CALIBRATING FUEL CONSUMPTION AND EMISSION MODELS FOR MODERN VEHICLES

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Fuel Consumption and Emission Models

Estimation of fuel consumption and emissions for evaluating traffic conditions is useful for environmental assessment in traffic design, operations and planning. This also forms the basis of operating cost modelling.

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)
- four-mode elemental (modal)
- running speed (& PKE)
- average speed

HISTORY

KEY REFERENCES (available on sidrasolutions.com)

AKÇELIK, R. (1983). Progress in Fuel Consumption Modelling for Urban traffic Management. ARRB Research Report ARR No. 124.

AKÇELIK, R. and BIGGS, D.C. (1987). Acceleration profile models for vehicles in road traffic. Transportation Science.

BOWYER, D.P., AKÇELIK, R. and BIGGS, D.C. (1985). Guide to Fuel Consumption Analysis for Urban Traffic Management. ARRB Special Report SR No. 32

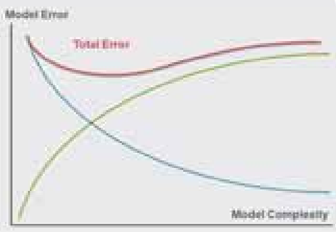
US AWARD

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

Traffic - Transport Model Hierarchy (from SR 32)

Appropriate fuel and emission model

Traffic - Transport Model	Examples	Fuel and Emission Model
Macro	VISUM, CUBE, EMME	Average Speed
Macro - Meso	SATURN, TRANSYT	Running Speed, Three-mode Elemental
Micro - Meso	SIDRA INTERSECTION	Four-Mode Elemental
Micro	SIDRA TRIP, VISSIM	Instantaneous



Fuel Consumption and Emission Models

- Four-mode elemental (modal) model:
  SIDRA INTERSECTION
- Instantaneous (second-by-second) model:
  SIDRA TRIP

SIDRA INTERSECTION: Micro-analytical traffic evaluation tool

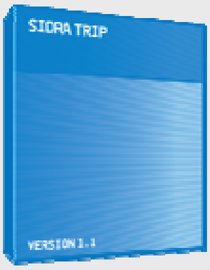
First released in 1984.
Current version: SIDRA INTERSECTION 5.1

Working towards: Version 6
(including SIDRA NETWORK)

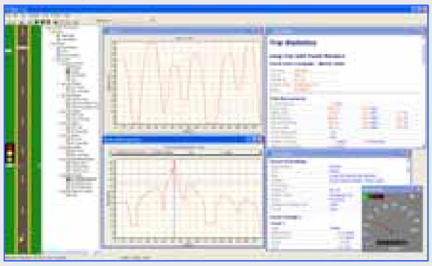
8200 licences in 1300 organisations across in 68 Countries

Four-mode elemental model using
SIDRA INTERSECTION vehicle path (drive cycle) model

SIDRA TRIP:
Single trip microsimulation



Vehicle Trip Assessment Software for GPS Data and Quick Scenario Analysis



Instantaneous model

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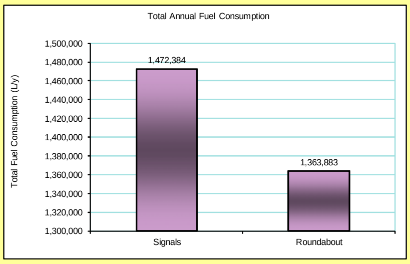
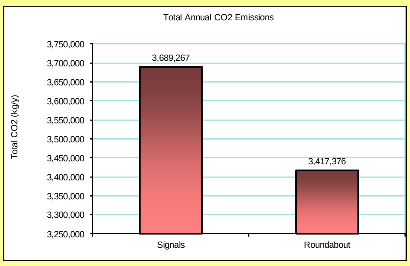
SIDRA INTERSECTION
ANNUAL SUMS Excel application

