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REPRINT

Estimation of Car Fuel Consumption in Urban Traffic

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REFERENCE:

D. C. BIGGS and R. AKÇELIK (1986). Estimation of Car Fuel Consumption in Urban Traffic. *Proc. 13th ARRB/5th REAAA(1986); Vol. 13(7), pp 123-132*

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 Though some aspects of this paper may be outdated, this reprint is provided as a record of important aspects of the SIDRA INTERSECTION software, and in order to promote software assessment and further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

ESTIMATION OF CAR FUEL CONSUMPTION IN URBAN TRAFFIC

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ABSTRACT

The concept of a hierarchy of fuel consumption models is discussed where models of different levels of detail are applicable to the various scales of traffic systems. Fuel consumption models of four levels of detail are described and easy to use functions and graphs are presented to assist in their application. The areas of use of each model are described and the appropriate fuel consumption model for various traffic models is given. The fuel consumption models range from a detailed energy-related instantaneous model to the aggregate average travel speed model. They are interrelated, forming part of the same modelling framework with an aggregate model being derived from a more detailed model. The vehicle parameters are explicit at all model levels but, for simplicity here, models are presented with a set of default parameters. The more detailed models are structured and calibrated so that the various components of fuel consumption are estimated seperately. This allows the incremental effect on fuel consumption of changes in traffic management to be estimated. Examples of the use of each model are given

INTRODUCTION

1. In recent years attention has focused on the use of traffic management as a means of reducing car fuel consumption. A large body of analytical aids exist to assist in the estimation of fuel consumption in urban traffic. However, recent research, particularly that reported by Bowyer et al. (1984), has revealed the need for careful selection of these aids for a particular management task to ensure their cost effective use.

2. There are two primary means of deriving estimates of fuel consumption for use in urban traffic management. These are on-road measurement and using fuel consumption models. The use of models has many advantages over direct on-road measurement. Firstly, model estimates of fuel consumption are unaffected by weather conditions and changes in vehicle fuel consumption characteristics. Secondly, when combined with traffic models, fuel consumption models can be used for comparing different traffic management schemes or policies in advance. Finally, direct on-road measurement is often costly, especially if various traffic management schemes are to be evaluated, and it is difficult, if not impossible, to ensure similar operating conditions for the various schemes. It has therefore been necessary to establish rigorous models to estimate car fuel consumption which are applicable to the range of traffic management applications.

3. Models which are applicable for a particular area of use may be unduly complicated or of insufficient accuracy for another area of use. Akcelik et al. (1983) have shown that a hierarchy of vehicle fuel consumption models exists which includes models ranging from a basic energy-related model to the more aggregate average travel speed model.

ACKNOWLEDGEMENTS : The authors thank the Executive Director of ARRB, Dr. M.G. Lay, for permission to present this paper. The work reported was undertaken through a project supported by the National Energy Research, Development and Demonstration Council (NERDDC) of Australia. The views expressed in the paper are those of the authors, and not necessarily those of ARRB or NERDDC.

The choice of model depends on the intended application, the available data and the accuracy required.

4. In this paper, fuel consumption models of four levels of detail are described and easy to use functions and graphs are presented to assist in their application. The areas of use and the data requirements of each model are described and the appropriate fuel consumption model for various traffic models is given. The functions and graphs have been drawn out of a comprehensive guide to fuel consumption models by Bowyer, Akcelik and Biggs (1985) and are presented here for a 'default car' in urban driving conditions.

FUEL CONSUMPTION MODELS

5. Fuel consumption models have applications in widely diverse areas. These include automotive engineering, design of traffic management schemes, transport management and analysis of transport infrastructure and urban form. No one model is suitable for use in all areas. For a model to be applicable in a particular area, it must be able to predict the incremental effects on fuel consumption resulting from changes in parameters or designs applicable in that area. Thus, an instantaneous model is required to determine the difference in fuel consumption between stop and give-way control at an intersection while the average travel speed model is suitable for determining the effect on fuel consumption of various urban planning policies. Akcelik et al. (1983) showed that the existing fuel consumption models form a hierarchy and that each model is appropriate to a particular scale of traffic system.

6. Fuel consumption models of four levels of detail will be described. These are, in increasing order of aggregation:

(a) an energy-related instantaneous fuel consumption model,

(b) a four-mode elemental model of fuel consumption,

(c) a running speed model of fuel consumption, and

(d) an average travel speed model of fuel consumption.

All four models are inter-related and form part of the same modelling framework. A simpler model is derived from a more complicated model, e.g. the elemental model from the instantaneous model, keeping the vehicle characteristics such as mass, drag function and energy efficiency as explicit parameters at all model levels. Vehicle characteristics are likely to change over time and from country to country, and therefore this is a particularly useful property of the models. The more detailed models are structured and calibrated so that the various components to fuel consumption are estimated separately. This allows the incremental effect on fuel consumption of changes in traffic management to be estimated.

