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REPRINT

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NOTE:

This technical note is related to the intersection analysis methodology used in the SIDRA INTERSECTION software. Since the publication of this technical note, many related aspects of the traffic model have been further developed in later versions of SIDRA INTERSECTION. Though some aspects of this technical note may be outdated, this reprint is provided as a record of important aspects of the SIDRA INTERSECTION software, and in order to promote software assessment and further research.

Technical Note No. 1

An Interpretation of the Parameters in the Simple Average Travel Speed Model of Fuel Consumption

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A simple, widely used aggregate fuel consumption model is one which relates fuel consumption per unit distance to average travel speed (Chang, *et al.* 1976; Chang and Herman 1981; Cox and Searles 1978; Evans, Herman and Lam 1976; Evans and Herman 1976 and 1978; Evans 1978; Everall 1968; Messenger, *et al.* 1980; Pelensky, Blunden and Munro 1968; Pelensky 1970; Tobin 1979; Watson 1978; Watson, Milkins and Marshall 1979 and 1980). The model is expressed as

$$f_x = a/v_s + b \qquad (1)$$

where

f_x	=	fuel consumption per unit distance in mL/km,
v_s	=	average travel speed in km/h (= 3600 x_s / t_s , where x_s is the total travel distance in km and t_s is the total travel time including any stopped time in seconds), and
a, b	=	parameters to be determined (a in mL/h, b in mL/km).

In the literature, the model has usually been stated as valid for average speeds less than 60 km/h.

It is appropriate to use this model for estimating total fuel consumption in large urban traffic networks and for assessing the impacts of *transport* management schemes which are likely to affect on average speeds and travel demand. However, it is not suitable for the assessment of detailed *traffic* design schemes which require fuel consumption estimates for short road sections.

Recent work at the Australian Road Research Board (ARRB) has shown that the simple model given by eqn (1) can be derived from a comprehensive model of fuel consumption after several steps of aggregation (Biggs and Akcelik 1985). The comprehensive model gives predictions of instantaneous fuel consumption using instantaneous values of speed and acceleration as traffic variables. It also allows for road grade as a variable. The model parameters are related to vehicle characteristics such as mass, idle fuel rate, energy efficiency, rolling resistance and aerodynamic drag. The reader is referred to Bowyer, Akcelik and Biggs (1984) for a detailed description of the instantaneous fuel consumption model. The relation between the parameters of the comprehensive model and the coefficients of the simple model (eqn (1)) is discussed below.

Parameters a and b in eqn (1) have usually been determined jointly by linear regression, i.e. in terms of best fit to measured fuel consumption data. For example, Evans and Herman (1976) gave the following results for different cars driven in Detroit metropolitan area, U.S.:

Small car:	$a = 2390$,	$b = 45.5$
Medium car:	$a = 2722$,	$b = 85.1$
Large car:	$a = 3902$,	$b = 121.8$

Watson *et al.* (1980) gave $a = 2457$ and $b = 94$ for a test car driven on arterial roads in Melbourne, Australia.

In the literature (e.g. see Evans and Herman 1976) parameter a has been stated as 'approximately proportional to idle fuel rate' and parameter b has been explained as 'associated with the fuel consumed per unit distance to overcome rolling resistance, and consequently approximately proportional to the vehicle mass'. In a more recent paper, Post *et al.* (1984) have suggested that parameter b is related to power demand which consists of inertial, drag and gradient components. Work at the ARRB has extended the original power demand model of fuel consumption put forward by Post *et al.* and expressed it as a new energy-related model (see Biggs and Akcelik 1985; Bowyer *et al.* 1984). Various aggregate (but detailed) fuel consumption functions have been derived from the new instantaneous fuel consumption function and these functions indicate that:

(a) parameter a, coefficient of the speed term in eqn (1), should be taken as the idle fuel rate (fuel to maintain engine operation), and

(b) parameter b, the constant term in eqn (1), is related to fuel to provide tractive force to the vehicle, and hence accounts for the drag, inertia (in acceleration and deceleration) and grade components of fuel consumption. It will therefore be influenced by the vehicle parameters such as mass, energy efficiency, rolling resistance and aerodynamic drag as well as the driving environment.

On-road data confirm that there is almost no loss in accuracy by setting parameter a to the idle rate and obtaining only parameter b by regression. It is not possible to account for the individual effects of all the factors mentioned above separately without greatly increasing the model complexity. However, the following expression can be used as a more explicit form of the average travel speed model for estimation of urban fuel consumption:

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$$f_x = f_i / v_s + cK \quad (2)$$

where

f_i	=	idle fuel consumption in mL/h,
v_s	=	average travel speed in km/h as in eqn (1),
c	=	a regression coefficient, and
K	=	an adjustment factor to allow for different values of vehicle parameters.