Option / Scenario	Short Caption
A	Signals
B	Roundabout

Comparison of Fuel, Emissions and Cost for alternative intersection treatments

Annual Values	Cost & Fuel		Emissions (Total)				Demand Flows (Total)			Delay (Total)		
	Cost	Fuel	CO2	HC	CO	NOX	Vehicles	Pedestrians	Persons	Vehicles	Pedestrians	Persons
	$/y	L/y	kg/y	kg/y	kg/y	kg/y	veh/y	ped/y	pers/y	veh-h/y	ped-h/y	pers-h/y
Signals	9,445,057	1,472,384	3,689,267	5,953	280,252	8,663	17,494,056	0	20,992,868	110,785	0	132,942
Roundabout	7,864,368	1,363,883	3,417,376	5,373	270,088	8,337	17,494,056	0	20,992,868	48,043	0	57,652
Difference (B - A)	-1,580,689	-108,501	-271,891	-580	-10,165	-326	0	0	0	-62,742	0	-75,290
Per cent difference	-16.7%	-7.4%	-7.4%	-9.7%	-3.6%	-3.8%	0.0%	0.0%	0.0%	-56.6%	0.0%	-56.6%





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ANNUAL SUMS Excel application

Option / Scenario A

Flow Period		Hours per Year	Cost & Fuel: Cost	Cost & Fuel: Fuel	Emissions (Total): CO2	Emissions (Total): HC	Emissions (Total): CO	Emissions (Total): NOX
			$/y	L/y	kg/y	kg/y	kg/y	kg/y
1	AM Peak	480	1,148,842	171,692	430,133	708	32,674	1,001
2	PM Peak	480	1,305,918	183,259	459,251	759	33,314	1,030
3	Business Hours	3160	4,846,641	773,759	1,938,759	3,120	149,891	4,613
4	Medium Off-Peak	2200	1,618,293	259,328	649,782	1,033	48,795	1,527
5	Light Off-Peak	2440	525,362	84,346	211,343	333	15,578	492
	Total per Year >>	**8,760**	**9,445,057**	**1,472,384**	**3,689,267**	**5,953**	**280,252**	**8,663**
1	% of Total >>	5%	12%	12%	12%	12%	12%	12%
2	% of Total >>	5%	14%	12%	12%	13%	12%	12%
3	% of Total >>	36%	51%	53%	53%	52%	53%	53%
4	% of Total >>	25%	17%	18%	18%	17%	17%	18%
5	% of Total >>	28%	6%	6%	6%	6%	6%	6%

Option / Scenario B

Flow Period		Hours per Year	Cost & Fuel: Cost	Cost & Fuel: Fuel	Emissions (Total): CO2	Emissions (Total): HC	Emissions (Total): CO	Emissions (Total): NOX
			$/y	L/y	kg/y	kg/y	kg/y	kg/y
1	AM Peak	480	961,139	162,327	406,666	657	33,220	1,002
2	PM Peak	480	995,724	169,611	425,042	683	34,874	1,051
3	Business Hours	3160	4,090,849	715,368	1,792,443	2,812	141,863	4,384
4	Medium Off-Peak	2200	1,373,331	239,533	600,183	927	45,868	1,443
5	Light Off-Peak	2440	443,325	77,043	193,043	294	14,263	457
	Total per Year >>	**8,760**	**7,864,368**	**1,363,883**	**3,417,376**	**5,373**	**270,088**	**8,337**
1	% of Total >>	5%	12%	12%	12%	12%	12%	12%
2	% of Total >>	5%	13%	12%	12%	13%	13%	13%
3	% of Total >>	36%	52%	52%	52%	52%	53%	53%
4	% of Total >>	25%	17%	18%	18%	17%	17%	17%
5	% of Total >>	28%	6%	6%	6%	5%	5%	5%

75% of Fuel, Emissions and Cost is outside AM & PM Peak periods

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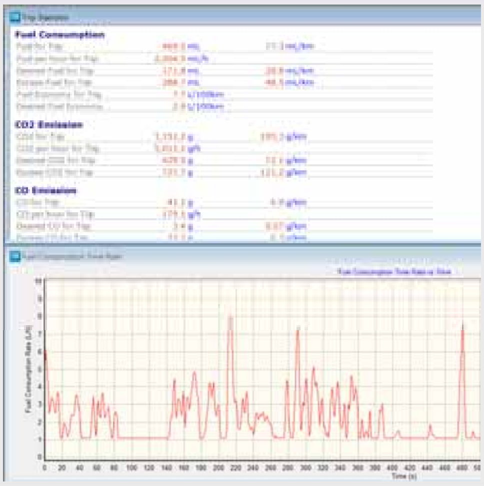
Before – After Assessments using GPS data



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Instantaneous Model of Fuel Consumption

