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REPRINT

Models for Estimation of Car Fuel Consumption in Urban Traffic

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NOTE:

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 Though some aspects of this paper may be outdated, this reprint is provided as a record of important aspects of the SIDRA INTERSECTION software, and in order to promote software assessment and further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

Models for Estimation of Car Fuel Consumption in Urban Traffic

by David C. Biggs and Rahmi Akcelik

This article describes four fuel-consumption models. The models are interrelated and form part of the same modeling framework. A simpler model is derived from a more complicated model keeping the vehicle characteristics such as mass, drag function, and energy efficiency as explicit parameters at all model levels. Because vehicle characteristics are likely to change over time and from country to country, this is a particularly useful model property.

For simplicity here, only the instantaneous fuel-consumption model is described in any detail. However, because of the derivation procedure, many of the features and properties of this model are present in the more aggregate models. Easy-to-use functions and graphs are given for the more aggregate models based on a "default car" in urban driving conditions. The default car is defined by the parameters given in Table 1. All parameters related to the speed profile and driving environment were calibrated using on-road data collected in Sydney, Australia. Use of the models is illustrated by estimating the fuel consumption for the microtrip shown in Figure 1. A full description of all models, together with details of model calibration and worked examples, is given in a guide to fuel consumption analyses by Bowyer, Akcelik, and Biggs.[1]

An Instantaneous Model of Fuel Consumption

Areas of Use and Data Required

The instantaneous fuel-consumption model is suitable for use in the detailed assessment of the impacts of proposed traffic management schemes for individual intersections, road sections, or small subarea networks. Instantaneous traffic data must also be available. These include instantaneous (typically second-by-second) values of speed, v (m/s), acceleration, a (m/s^2), and grade, G (expressed as a percentage).

Description of Model

Fuel consumption is related to the fuel needed to maintain engine operation, the energy consumed (work done) by the vehicle engine to move the vehicle, and the product of energy and acceleration during periods of positive acceleration. The energy consumed is further separated into drag, inertial, and grade components. The energy-acceleration term allows for the inefficient use of fuel during periods of hard acceleration. The fuel

Table 1. Default Vehicle Parameters Applicable to All Models

Parameter	*Default Value*	*Description*
α	0.444	Idle fuel rate in ml/sec
f_i	1600	As α but in ml/h
M	1200	Mass in kg
β_1	0.090	Energy efficiency parameter in ml/kJ
β_2	0.045	Energy-acceleration efficiency parameter in ml/(kJ/m·s^2)
b_1	0.333	Drag force parameter in kN, mainly related to rolling resistance
b_2	0.00108	Drag force parameter in kN/(m/s)^2, mainly related to aerodynamic resistance

NOTE: b_1 and b_2 are also related to the component of drag associated with the engine.

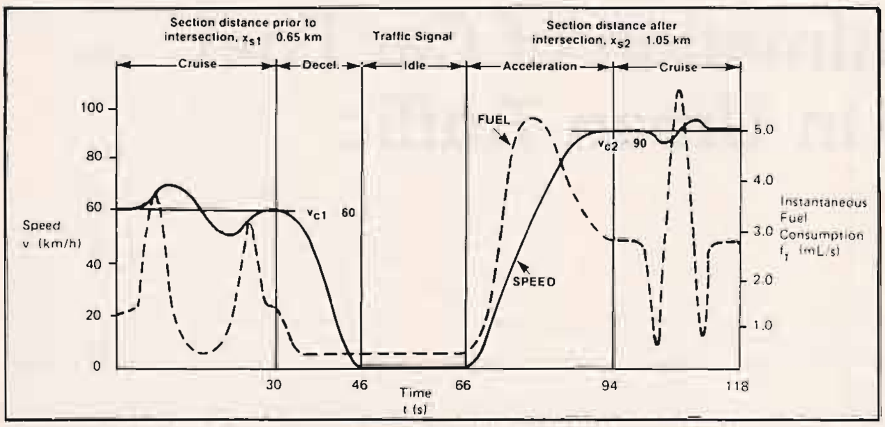

Figure 1. Speed-time trace and estimated instantaneous fuel consumption.

