUEDC-P drive cycle (second-by-second fuel consumption values compared)

Fuel consumption rates estimated using the calibrated test vehicle parameters indicated very high accuracy levels in terms of both instantaneous values. This can be seen from *Figures 4 and 5* which shows comparison of estimated and measured fuel consumption rates for the Toyota Corolla for a section of the drive cycle.

The errors in fuel consumption (and CO₂ 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 full CUEDC-P drive cycle is also shown in *Figure 5*. On the other hand, the error levels in emission (HC, CO, NO_x) estimation were significantly higher (-23.1 to +2.5 per cent for all vehicles).

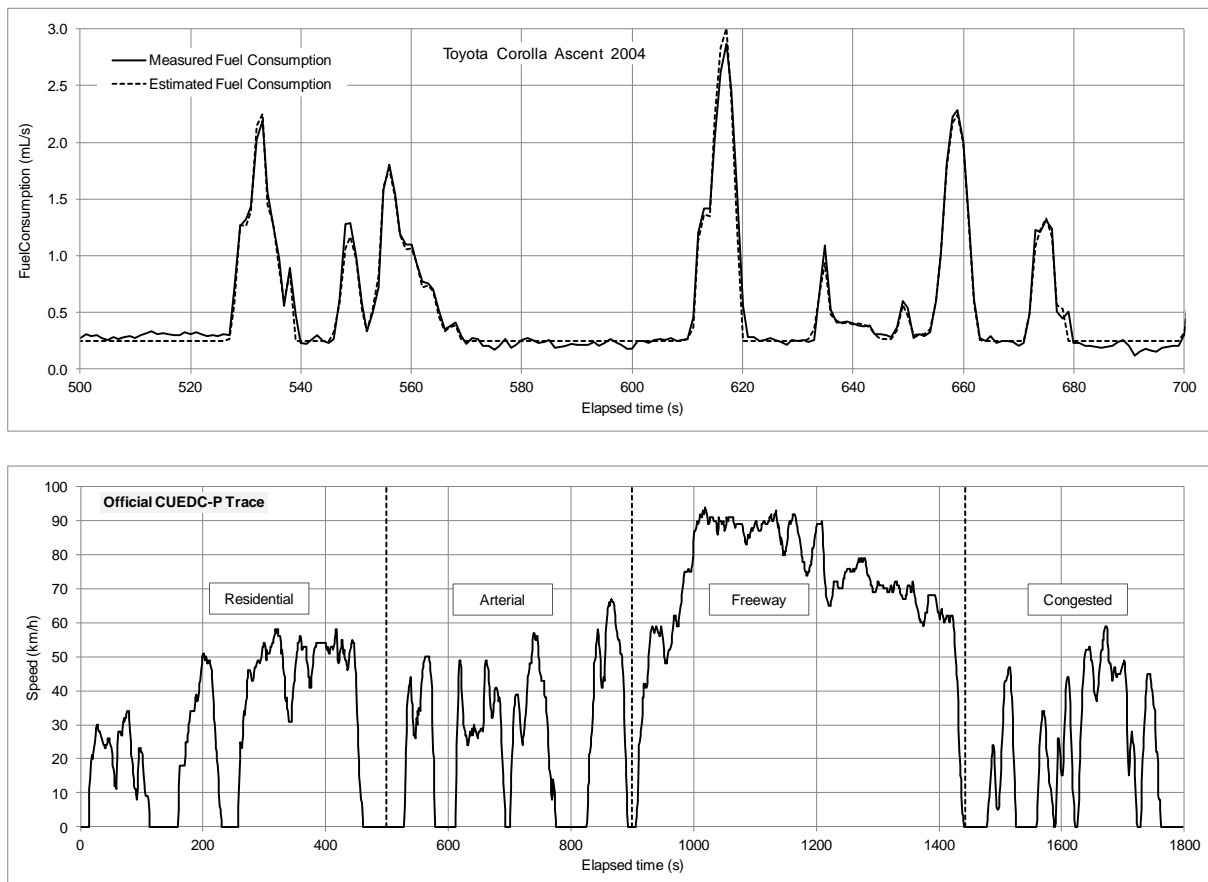


Figure 5 – Accuracy of the instantaneous fuel consumption model for Toyota Corolla (vehicle details given in Figure 3) with the full CUEDC-P drive cycle also shown

COMPARISON OF ALTERNATIVE INTERSECTION TREATMENTS

A case study is used as an example to investigate the implications of the change in model parameters on assessing the effectiveness of roundabout metering signals in terms of fuel consumption and emissions (CO_2 , HC, CO, NO_x) as well as operating costs (including vehicle operating cost and value of time). This is the case of the Nepean Highway - McDonald Street roundabout in Melbourne, Australia. Studies of roundabout metering signals that operate at this intersection were published previously (27, 36). There is extensive literature on roundabout metering signals (36-45). A recent study of emission estimation at multi-lane roundabouts should also be mentioned (46).