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

$= \alpha$ 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

$f_t = \alpha + \beta_1 P_T$ for $P_T > 0$

$= \alpha$ for $P_T \leq 0$

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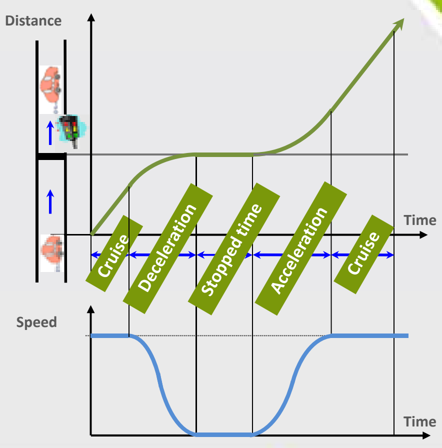
Four-Mode Elemental Model

Vehicle path (drive cycle) model for
- Fuel Consumption
- Emissions: CO_2 / CO / HC / NO_x
- Operating COST

Integral functions are used for each element (mode) of vehicle path:
- Cruise
- Deceleration
- Idling
- Acceleration



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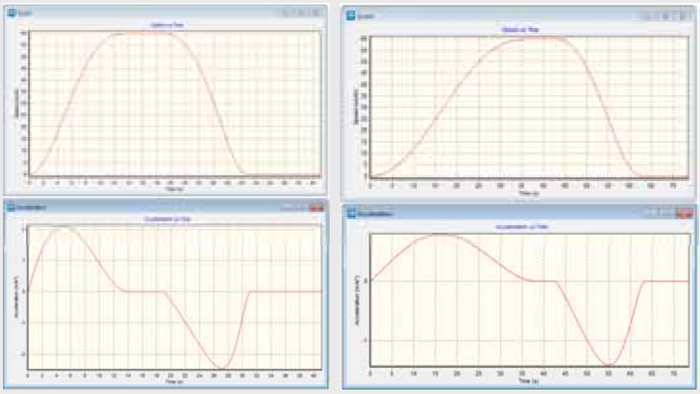
Acceleration – Deceleration models

Polynomial acceleration profile model

Light Vehicles | **Heavy Vehicles**



Model Calibration

Vehicle parameters are being calibrated using data for a modern vehicle fleet.

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 is being 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.

Test Vehicle

The paper describes the models and the **calibration method** used, and presents results for a **medium-size passenger** car:

Toyota Corolla Ascent 2004
Mass = 1250 kg
Max. Power = 100 kW
4 cylinder petrol engine
ADR79/00 certified
automatic transmission

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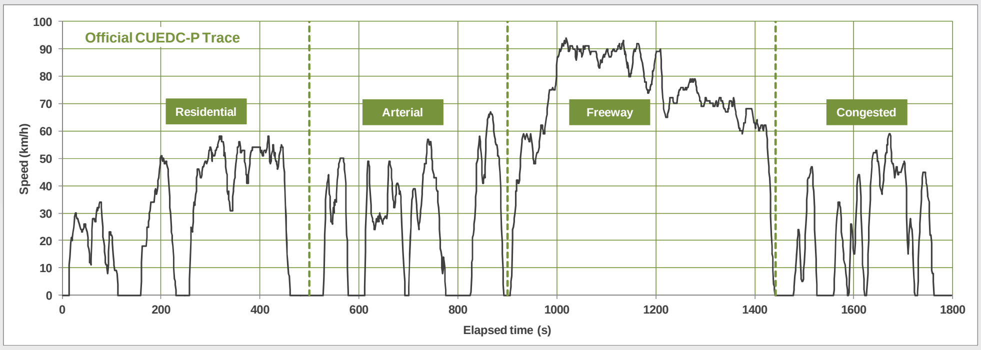
Official CUEDC-P Speed-Time Profile



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CALIBRATION RESULTS

Comparison of fuel consumption model parameters for Toyota Corolla and SIDRA TRIP default passenger car

Param.	Description	Units	SIDRA TRIP P.C.	Toyota Corolla	Diff.
M_v	Average vehicle mass	kg	1250	1250	0%
P_{max}	Maximum power	kW	80	100	25%
f_i	Idle fuel consumption rate	mL/h	1300	889	-32%
A	Drag fuel consumption parameter (rolling resistance)	mL/km	20.0	12.2	-39%
B	Drag fuel consumption parameter (aerodynamic drag)	(mL/km)/(km/h)^2	0.0050	0.0036	-28%
β_1	Efficiency parameter	mL/kJ	0.0900	0.0926	3%
β_2	Energy-acceleration eff. parameter	mL/(kJ.m/s^2)	0.0300	NA	NA

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Comparison with current default model results

The test car (Toyota Corolla) is significantly more efficient indicating **19% lower fuel consumption and CO2** emission estimates (using the same CO_2 to fuel consumption rate, f_{CO2} = 2.35 g/mL) for the overall drive cycle (all segments).

