

REPRINT

Fuel Consumption Analyses for Urban Traffic Management

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 Though some aspects of this paper may be outdated, this reprint is provided as a record of important aspects of the SIDRA INTERSECTION software, and in order to promote software assessment and further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

1986 Transportation Energy Conservation Award in Memory of
Frederick A. Wagner

Fuel Consumption Analyses for Urban Traffic Management

by Darrell P. Bowyer, Rahmi Akcelik, and David C. Biggs

A primary output from the fuel consumption research conducted by the Australian Road Research Board (ARRB) is the ARRB Special Report, *Guide To Fuel Consumption Analyses*.¹ This article briefly summarizes the background of the guide, describes its major features, and considers its relevance to urban traffic management decision. The guide was a result of a technical audit of studies relating to energy consumption in traffic and transport systems. A brief summary of the audit process and findings is given.

The guide is intended primarily as an aid to effective use of fuel consumption models in the design of traffic management schemes. The forms of four inter-related fuel consumption models of the guide are described and their likely transferability to various situations is indicated. Each traffic and fuel consumption model is appropriate to a particular scale of traffic system. This link is shown for several selected traffic models. As an example, a discussion of the importance of accurate fuel consumption estimates for the case of priority control at a particular intersection is given.

Technical Audit of Energy Studies

In response to the energy crises during the 1970s, a considerable number of studies relating to energy consumption in traffic and transport systems were undertaken in many countries. A particular focus of the studies was on the potential for reducing the consumption of petro-

leum-based fuels. Estimates of the potential fuel savings reported from these studies varied widely, however, creating a climate of uncertainty as to the savings likely to be realized from traffic management in particular urban situations. For example, estimates of the impacts of traffic signal coordination on fuel consumption for major urban roads ranged from 7% to 20%. The variation in fuel consumption estimates also created uncertainty as to the related energy research priorities.

To assist in clarifying the situation, the Australian Road Research Board undertook an audit of relevant studies, particularly those relating to the impacts of traffic management on fuel consumption. The primary funding source for this study was the National Energy Research Development and Demonstration Program conducted by the Australian Department of Resources and Energy. A primary aspect of the audit was the detailed investigation of the technical procedures that had been developed and used in reported studies to establish their validity before establishing the validity of the resulting fuel consumption estimates. Particular attention was placed on the validity of vehicle fuel consumption models and of network-based traffic models. The audit procedures and findings have been reported in Bowyer and Bayley² and in a number of associated technical reports.

Findings of the Audit

The audit produced two major findings. First, the impact of a particular form

of traffic management on fuel consumption can be highly sensitive to the characteristics of the traffic system under study. Yet, previous guides to practice typically provided graphs of fuel consumption rates, which were based on data sampled in a particular traffic system (see, for example, Reference 3). The accuracy and suitability of these guides for estimation in other traffic systems cannot be determined. A second finding was that there exists a substantial set of fuel consumption models and traffic models that could assist in considering fuel consumption in urban traffic systems. The effective use of these models in practice, however, was being limited by the lack of a suitable guide to aid selection of models that are appropriate for the various traffic management contexts. These two findings led to the development of the *Guide to Fuel Consumption Analyses*.

Information Requirements and Management Tasks

The requirements for fuel consumption information are likely to vary significantly across traffic systems and traffic management tasks. At one extreme is the micro-assessment of operations at a particular intersection to aid the selection and design of an appropriate form of control. At the other extreme is the evaluation of alternative management programs to determine their impacts on fuel consumption in the total urban area.

A major task in the traffic management process is the design of management

schemes. This calls for estimates of the impacts of the alternative schemes on travel time, fuel consumption, safety, etc., to enable evaluation of the alternatives. Traffic models are often the only practical means of estimating the impacts of alternative traffic management schemes. The major focus of the guide is on the form and use of models to provide fuel consumption estimates in the scheme design phase.