This investigation will compare the performance of roundabout metering signals with unsignalised roundabout conditions. Fuel consumption, emission and operating cost results will be obtained using SIDRA INTERSECTION Version 6 with:

- (i) older default values for light and heavy vehicles and
- (ii) new default values based on the recalibration effort.

The specific purpose of the paper is to investigate whether changes in vehicle parameters change the assessment results significantly.

The example is shown in *Figure 6*. The intersection has been mirror-imaged for driving on the right hand side of the road (to make the example easier to understand for North American readers). The Standard Right-Hand version of the software has been used with the SIDRA Standard roundabout capacity model (Environment Factor = 1.0) in order to emulate the traffic conditions relevant to this case study. Metric units apply. The original AM peak volumes have been increased by 10 per cent. Gap Acceptance Factor and Opposing Vehicle Factor values for Heavy Vehicles are specified as 2.0. Pedestrian movements are not included in the analysis.

Under AM peak conditions, the Nepean Highway SW approach is oversaturated for the unsignalised roundabout (without metering signals) due to unbalanced flow conditions. Metering signals where Nepean Highway SW is the *controlling approach* and McDonald Street NW is the *metered approach* balance the operating conditions on these two approaches introducing significant improvements to the performance of the intersection.

The total fuel consumption, emission and operating cost values as well as various intersection performance indicators (largest degree of saturation, largest 95th percentile back of queue, average intersection delay and the corresponding level of service) are given for the two conditions analyzed. Two sets of total fuel consumption, emission (CO₂, HC, CO, NO_x) and operating cost values are given corresponding to the use of old and new default values of vehicle parameters for the same intersection performance.

The results of the assessment of the effectiveness of roundabout metering signals using old and new default values of vehicle parameters are summarized in *Table 3*. It is seen that the changes in the default parameters made little difference to the relative levels of benefits obtained from the use of metering signals assessed in terms of fuel consumption, emissions and operating cost results. The differences in fuel consumption and CO₂ emissions using the old and new default values were very small whereas the differences in HC, CO and NO_x emissions were very large. While large differences in emission results are as expected due to the effect of emission control technologies, it was surprising to see very small differences in fuel consumption and CO₂ emissions (larger differences in CO₂ emissions are due to the effect of the change in the CO₂ to Fuel Consumption Rate). The main reason for these small differences is the increases in the light vehicle and heavy vehicle mass values. In particular, the composite light vehicle was affected by significant increases in the SUV and light rigid truck percentages in vehicle fleet composition used in determining the mass values for the new defaults.