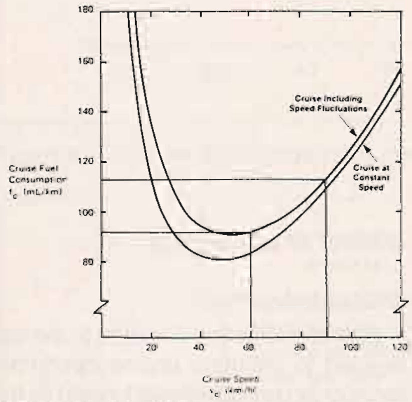

Figure 2. Cruise fuel consumption rate as a function of average cruise speed.

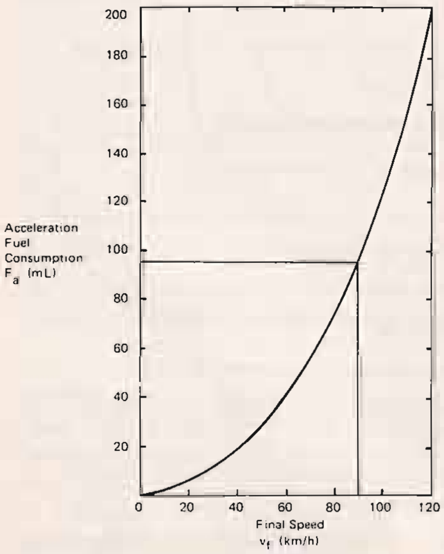

Figure 3. Acceleration fuel consumption as a function of final speed.

consumption rate, f_t (ml/s), can be estimated by

$$f_t = \alpha + \beta_1 R_T v + [\beta_2 M a^2 v/1000]_{a>0} \quad \text{for } R_T > 0$$
$$= \alpha \text{ for } R_T \leq 0 \quad (1)$$

where
α, β_1, β_2, M, b_1, b_2 are vehicle parameters defined in Table 1, and R_T is the total force required to drive the vehicle (kN):

$$R_T = b_1 + b_2 v^2 + Ma/1000 + 9.81M(G/100)/1000 \quad (2)$$

Example

Figure 1 shows the speed-time trace of a car traveling over a road section composed of 0.65 km prior to a traffic signal and 1.05 km after the signal. The microtrip takes 118 sec and involves a cruise—deceleration—idle—acceleration—cruise cycle. Assume grade is zero. Estimate the fuel consumption during this microtrip for the default car.

Even with this simple example, equation 1 must be applied 118 times. Thus, a computer program has been used to calculate the instantaneous fuel consumption rates. These rates are also plotted in Figure 1. Summing the instantaneous values, fuel consumption for the microtrip equals 231 ml.

A Four-Model Elemental Model of Fuel Consumption

Areas of Use and Data Required

Areas of use are similar to those of the instantaneous model. In particular, it is suitable for predicting the incremental effect of delays and number of stop/starts because of traffic control devices. Hence, it is useful for the design of traffic control and management schemes. Macroscopic data such as cruise speeds, v_c (km/h), number of stops and stopped time, t_i (s) are required. The section distance, x_s (km), and average grade prior to and after the intersection for each road section are also required. More accurate estimates will be obtained if initial and final speeds (v_i and v_f) in each acceleration and deceleration are known.

Description of Model

Fuel consumption over any road section is estimated by the sum of the fuel consumed during each mode of driving over that section. The total fuel consumption over a cruise—deceleration—idle—acceleration—cruise cycle is therefore estimated by

$$F_s = f_{c1}(x_{s1} - x_d) + F_d + \alpha t_i + F_a + f_{c2}(x_{s2} - x_a) \quad (3)$$

where

f_{c1}, f_{c2} = cruise fuel consumption per unit distance (ml/km) for the initial and final cruise speeds, v_{c1} and v_{c2}, respectively, and can be found from Figure 2 given zero grade for the default car,

F_d, F_a, x_d, x_a = total deceleration and acceleration fuel consumptions (ml) and distances (km), respectively, which can be found from Figures 3, 4, and 5 for given initial deceleration and final acceleration speeds and zero grade for the default car,

α = idle fuel rate (0.444 ml/s for default car), and

t_i, x_{s1}, x_{s2} = known idle time (s) and section distances (km) prior to and after

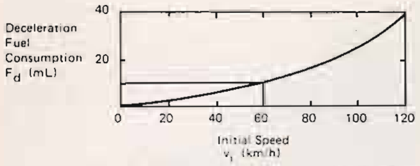

Figure 4. Deceleration fuel consumption as a function of initial speed.