7. 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 condtions. The default car is defined by the parameters given in Table I and all parameters related to the speed profile and driving environment were calibrated using on-road data collected in Sydney. Use of the models is illustrated by estimating the fuel consumption for the trip segment shown in Fig. 1. A full description of all models, together with details of model calibration and worked examples, are given in a guide to fuel consumption analyses by Bowyer, Akcelik and Biggs (1985).

AN INSTANTANEOUS MODEL OF FUEL CONSUMPTION

AREAS OF USE AND DATA REQUIRED

8. 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 sub-area networks. A model of this level of detail is particularly useful when the management schemes produce only small differences in the speed profile and when grades are variable. Instantaneous traffic data must also be available. These include instantaneous values of speed, v, and grade, G, for a car when driven through the particular traffic system. The unit of time is typically one second and the speed data must be of sufficient accuracy to calculate instantaneous acceleration rates, a.

TABLE I

DEFAULT VEHICLE PARAMETERS APPLICABLE TO ALL MODELS

Parameter	*Default Value*	*Description*
α	0.444	Idle fuel rate in mL/s
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/s²)
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*

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

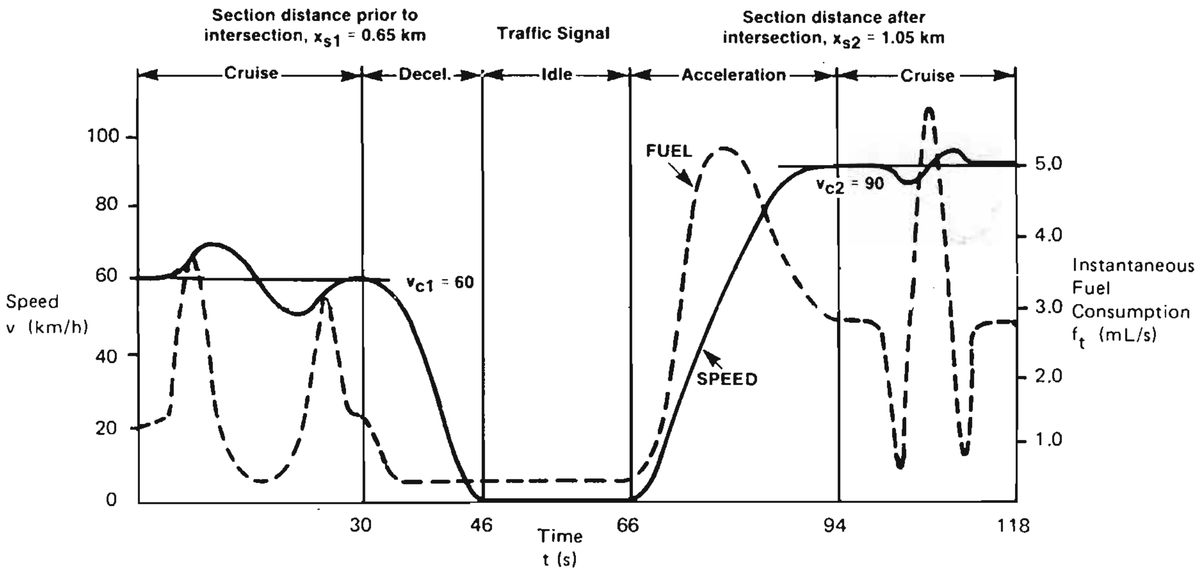

Fig. 1 — Speed-time trace and estimated instantaneous fuel consumption

DESCRIPTION OF MODEL

9. The instantaneous fuel consumption model relates fuel consumption to:

(a) the fuel to maintain engine operation, estimated by the idle rate, α ,

(b) the energy consumed (work done) by the vehicle engine to move the vehicle,

(c) the product of energy and acceleration during periods of positve acceleration.

The energy consumed in moving the vehicle is further separated into drag, inertial and grade components. Part (c) allows for the inefficient use of fuel during periods of hard acceleration.

10. The fuel consumption rate per unit time , f_t, can be estimated by:

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

where

v = speed in m/s,

a = instantaneous acceleration rate in m/s² ,

R_T = total force required to drive the vehicle, which is the sum of drag force (R_D), inertial force (R_I) and grade force (R_G) in kN:

$$R_D = b_1 + b_2 v^2 \qquad (2)$$

$$R_I = Ma/1000 \qquad (3)$$

$$R_G = 9.81M(G/100)/1000 \qquad (4)$$

where

G is the per cent grade which is negative for downhill, and

α, β_1, β_2, M, b_1, b_2 are vehicle parameters defined in Table I.