The adjustment factor can be calculated from

$$K = 1 - K_1(1 - M/1200) - K_2(1 - \beta_1/0.090) - K_3(1 - \beta_2/0.045) - K_4(1 - b_1/0.000278M) - K_5(1 - b_2/0.00108) \quad (3)$$

where M, β_1, β_2, b_1 and b_2 are the vehicle parameters described in *Table I.* A set of 'default' vehicle parameter values for a typical car are also given in *Table I.* The adjustment factor has been found to work well for most vehicle parameters but tends to underestimate the constant term for very low mass cars ($M < 900$ kg).

Table I

Vehicle Parameters and Default Values*

Parameter	*Default Value*	*Description*
f_i	1600	Idle fuel rate (mL/h)
M	1200	Mass (kg)
β_1	0.090	Energy efficiency parameter (mL/kJ) (small values of β_1 indicate high efficiency)
β_2	0.045	Energy-acceleration efficiency parameter (mL/(kJ.m/s²)) (small values of β_2 indicate high efficiency
b_1	0.333	Drag force parameter (kN), mainly related to rolling resistance
b_2	0.00108	Drag force parameter (kN/(m/s²)), mainly related to aerodynamic resistance

* The approximate range of, and the procedure for estimating, vehicle parameters are given in Biggs and Akcelik (1985).

From the analysis of on-road data collected in Sydney, parameters c and K_1 to K_5 (hence K) in eqns (2) and (3) have been found to depend on driving environment. The calibration procedure for obtaining these values is described in detail in Biggs and Akcelik (1985). The values of the parameters are summarised in *Table II.* Using the default parameters given in *Table I*, K = 1 and c = 73.8 are found for the general urban environment, and therefore

$$f_x = 1600/v_s + 73.8 \quad (4)$$

The values of $a = 1600$ mL/h and $b = 73.8$ mL/km can be compared with the parameters given earlier for cars tested by Evans and Herman (1976) in the U.S. and by Watson *et al.* (1980) in Melbourne, Australia. The value of parameter b is found to be reasonably close to those found for the medium car tested by Evans and Herman (1976) and for the Melbourne University test car by Watson *et al.* (1980). However, the value of parameter a for the default car is seen to be much smaller. This reflects the smaller engine size and more fuel efficient nature of a typical Australian car in 1983 compared with an American car in 1976. Note that Post *et al.* (1984) used a = 1560 mL/h for a 'fleet-averaged' Australian car. Using eqns (2) and (3) and vehicle parameter values ($f_i = 2400$, $M = 1680$, $\beta_1 = 0.0717$, $\beta_2 = 0.0344$, $b_1 = 0.527$ and $b_2 = 0.000948$) measured in 1983 for the test car used by Watson *et al.* (1980), model parameter values of $a = 2400$ and $b = 81.0$ were found (general urban environment). These values compare well with those given earlier for this car ($a = 2457$, $b = 94$) considering the variability in the idle fuel rate and efficiency parameters over a period of time, different driving environments and different methods of deriving the parameters.

Table II

Effect of Driving Environment on the Parameters of the Average Travel Speed Model

Driving Environment	c	K_1	K_2	K_3	K_4	K_5
CBD	70.6	0.893	0.790	0.210	0.421	0.109
Other urban	74.2	0.701	0.875	0.125	0.404	0.299
Urban* (general)	73.8	0.720	0.867	0.134	0.406	0.280

* Average of CBD and 'other urban' assuming 10 per cent of driving in CBD and 90 per cent in other urban areas.

The statement in the literature that parameter b in eqn (1) is proportional to the vehicle mass, M (Evans and Herman 1976) can be tested as follows. Coefficient K_1 in eqn (3) is related to mass (M) which affects fuel consumption components due to, not only rolling resistance, but also inertia and grade. To relate K to mass only, the values of β_1, β_2, b_1/M and b_2 can be considered as constant (note that since rolling resistance is proportional to mass, b_1/M should be approximately constant). If these parameters are set equal to the default values given in *Table I*, eqn (3) gives

$$K = (1 - K_1) + (K_1/1200)\,M \quad (5)$$

and using the values of K_1 and c for the general urban environment in *Table II*, parameter b in eqn (1) is expressed as