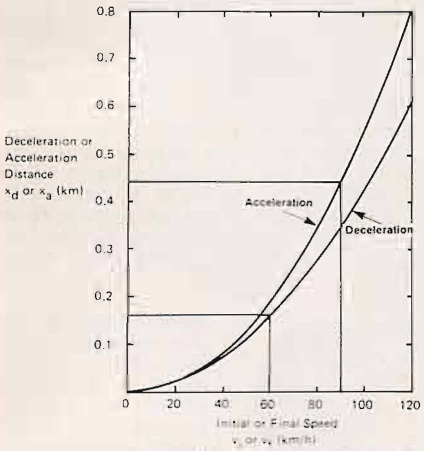

Figure 5. Deceleration and acceleration distances as a function of initial and final speeds.

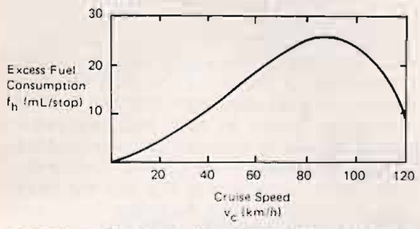

Figure 6. Excess deceleration-acceleration fuel consumption as a function of cruise speed.

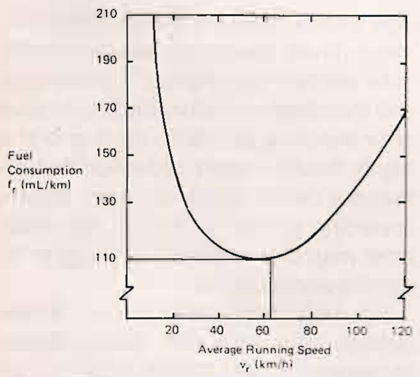

Figure 7. Fuel consumption per unit distance, f_r, as a function of average running speed.

the intersection, respectively.

Note that Figures 2 to 5 are applicable for cycles involving a complete stop. The excess fuel consumed during a deceleration and an acceleration from speed v_c to zero and back to v_c compared with cruising the same distance at v_c is shown in Figure 6 for the default car and zero grade.

Example

From Figure 1 the required speeds for each drive mode are

v_{c1} = 60 and v_{c2} = 90 km/h for the two cruise modes,
v_i = 60 and v_f = 0 km/h for deceleration, and
v_i = 0 and v_f = 90 km/h for acceleration.

Section distances are x_{s1} = 0.65 km and x_{s2} = 1.05 km. Using Figures 2 to 5, total fuel consumption is estimated to be $F_s = 92(0.65 - 0.16) + 10 + 0.444 \times 20 + 96 + 113(1.05 - 0.44) = 229$ ml.

A Running Speed Model of Fuel Consumption

Areas of Use and Data Required

The running speed model of fuel consumption is suitable for estimation of fuel consumption for a trip, but not for short road sections or for the design of traffic management schemes. A trip will typically be longer than 1 km. The minimum data required are travel time, t_s, distance, x_s, and stopped time, t_i, over the total trip. Increased accuracy can be achieved if the initial and final speeds in each acceleration are known. Functions for estimating the running speed, v_r, and stopped time from average travel speed, v_s, allow the running speed model to be used when only v_s is known.

Description of Model

The running speed model estimates the fuel consumed during the idle and nonidle (or running) modes separately. Trip fuel consumption is estimated by

$$F_s = x_s f_r + \alpha t_i \text{ (ml)} \qquad (4)$$

where

f_r = fuel consumption per unit distance (ml/km) excluding stopped time effects and can be found from Figure 7 for the default car and a given running speed $v_r = 3600\, x_s/(t_s - t_i)$

The values of distance x_s (km) and stopped time t_i (sec.) are known. Figure 8 shows the relationship between the fuel consumption per unit distance, f_x, and the average travel speed, v_s, using the running speed model for the default car. Total fuel consumption is then estimated by $F_s = x_s f_x$.