Eqn (1) for the default car, with parameters given in Table I, becomes:

$$f_t = 0.444 + 0.090\, R_T v + [0.054\, a^2 v]_{a>o} \quad \text{for } R_T > 0$$
$$= \alpha \quad \text{for } R_T \leq 0 \qquad (5)$$

where the total tractive force is

$$R_T = 0.333 + 0.00108\, v^2 + 1.20\, a + 0.1177\, G \qquad (6)$$

11. The instantaneous model has been found to estimate the fuel consumption during constant speed driving and acceleration (including hard accelerations) to within 10 per cent of measured values and to within 5 per cent over acceleration-cruise-deceleration cycles. Further detials on the model and calibration procedures are given in Bowyer et al. (1985) and Biggs and Akcelik (1985a).

EXAMPLE

12. The speed time trace in Fig. 1 represents the instantaneous speeds for a car travelling over a road section comprised of 0.65 km prior to a traffic signal and 1.05 km after the signal. The total micro-trip takes 118 seconds and involves a cruise-deceleration-idle-acceleration-cruise cycle. Assume that there is zero grade. Estimate the total fuel consumption during this micro-trip for the default car.

13. Even with this simple example, eqn (5) 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 Fig. 1. For example, consider the simple case at the point where t = 30 seconds at which the speed is constant. The fuel consumption rate is calculated as follows:

$$v = 60 \text{ km/h} = 16.7 \text{ m/s}$$
$$a = 0 \text{ m/s}^2$$
$$R_T = 0.333 + 0.00108 \times 16.67 \times 16.67 = 0.6331 \text{ kN}$$
$$f_t = 0.444 + 0.090 \times 0.6331 \times 16.67 = 1.39 \text{ mL/s}$$

By summing the instantaneous values, the total fuel consumption over the complete micro-trip is found to be 231 mL.

A FOUR-MODE ELEMENTAL MODEL OF FUEL CONSUMPTION

AREAS OF USE AND DATA REQUIRED

14. The areas of use of the elemental model are similar to those of the instantaneous model. In particular, it is suitable for predicting the incremental effects of delays and number of stop/starts due to traffic control devices. Hence, it is useful for the design of traffic control and management schemes. The elemental model requires only macroscopic data such as cruise speeds, v_c, number of stops and stopped time, t_i. The section distance, x_s, and average grade prior to and after the intersection for each road section in the traffic system 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 and if acceleration and/or deceleration times and/or distances are known, these, rather than estimated values, can be used.

DESCRIPTION OF MODEL

15. The elemental model estimates the fuel consumed over any road section 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 (as for example, in Fig. 1) is therefore estimated by summing over each mode as follows:

$$F_s = f_{c1}(x_{s1} - x_d) + F_d + \alpha t_i + F_a + f_{c2}(x_{s2} - x_a) \qquad (7)$$

where

f_{c1}, f_{c2} = cruise fuel consumption per unit distance (mL/km) for the initial and final cruise speeds, v_{c2} and v_{c1},

x_{s1}, x_{s2} = known section distances (km) prior to and after the intersection, respectively,

x_d, x_a = deceleration and acceleration distances (km), respectively,

F_d, F_a = total deceleration and acceleration fuel consumption (km), respectively,

α = idle fuel consumption rate (α = 0.444 mL/s for the default car), and

t_i = idle or stopped time (s), assumed known.

The elemental model is comprised of a set of equations for estimating the cruise fuel consumption, and the acceleration and deceleration fuel consumptions. These functions were dervived by integration of the instantaneous model and include vehicle parameters, initial and final speeds, acceleration and deceleration times and distances, average grades, etc. The full set of functions, including equations for calculating unknown parameter values, are given in Bowyer et al. (1985).

16. The cruise fuel consumption for a given cruise speed and the acceleration and deceleration fuel consumptions and distances for given inital deceleration and and final acceleration speeds are shown in Figs 2 to 5 for the default car. It has been assumed that the final deceleration and initial acceleration speeds are zero, thus Figs 2 to 5 are only applicable for cycles involving a complete stop. In addition zero grade has been assumed. Fig. 2 includes the fuel consumption rates for constant speed travel and for cruising which involves some speed fluctuations. The cruise fuel consumption function was calibrated to include all speed fluctations above 20 km/h. Figs 2 to 5 can be used in conjunction with eqn (7) to estimate the fuel consumption for the default car over a cruise-deceleration-idle-acceleration-cruise cycle.