$$b = 20.7 + 0.0443\,M \quad (6)$$

The values of b from eqn (6) compare fairly well with those given by Evans and Herman (1976) and quoted earlier in this note. Thus, a linear increasing rather than a simple proportional relation is obtained between parameter b and the vehicle mass. The simple average speed model of fuel consumption for a typical car could therefore be expressed with the vehicle mass (M in kg) as an explicit parameter:

$$f_x = f_i / v_s + 20.7 + 0.0443\,M \quad (7)$$

The dependence of fuel consumption estimates from the average travel speed model on driving environment and vehicle size is shown in *Figs 1* and *2.* More detailed models of fuel consumption calibrated using the same on-road data indicate that the average travel speed model does not adequately reflect the increase in aerodynamic drag, and therefore fuel consumption, at high speeds. This is indicated in *Fig. 1.* Thus, the model is only applicable for urban driving where the average travel speed (over a trip or network) is below about 50 km/h. Where average travel speeds are over 50 km/h, e.g. in freeway sections of a traffic network, more detailed models which can reflect increases in fuel consumption with increasing speeds should be used. Such functions are described in Bowyer *et al.* (1984).

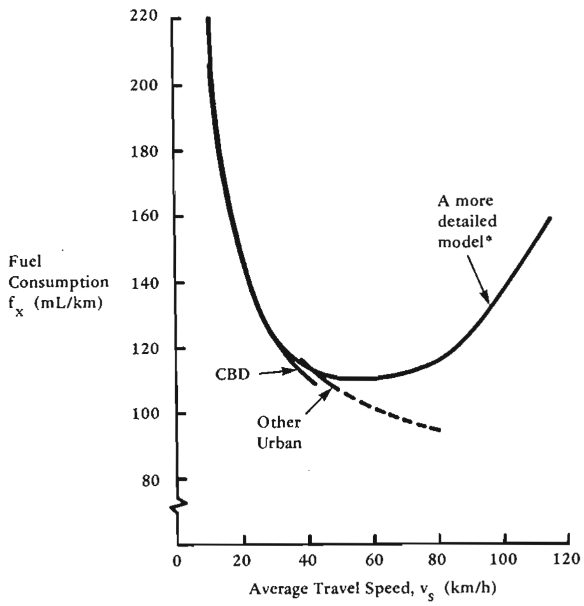

Fig. 1 — Fuel consumption per unit distance as a function of average travel speed
*'Running-speed' model described in Bowyer, Akcelik and Biggs (1984)

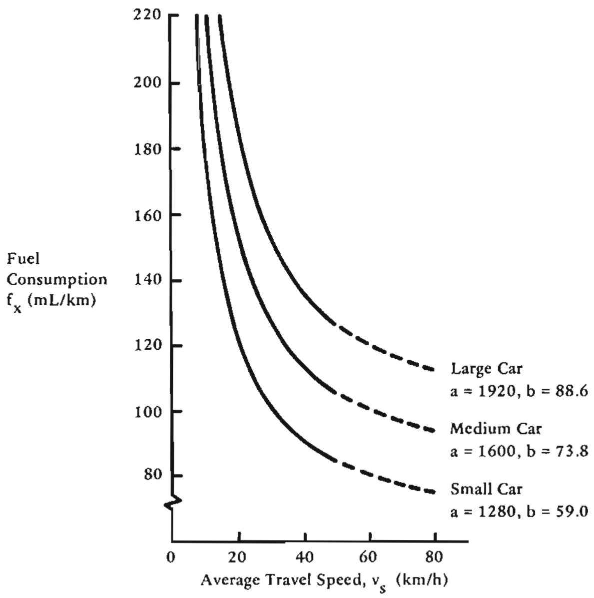

Fig. 2 — Fuel consumption per unit distance as a function of average travel speed for a small, medium and large car in urban driving

The dependence of the estimation function, f_x, on vehicle type is illustrated in *Fig. 2.* These results are based on the use of default car parameters (*Table I*) as a medium car, and an assumed increase or decrease of 20 per cent in f_i, M, b_1 and b_2 parameters to represent large and small cars, respectively (β_1 and β_2 are the same for the three car types). Parameters for a general urban environment are used in all cases.

An interpretation of the parameters of the average travel speed model of fuel consumption has been presented in this technical note. A simple method has been given to allow the adjustment of model parameters to suit different cars and different driving environments. However, if more detailed traffic data are available, better models can be used which allow for vehicle parameters and driving environment. The reader is referred to Bowyer *et al.* (1984) for detailed description of these models.

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