Fuel Consumption Models

No one fuel consumption model is likely to be suitable for all situations. For a model to be applicable in a particular situation, it must be able to predict the incremental effects on fuel consumption resulting from changes in elements of the traffic system (e.g., traffic facilities, vehicles, driver behavior). Thus, for example, a detailed instantaneous fuel consumption model is required to determine the difference in fuel consumption between stop and give-way control at an individual intersection. However, a less detailed, average travel speed model is likely to be suitable for determining the urban-wide effects of traffic management or planning policies. The existing fuel consumption models can be shown to form a hierarchy, in which each model can be related to a particular scale of traffic system.⁴

A particular hierarchy of four fuel consumption models has been incorporated into the guide. The models are in order of aggregation:

1. An energy-related instantaneous fuel consumption model;
2. A four-mode elemental model of fuel consumption;
3. A running speed model of fuel consumption; and
4. An average travel speed model of fuel consumption.

A particular feature of this model set is that the models are interrelated, with a simpler, higher-level model being derived from a more detailed model. For example, the elemental model is derived from the instantaneous model, keeping the vehicle mass, drag function, and energy efficiency as explicit parameters. Because vehicle characteristics are likely to change over time and from country to country, this feature is particularly important and should enable the models to be readily transferred, calibrated, and updated.

A detailed description of the models, with calibration procedures, is given in the guide. It is also possible to express each of the models in graphical forms for a particular "default car." These simpler model presentations could be appropriate to some traffic analyses and are reported in the guide and in recent publications by Biggs and Akcelik.^{5,6}

The suitability of a fuel consumption model will, of course, also depend on the availability of estimates of the appropriate traffic variables. The traffic variables required for each of the above four models are shown in Table 1. As the table indicates, it is also possible to specify different forms of the elemental model (options a, b) and the running speed model (options a, b, c). In each case, the successive levels of model require more traffic information, but could be expected to yield increased accuracy in the fuel consumption estimates.

Linking Traffic Systems, Traffic Models, and Fuel Consumption Models

Estimates of the traffic variables required by the fuel consumption models can be derived from either on-road measurements or traffic models. In practice, traffic models are likely to be the

primary means of deriving these estimates, particularly for the design of traffic management schemes.

A wide range of traffic systems and traffic management techniques must be considered in practice. A large number of traffic models have been developed to aid investigations relating to particular traffic systems and management techniques. Thus, the choice of traffic model and the choice of fuel consumption module within the traffic model are important for their effective use in a particular management situation.

A number of factors must be addressed when choosing the traffic model and ensuring that the fuel module is appropriately specified. These are discussed in the guide and relate to the management objectives, the management task at hand, and the scale of traffic system.

A number of traffic models are in use in Australia and the scales of traffic system to which several of these are appropriate are shown in Table 2. As depicted by the table, each model is appropriate to a particular level. A particular model is not likely to be sufficiently accurate if used below its intended level and is likely to be unnecessarily costly if used above its level. The table also gives a broad specification for the fuel consumption

Table 1. 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, E_{k+} 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, f_i and v_i, v_j , for each acceleration/deceleration, for each road section
Instantaneous	v, G for each second over a road section

*Variables defined

- t_i = Stopped (idling) time, s;
- t_s = Time to travel along the total section distance, including all delays, s;
- v = Instantaneous speed (= dx/dt), m/s;
- v_c = Cruise speed—average speed while cruising uninterrupted by traffic control devices, allowing for speed fluctuations, km/h;
- v_f = Final speed of an acceleration or deceleration, km/h;
- v_i = Initial speed of an acceleration or deceleration, km/h;
- x_s = Total section distance, km;
- E_{k+} = Sum of changes in kinetic energy per unit mass per unit distance during positive acceleration(s) (= $1/2 \sum (v_i^2 - v_j^2) / (12960 \times)$ where $v_i < v_j$ and x is x_c for cruise model or x_s for running speed model), J/(kg · m);
- G = Percent grade (negative for downhill).

module that would be appropriate for each of the traffic models. This indicates both the form of fuel consumption model and the level at which fuel consumption should be calculated.

Relevance to Traffic Management Decisions

The importance of choosing the correct tool for a particular task will ultimately depend on whether fuel consumption estimates are important to the management decisions. Case studies reported in the guide indicate that the choices of traffic model and fuel consumption model are important for accurate fuel consumption estimation and that fuel consumption could be a significant element in traffic management decisions.