17. The excess fuel consumed during a deceleration and an acceleration from speed v_c to zero and back to v_c compared to cruising the same distance at v_c is shown in Fig. 6 for the default car. For example, for a stop-start from 60 to 0 and back to 60 km/h, the excess fuel consumption is 19 mL. Using the full set of functions given in Bowyer et al. (1985), it is possible to estimate deceleration and acceleration fuel consumption from and to any speeds, thus allowing the effect of slow-downs and move-ups in a queue to be modelled. In addition, excess fuel consumption for stops or slow-downs involving different initial and final cruise speeds can be estimated.

18. Estimates based on the elemental model have been found to be within 10 per cent of the instantaneous model values in 85 per cent of cases over idle-acceleration-cruise-deceleration cycles when only cruise speed, section distance and stopped time were known. On average the the difference in estimates between the two models is less than 2 per cent.

EXAMPLE

19. Estimate the total fuel consumed by a car over sections of road, x_{s1} and x_{s2}, prior to and after a traffic signal. The vehicle follows the speed-time trace given in Fig. 1.

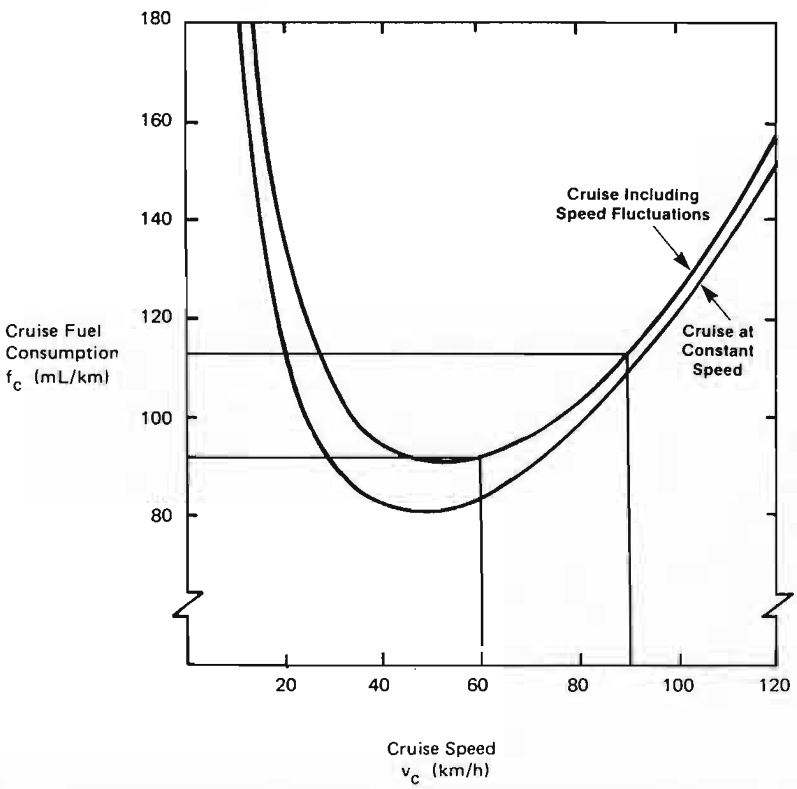

Fig. 2 — Cruise fuel consumption rate as a function of average cruise speed

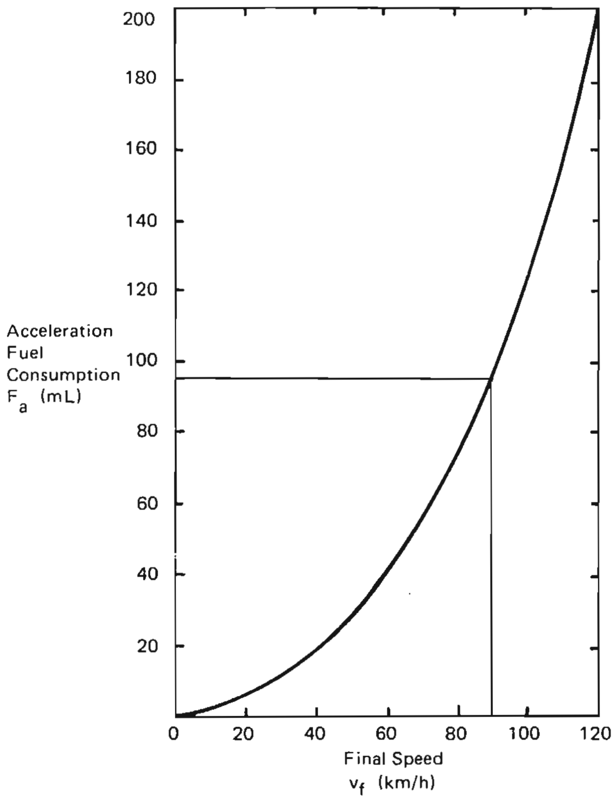

Fig. 3 — Acceleration fuel consumption as a function of final speed

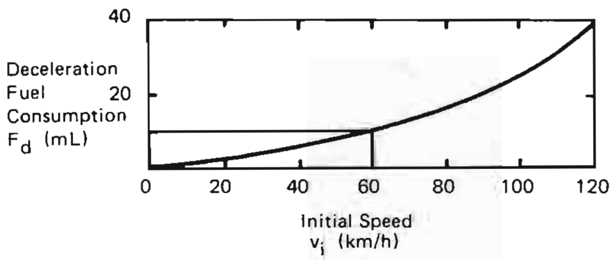

Fig. 4 — Deceleration fuel consumption as a function of initial speed

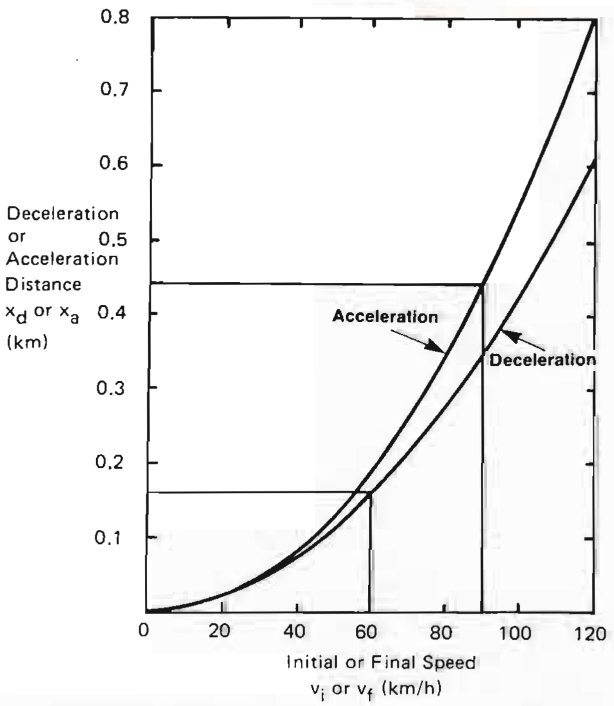