Example

From Figure 1, section distance, x_s, = 0.65 + 1.05 = 1.7 km, t_s = 118 sec, and t_i = 66 − 46 = 20 sec. The average running speed, v_r, therefore = 3600 × 1.7/(118-20) = 62.4 km/h; using f_r = 106

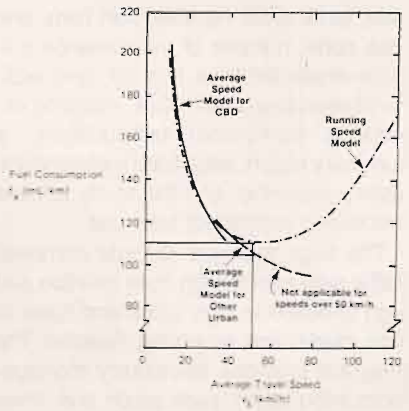

Figure 8. Fuel consumption per unit distance as function of average travel speed.

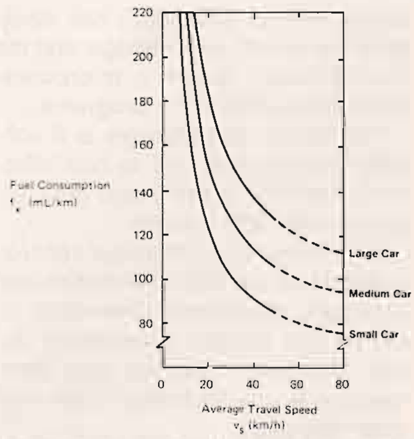

Figure 9. Fuel consumption per unit distance as a function of average travel speed for a small, medium, and large car in general urban driving.

from Figure 7, the section fuel consumption is F_s = 1.7 × 106 + 0.444 × 20 = 189 ml.

An Average Travel Speed Model

Areas of Use and Data Required

The average travel speed model of fuel consumption is suitable for estimation of total fuel consumption in large urban traffic systems and for assessing the impacts of transport management schemes that are likely to impact on average travel speeds and the level of travel demand. This model is accurate only for average travel speeds less than 50 km/h. The only data required are the vehicle travel distance, x_s (km), and either the average travel speed, v_s (km/h), or the travel time, t_s in seconds ($v_s = 3600x_s/t_s$).

Description of Model

Fuel consumption per unit distance, f_x (ml/km), is estimated by

$$f_x = f_i/v_s + b \qquad (5)$$

where

f_i = idle fuel rate in ml/h (f_i = 1600 for default car), and

b = parameter related to the drag, inertia, and grade components of fuel consumption and is dependent on the vehicle parameters and driving environment (b = 73.8 for default car).

Total travel fuel consumption, F_s (ml), is then estimated by $F_s = x_s f_x$. The dependences of f_x on the driving environment and car size are shown in Figures 8 and 9, respectively. When average travel speeds are greater than 50 km/h, the running speed model, given in Figure 8, should be used.

Example

Applying the average travel speed model to the cycle shown in Figure 1, v_s = 3600 × 1.7/118 = 51.9 km/h. From Figure 8, f_x = 105 ml/km assuming the "other urban" driving environment; thus trip fuel consumption is F_s = 1.7 × 105 = 179 ml. However, as v_s > 50 km/h, the running speed model should be used. Trip fuel consumption is estimated from figure 8 to be F_s = 1.7 × 110 = 187 ml.

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Reference

1. Bowyer, D.P.; Akcelik, R.; and Biggs, D.C. *Guide to Fuel Consumption Analyses for Urban Traffic Management. Special Report, SR No. 32.* Nunawarding, Victoria, Australia; Australian Road Research Board, 1985.

David C. Biggs has been working at the Australian Road Research Board since 1981. His main interests have been in fuel consumption modeling and the effect of driver behavior and traffic management on fuel consumption. He also has an interest in indicators to reflect urban system performance. Biggs received an M.Sc. at Monash University, Australia, in 1978. Prior to joining ARRB he worked as a statistical consultant and research analyst in Canada for National Health and Welfare; the Atomic Energy Control Board; and Industry, Trade and Commerce.

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