The preliminary results indicate that all emissions (CO, HC and NO_x) are also substantially lower.

These results are as expected due to technological improvements in the vehicle fleet since the 1980s.

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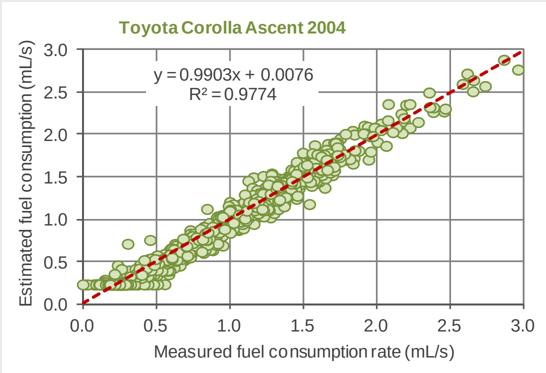
Calibration Quality

Estimated vs measured instantaneous fuel consumption rates



19 of 25

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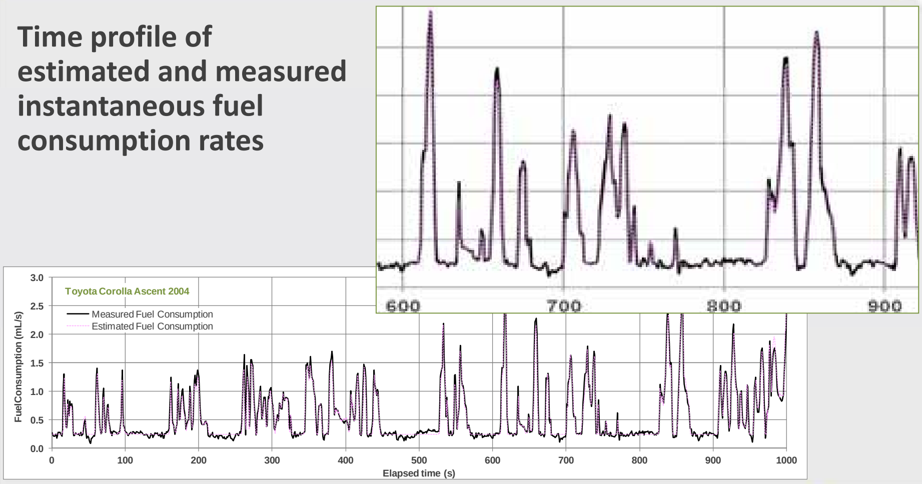
Calibration Quality

Time profile of estimated and measured instantaneous fuel consumption rates



20 of 25

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Calibration Quality

Using the calibrated test vehicle parameters, fuel consumption rates were estimated with high accuracy :

- instantaneous values:
  differences in the range -0.4 mL/s to +0.4 mL/s
- total values for the drive cycle:
  total error 2.4 mL (0.2%)

Calibration Quality

When the calibration parameters optimised for the overall drive cycle were used for estimating fuel consumption and CO_2 emission for the Residential, Arterial, Freeway and Congested speed-profile segments, both instantaneous values and the total values were still highly accurate:

- 3% error for the Freeway segment
- -2% error for the Residential, Arterial and Congested segments together

CONCLUDING REMARKS

As expected, significant differences have been found in fuel consumption and emission model parameters for the medium-size test vehicle compared with parameters established in the 1980s.

Similar results have been obtained for a large passenger car (not presented in this paper).

Work is in progress for calibrating the fuel consumption and emission model described in this paper using data for a large number of vehicles. The results will be made available in due course.

CONCLUDING REMARKS

While the reliability of fuel consumption estimates has been found to be very high, large variability has been observed in estimates obtained from emission models optimized for the overall drive cycle.

Although the errors in estimates of total emission for the whole drive cycle were small (in the range 7% to 10%), rather large errors were found in total emission values when applied to shorter segments. This will be the subject of further investigation.

END OF PRESENTATION

Thank you!

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