Fig. 5 — Deceleration and acceleration distances as a function of initial and final speeds

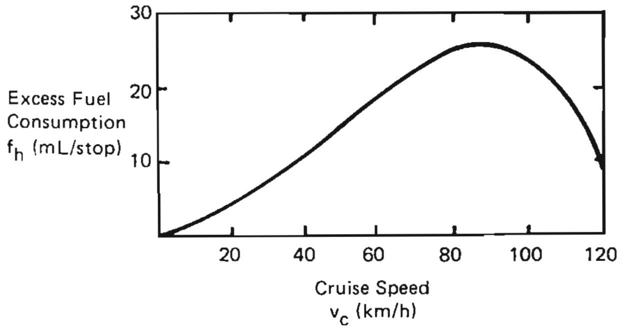

Fig. 6 — Excess deceleration-acceleration fuel consumption as a function of cruise speed

20. From Fig. 1 the required speeds for each drive mode are:

Cruise : v_{c1} = 60 and v_{c2} = 90 km/h
Deceleration : v_i = 60 and v_f = 0 km/h
Acceleration : v_i = 0 and v_f = 90 km/h

Section distances are x_{s1} = 0.65 km and x_{s2} = 1.05 km. Using the values found from Figs 2 to 5, total fuel consumption is calculated as follows:

$$F_s = 92(0.65 - 0.16) + 10 + 0.444 \times 20 + 96 + 113(1.05 - 0.44) = 229 \text{ mL}$$

This compares with 231 mL calculated using the instantaneous model.

A RUNNING SPEED MODEL OF FUEL CONSUMPTION

AREAS OF USE AND DATA REQUIRED

21. The running speed model 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 to apply the running speed model 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

22. The running speed model estimates the fuel consumed during the idle and non-idle (or running) modes separately. The form of function used to estimate the 'running' fuel consumption is similar to the cruise

fuel consumption function of the elemental model, but with speed fluctuations down to zero allowed. The total fuel consumption, F_s in mL, over a road section is estimated by:

$$F_s = x_s f_r + \alpha t_i \quad (8)$$

where

f_r = fuel consumption per unit distance (mL/km) excluding stopped time effects, and

α = idle fuel consumption rate in mL/s (α = 0.444 mL/s for the default car).