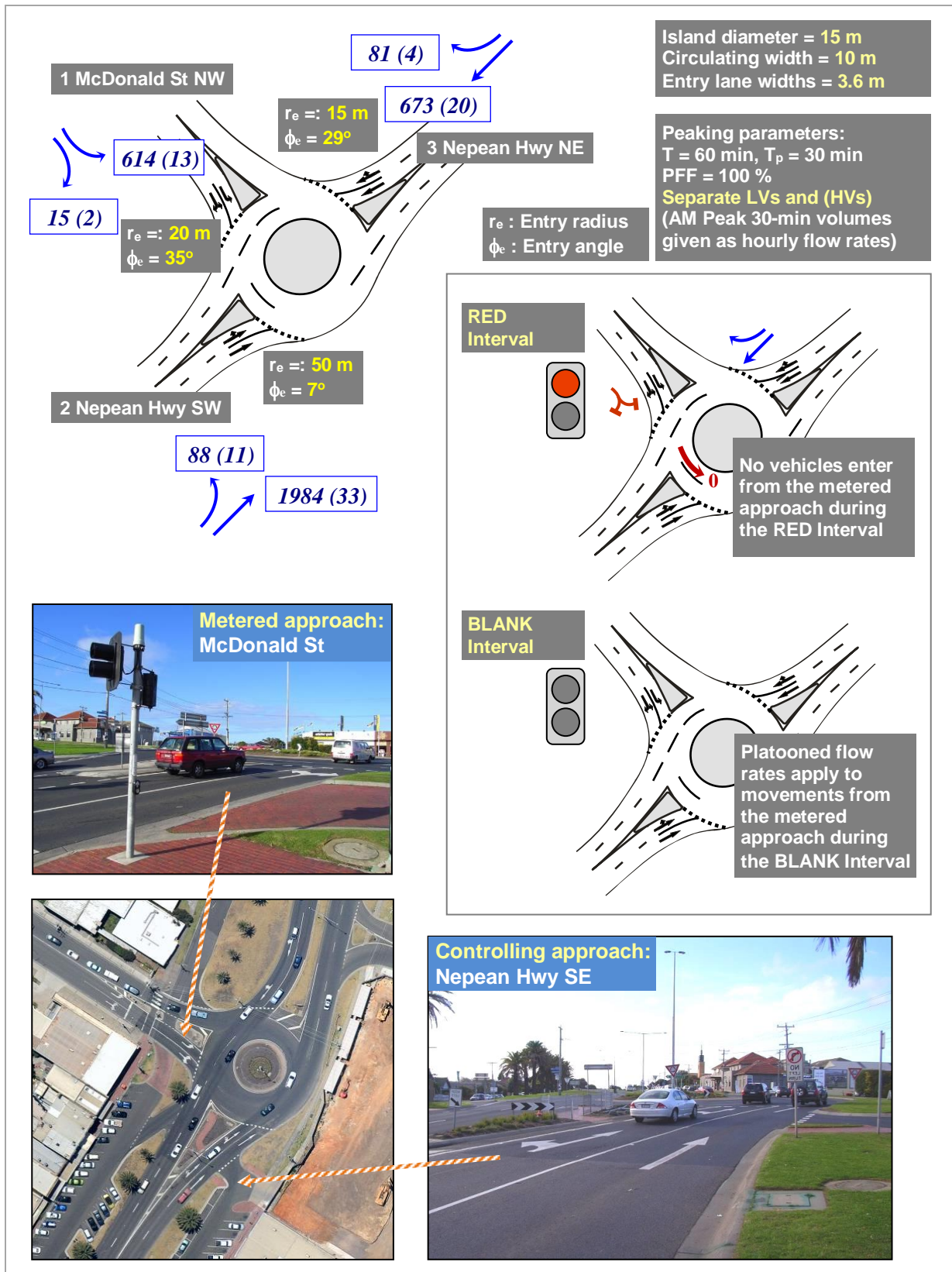


Figure 6 - Roundabout metering signals case study: Nepean Highway - McDonald Street, Melbourne, Australia

Table 3 - 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%
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%
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%	

* The reduction in the CO₂ rate is affected by the new lower default value used.

CONCLUDING REMARKS

This paper described the instantaneous form of the fuel consumption and emission models, presented the model recalibration results for a number of vehicles, and compared the default vehicle parameters for the composite "Light Vehicle" in SIDRA INTERSECTION before and after recalibration.

A roundabout evaluation case is presented as an example to assess the implications of the change in fuel and emission model parameters. The example evaluates the effectiveness of roundabout metering signals using the fuel consumption and emission models with (i) older vehicle parameter values and (ii) the recalibrated parameter values to investigate whether changes in vehicle parameters change the results significantly.

The results of this investigation indicated that the changes in the default parameters made little difference to the relative levels of benefits obtained from the use of metering signals assessed in terms of fuel consumption, emissions and operating cost results. While the differences in fuel consumption and CO₂ emissions using the old and new default values were very small, the differences in HC, CO and NO_x emissions were very large.

Large differences in emission results are as expected due to the effect of emission control technologies. However, it was surprising to see very small differences in fuel consumption and CO₂ emissions in view of the decreases in vehicle parameters shown in *Table 1*. The main reason for this finding is the increases in the light vehicle and heavy vehicle mass values. In particular, the new light vehicle mass value was affected by significant increases in the SUV and light rigid truck percentages in vehicle fleet composition. This means that while the energy and CO₂ emission efficiencies of modern vehicles are improved, the total fuel consumption and CO₂ emissions of the vehicle fleet are not necessarily decreased due to the higher percentage of larger vehicles. Further analyses are recommended using the same (new) vehicle mass values to isolate the effect of other vehicle parameters.

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