For example: A common and important consideration in Australian urban areas is the appropriate form of control at individual intersections. The Australian standard for control devices (Standards Association of Australia) encourages cost-benefit analyses to determine the appropriate control system at a particular intersection, but provides only broad volume and safety warrants to aid the traffic manager.⁷ Decisions relating to the level of control might be aided by more detailed information on traffic performance under the alternative forms of control.

Consider the simple case of a T intersection, as depicted in Figure 1, with one-way flow on the major arm and prior-

ity control on the minor arm. The decision to apply stop control rather than give-way control should be based on a trade-off between the higher level of safety and the increased delay and fuel consumption. Differences in these performance variables are likely to be small and thus a micro-level analysis is necessary. As indicated in Table 2, the micro-simulation traffic model INSECT, with an instantaneous fuel consumption model, is most appropriate for this level of analysis.

The effect of incorporating a simple form of the elemental model (different from that in the guide) into INSECT is shown in Table 3. The instantaneous model estimates a fuel consumption loss

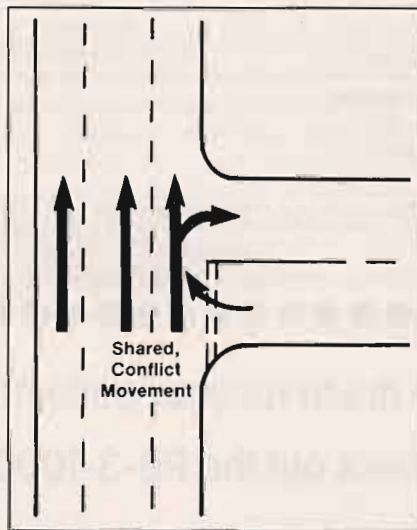


Figure 1. 'T' intersection, showing the conflict movement in the shared lane.

of 3 ml per vehicle, under stop control, while the elemental model estimates a difference of 12 ml per vehicle. The instantaneous estimate is of the same order as has been measured on-road,⁹ indicating that the particular form of the elemental model significantly overestimates the fuel consumption loss in this traffic system. The small fuel loss of 3 ml per vehicle per hour equates to a conservative loss of 450 l per year for the



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Rahmi Akcelik is a principal research scientist at the Australian Road Research Board. His current work is in the traffic signal and fuel consumption areas of research and development. Previously, he worked as a traffic engineer with the National Capital Development Commission in Canberra, Australia, and as a lecturer in Roads and Traffic Engineering at the Black Sea University, Turkey. Currently, he is a member of the Traffic Signal Systems Committee of the Transportation Research Board. He graduated 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 is a member of ITE and the Institution of Civil Engineers, Australia.



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.

Table 2. Traffic Models and Fuel Consumption Modules Appropriate to Levels of Traffic System Scale

Traffic System Scale	Traffic Model*	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.
Meso/Micro	TRANYST	Elemental model (option a) calculated at the link level.
	SCATSIM	Elemental model (option b)
Micro	SIDRA	Elemental model (option b) calculated at the lane level.
	MULTSIM	Instantaneous model, calculated at 1-second intervals.
	INSECT	Instantaneous model, calculated at 1-second intervals.

*The options for fuel consumption models are given in Table 1.

†References that give details of traffic models are given in footnotes to Table III, Chapter B.3 of the Guide to Fuel Consumption Analyses.¹¹

individual intersection. The importance of this small, but significant fuel loss will depend on the management objectives and on the differences in safety levels, the latter being difficult to estimate. If, as in Australian cities, there are many such intersections, then the decision on the form of priority control could have a significant impact on total urban fuel consumption.

Similar discussions of the fuel consumption impacts of alternative traffic management techniques in particular situations are given in the guide. These discussions are based on case studies relating to signalized intersections and one-way street systems.

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Table 3. Estimated Fuel Consumption for the Minor Arm of Figure 1

Form of Control	Estimated Fuel Consumption* (ml/veh)		
	Elemental Model†	Instantaneous Model	Difference
Give-Way	30	44	-14
Stop	42	47	-5
Difference (ml/veh)	-12	-3	

*Results are for a 'medium' conflict level; 148 veh/h during peak period on the minor arm.

†An elemental form derived from Kent *et al.* as used in INSECT.⁸