The values of distance, x_s (km), and stopped time, t_i (s), are known. The fuel consumption rate, f_r, is a function of the average running speed, v_r, which is given by:

$$v_r = 3600\, x_s/(t_s - t_i) \quad (9)$$

The general equation giving f_r as a function of the vehicle parameters, average grade and the change in positive kinetic energy (calculated from the initial and final speeds during each acceleration) is given in Bowyer et al. (1985). The relationship between f_r and running speed is shown in Fig. 7 for the default car and zero grade.

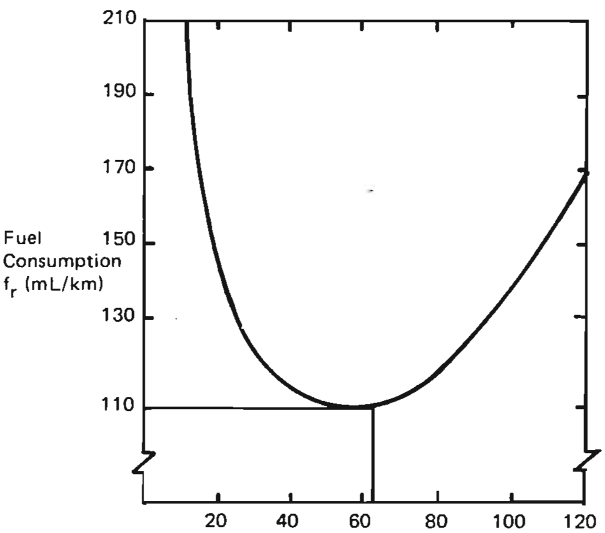

Fig. 7 — Fuel consumption per unit distance, f_r, as a function of average running speed

23. Running speed and idle time can be related to the average travel speed. Thus, the running speed model can be applied at a trip or network level when only the average travel speed is known. It has an advantage over the average travel speed model (discussed later) in that no restrictions are made on the maximum speed at which it can be applied. Such a restriction is necessary for the average travel speed model. Fig. 8 shows the relationship between the fuel consumption per unit distance, f_x, and v_s using the running speed model for urban driving in Sydney. Total fuel consumption is then estimated by $F_s = x_s f_x$.

24. The running speed model was found to predict fuel consumption within 10 per cent of the instantaneous model estimate on 67 per cent of cases for idle-acceleration-cruise-deceleration cycles of at least 0.7 km when only the running speed was known. When initial and final speeds during each acceleration are also known, this increased to 97 per cent. For trips over 10 km, estimates were within 10 per cent on 99 per cent of cases.

EXAMPLE

25. Estimate the total fuel consumed for the micro-trip depicted in Fig. 1 using the running speed model.

26. From Fig. 1, section distance, x_s = 0.65 + 1.05 = 1.7 km, t_s = 118 s and t_i = 66 - 46 = 20 s. The average running speed is therefore,

$$v_r = 3600 \times 1.7/(118-20) = 62.4 \text{ km/h}$$

and using f_r = 106 from Fig. 7, the section fuel consumption is:

$$F_s = 1.7 \times 106 + 0.444 \times 20 = 189 \text{ mL}$$

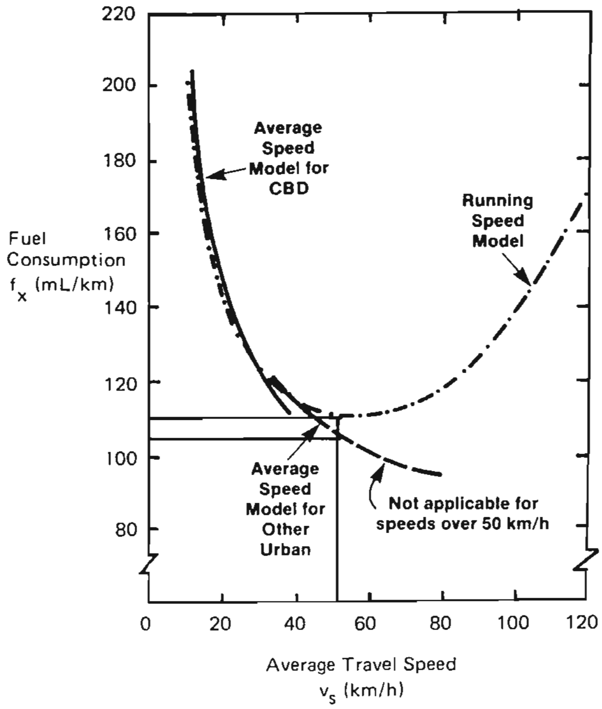

Fig. 8 — Fuel consumption per unit distance as a function of average travel speed

In this example the running speed model underestimates total fuel consumption considerably (189 compared to 231 mL for the instantaneous model). This is due, in part, to the default estimates of the total positive kinetic energy change. Generally, the model is suited to estimating fuel consumption over trips, rather than short road sections as in this example.

