REPRINT

Models for Estimation of Car Fuel Consumption in Urban Traffic

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REFERENCE:
David C. Biggs and Rahmi Akçelik (1986). Models for Estimation of Car Fuel Consumption in Urban Traffic Institute of Transportation Engineers,

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 Though some aspects of this paper may be outdated, this reprint is provided as a record of important aspects of the SIDRA INTERSECTION software, and in order to promote software assessment and further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.

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/s²), 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>
<thead>
<tr>
<th>Parameter</th>
<th>Default Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>0.444</td>
<td>Idle fuel rate in ml/sec</td>
</tr>
<tr>
<td>$f_1$</td>
<td>1600</td>
<td>As $\alpha$, but in ml/h</td>
</tr>
<tr>
<td>$M$</td>
<td>1200</td>
<td>Mass in kg</td>
</tr>
<tr>
<td>$b_1$</td>
<td>0.090</td>
<td>Energy efficiency parameter in ml/kJ</td>
</tr>
<tr>
<td>$b_2$</td>
<td>0.045</td>
<td>Energy-acceleration efficiency parameter in ml(kJ/m-s²)</td>
</tr>
<tr>
<td>$b_1$</td>
<td>0.333</td>
<td>Drag force parameter in kN, mainly related to rolling resistance</td>
</tr>
<tr>
<td>$b_2$</td>
<td>0.00108</td>
<td>Drag force parameter in kN/(m/s)², mainly related to aerodynamic resistance</td>
</tr>
</tbody>
</table>

Note: $b_1$ and $b_2$ are also related to the component of drag associated with the engine.
consumption rate, \( f_c \) (ml/s), can be estimated by

\[
f_c = \alpha + \beta_s R_t v + \left[ \beta_w M s^2 v^2/1000 \right]_{s \to 0} \quad \text{for } R_t > 0
\]

\[
= \alpha \quad \text{for } R_t \leq 0
\]

(1)

where

\( \alpha, \beta_s, \beta_w, M, b_1, b_2, a_1 \) are vehicle parameters defined in Table 1, and \( R_t \) is the total force required to drive the vehicle (kN):

\[
R_t = b_1 + b_2 v^2 + M a_1 1000 + 9.81 M (G/100)/1000
\]

(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/start because of traffic control devices. Hence, it is useful for the design of traffic control and management schemes. Macroscopic data such as cruising speeds, \( v_c \) (km/h), number of stops and stopped time, \( t_s \) (s) are required. The section distance, \( x_e \) (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 \( (v_i, v_f) \) 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

\[
F = f_i(x_i - x) + F_a + \alpha t_s + F_a + f_d(x_{f2} - x)
\]

(3)

where

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

\[
F = f_{c1} x_{c1} x_{c2} = \text{total deceleration and acceleration fuel consumptions (ml) and distances (km), respectively, which can be found from Figures 3, 4, and 5 for given initial deceleration and final acceleration speeds and zero grade for the default car,}
\]

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

\[
l_s, x_{f1}, x_{f2} = \text{known idle time (s) and section distances (km) prior to and after}
\]
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 \( v_e \) to zero and back to \( v_e \) 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:
\[
\begin{align*}
  v_{cl} &= 60 \text{ and } v_{c2} = 90 \text{ km/h for the two cruise modes,} \\
  v_i &= 60 \text{ and } v_f = 0 \text{ km/h for deceleration,} \\
  v_i &= 0 \text{ and } v_f = 90 \text{ km/h for acceleration.}
\end{align*}
\]

Section distances are \( x_{cl} = 0.65 \text{ km} \) and \( x_{c2} = 1.05 \text{ km} \). Using Figures 2 to 5, total fuel consumption is estimated to be
\[
F_s = 92(0.65 - 0.16) + 10 + 0.444 
\times 20 + 96 + 113(1.05 - 0.44) = 229 \text{ ml.}
\]

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, \( t_c \), distance, \( x_\text{r} \), and stopped time, \( t_s \), 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, \( v_\text{r} \), and stopped time from average travel speed, \( v_\text{av} \), allow the running speed model to be used when only \( v_\text{r} \) 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
\[
F_s = x_\text{r} f_s + x_\text{f} (\text{ml})
\]

where
\[
f_s = \text{fuel consumption per unit distance (ml/km)} \quad \text{excluding stopped time effects and can be found from Figure 7 for the default car and a given running speed } v_\text{r} = 3600 x_\text{r} / (t_c - t_i)
\]

The values of distance \( x_\text{r} \) (km) and stopped time \( t_\text{i} \) (sec.) are known. Figure 8 shows the relationship between the fuel consumption per unit distance, \( f_s \), and the average travel speed, \( v_\text{av} \), using the running speed model for the default car. Total fuel consumption is then estimated by
\[
F_s = x_\text{r} f_s.
\]

Example
From Figure 1, section distance, \( x_\text{r} = 0.65 + 1.05 = 1.7 \text{ km, } t_\text{i} = 118 \text{ sec, and } t_\text{s} = 66 - 46 = 20 \text{ sec. The average running speed, } v_\text{r}, \text{ therefore } = 3600 \times 1.7 / (118-20) = 62.4 \text{ km/h; using } f_s = 106
from Figure 7, the section fuel consumption is $F_s = 1.7 \times 106 + 0.444 \times 20 = 189$ 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 ($v_s = \frac{3600x_s}{t_s}$).

**Description of Model**

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

$$f_s = \frac{f_i}{v_s} + b$$

(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 $F_s = x_s f_s$. The dependences of $f_s$ 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, $v_s = 3600 \times 1.7/118 = 51.9$ km/h. From Figure 8, $f_s = 105$ ml/km assuming the "other urban" driving environment, thus trip fuel consumption is $F_s = 1.7 \times 105 = 179$ 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 $F_s = 1.7 \times 110 = 187$ ml.

**Acknowledgments**

The authors thank the executive director of the Australian Road Research Board (ARRB), Dr. M.G. Lay, for permission to present this article. The work reported was undertaken through a project supported by the National Energy Research, Development and Demonstration Council (NERDNC) of Australia. The views expressed in the article are those of the authors and not necessarily those of ARRB or NERDNC.

**Reference**


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 1970. 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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