AN AVERAGE TRAVEL SPEED MODEL

AREAS OF USE AND DATA REQUIRED

27. The average travel speed model is suitable for estimation of total fuel consumption in large urban traffic systems and for assessing the impacts of transport management schemes which 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 is the vehicle travel distance, x_s , and either the average travel speed, v_s, or the travel time, t_s.

DESCRIPTION OF MODEL

28. The average travel speed model relates fuel consumption per unit distance, f_x, to the inverse of average travel speed:

$$f_x = f_i/v_s + b \qquad (10)$$

where

f_i = idle fuel consumption rate in mL/h (f_i = 3600 α), and

v_s = average travel speed ($v_s = 3600\ x_s/t_s$),

b = parameter related to the drag, inertia and grade components of fuel consumption and is dependent on the vehicle parameters and driving environment.

The fuel consumption rate for the default car was found to be

$$f_x = 1600/v_s + 73.8 \qquad (11)$$

using calibration data collected in urban driving in Sydney. Total travel fuel consumption, F_s (mL), is then estimated by:

$$F_s = x_s f_x \qquad (12)$$

The dependence of f_x on the driving enviroment is shown in Fig. 8. When average travel speeds are greater than 50 km/h the running speed model, with running speed and idle time estimated from average travel speed, should be used (see Fig. 8). The fuel consumption rate is also dependent on car size as shown in Fig. 9. The method of adjusting the b parameter for different vehicle parameters is described in Bowyer et al. (1985) and a full discussion of the average travel speed model is given in Biggs and Akcelik (1985b).

29. The average travel speed model was found to predict fuel consumption to within 5 per cent of the instantaneous model estimate on 84 per cent of cases for trips over 10 km with v_s less than 50 km/h.

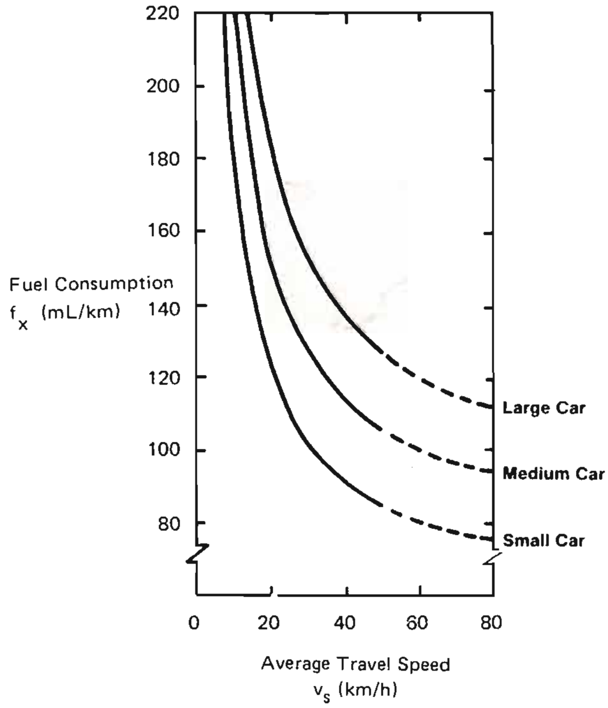

Fig. 9 — Fuel consumption per unit distance as a function of average travel speed for a small, medium and large car in general urban driving

EXAMPLE

30. Estimate the total fuel consumption for the micro-trip shown in Fig. 1 assuming only the average travel speed is known.

31. Applying the average travel speed model,

$$v_s = 3600 \times 1.7/118 = 51.9 \text{ km/h}$$

and f_x = 105 mL/km from Fig. 8 assuming the 'other urban' driving environment. Trip fuel consumption is therefore,

$$F_s = 1.7 \times 105 = 179 \text{ mL}$$

However, as the average travel speed is greater than 50 km/h, the running speed model based on average travel speed should be used. Trip fuel consumption is estimated from Fig. 8 to be:

$$F_s = 1.7 \times 110 = 187 \text{ mL}$$

These estimates are significantly less than the instantaneous model estimate (231 mL) and, in general, models using average travel speeds are too coarse to give accurate estimates of fuel consumption in this micro-trip context.

LINKS BETWEEN TRAFFIC AND FUEL CONSUMPTION MODELS

32. The vehicle and/or traffic data required by fuel consumption models can be collected during on-road experiments or generated using traffic models. In practice, traffic models are the primary means of estimating these data, especially for the design of traffic management schemes. Most traffic models have a fuel consumption module incorporated in them, but some rely on the user to estimate fuel consumption from the traffic variables included in their output.

33. There is a wide range of both traffic systems and forms of traffic management techniques to be considered in traffic management practice. Traffic models have been developed to cover this wide range of applications. Thus, the choice of traffic model and form of the fuel consumption module within the traffic model are important for their effective use in a particular management situation. The factors which must be addressed when choosing the traffic and fuel consumption models are discussed in Bowyer et al. (1985). Tables II and III provide a summary of the fuel consumption models suitable for a range of traffic models in use in Australia and shows the scale of traffic system to which each is appropiate. Several points should be stressed. Firstly, a hierarchy of models exists and each traffic model is appropriate to a particular scale of traffic system. Models are not sufficiently accurate if used below their indicated level and would be unnecessarily costly if used above their level. The second point is that the traffic model should contain a fuel consumption model appropriate to the type of traffic data that it generates.

TABLE II

TRAFFIC VARIABLES REQUIRED FOR EACH FUEL CONSUMPTION MODEL

Fuel Consumption Model	*Required Traffic Variables**
Average Speed	x_s, t_s for each trip or network
Running Speed	
Option a.	x_s, t_s for each trip or road section
Option b.	t_s, t_i, x_s for each trip or road section
Option c.	t_s, t_i, x_s, and, v_i, v_f for each acceleration, for each trip or road section
Elemental	
Option a.	x_s, t_i, v_c, number of stops for each road section
Option b.	x_s, t_i and, v_i, v_f for each acceleration/deceleration, for each road section
Instantaneous	v, G for each second over a road section

* Variables defined in Notations and Definitions section at start of report.

TABLE III

TRAFFIC MODELS AND FUEL CONSUMPTION MODULES APPROPRIATE TO LEVELS OF TRAFFIC SYSTEM SCALE

Traffic System Scale	*Traffic Model*[1]	*Fuel Consumption Module Specification**
Macro	UTPS	(a) No freeways: use average speed model, calculated at the total network level. (b) With freeways: use running speed model (option a) for freeways, calculated at the trip level.
	LATM	Running speed model (option b), calculated at road section level.
Macro/Meso	SATURN	Elemental model (option a) calculated at road section level.
	TRANSYT	Elemental model (option a) calculated at the link level.
Meso/Micro	SCATSIM	Elemental model (option b)
	SIDRA	Elemental model (option b) calculated at the lane level
Micro	MULTSIM	Instantaneous model, calculated at 1 second intervals.
	INSECT	Instantaneous model, calculated at 1 second intervals.

CONCLUSIONS

34. Easy to use functions and graphs have been given for four fuel consumption models and examples have been given to illustrate their use. These models cover the range of applications of fuel consumption models in the areas of traffic and transport management. The areas of use and data requirements of each model have been described. Traffic models are a primary means of obtaining data for fuel consumption models and the appropriate fuel consumption model for various traffic models has been given. The fuel consumption models are all inter-related and form part of the same modelling framework. Vehicle parameters are explicit at all model levels. This allows the user to choose vehicle parameters for a particular application. The changes in vehicle characteristics over time and from country to country are allowed for without need to derive new sets of regression equations. Full details on the four models are given in a guide to fuel consumption analyses by Bowyer, Akcelik and Biggs (1985).

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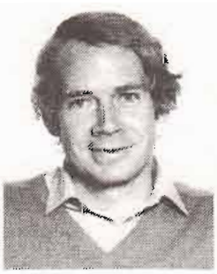
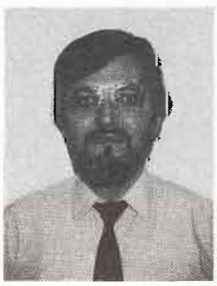


D.C. Biggs

David Biggs graduated from Monash University in 1978 with a Master of Science degree, majoring in Statistics. After graduating, he worked in Canada as a statistical consultant and research analyst for National Health and Welfare, the Atomic Energy Control Board and Industry, Trade and Commerce. He joined the transport work area at the the Australian Road Research Board in 1981 and has worked in the areas of urban system indicators and fuel consumption in urban traffic. He is currently studying the effect on fuel consumption of different forms of traffic management.



R. Akcelik

Rahmi Akcelik graduated as a Civil Engineer (M.Sc.) from Istanbul Technical University, Turkey, in 1968, and received his Ph.D. degree in Transportation Engineering from the University of Leeds, England in 1974. He worked as a lecturer at the Black Sea University, Turkey, before he migrated to Australia in 1975. He worked as a traffic engineer with the National Capital Development Commission in Canberra for four years before he joined the Australian Road Research Board in 1979. He is a Principal Research Scientist in the road users work area of ARRB. His main interests have been in the traffic signal and fuel consumption areas of research and development.