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REPRINT

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 Though some aspects of this paper may be outdated, this reprint is provided as a record of important aspects of the SIDRA INTERSECTION software, and in order to promote software assessment and further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

Estimating Effect of Vehicle Characteristics on Fuel Consumption

By D. C. Biggs[1] and R. Akcelik[2]

(Reviewed by the Urban Transportation Division)

Introduction

This technical note relates to a paper by Lam (4), "Estimating Fuel Consumption from Engine Size," which recently appeared in this journal. Using the average travel speed model and data primarily from official fuel consumption tests, Lam investigated the relationship between engine capacity and fuel consumption. However, it is difficult to isolate the effects of individual vehicle characteristics using a very aggregate model such as the average travel speed model. The approach used by Lam could be described as a correlation/regression approach. This type of approach can cause inconsistencies and anomalies when estimating fuel consumption, and may lead to errors in the interpretation of parameters. To determine the actual effect of any one vehicle characteristic, it is necessary to include all relevant characteristics in the fuel consumption model. Regression estimation of these effects, especially in aggregate models, may not result in reliable estimates due to multicollinearity caused by high correlation between the vehicle parameters.

Calculation of Effect of Vehicle Characteristics

A different approach, which has been used by the writers, is to relate fuel consumption to the individual components that contribute to fuel consumption, e.g., drag, inertial, and grade forces. These components are then related to vehicle characteristics. To follow this approach, we started with a basic energy-related model of instantaneous fuel consumption. This type of model was first proposed by Post, et al. (5), and extended by Biggs and Akcelik (1). The extended model was found to accurately predict fuel consumption during accelerations, steady-speed driving and over acceleration-cruise-deceleration cycles. By integrating the instantaneous model over acceleration, deceleration, and cruise modes, a four-mode elemental model and a more aggregate "running speed" model were developed (1). Using this method of derivation, the vehicle parameters remained explicit at all model levels, as did the components contributing to fuel consumption. The average travel speed model was then shown to be a simplification of the running speed model. All four

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TABLE 1.—Contribution of Various Components to Fuel Consumption and Vehicle Parameters that Effect those Components

Location (1)	Components of Fuel Consumption (%)					
	Engine operation (2)	Roll-drag[a] (3)	Air-drag[a] (4)	Inertia (5)	aR_1[b] (6)	Grade (7)
CBD	61.5	16.2	4.2	9.2	8.1	0.9
Other urban	40.9	23.9	17.7	7.8	7.4	2.3
Nonurban	19.6	26.2	48.2	2.4	3.1	0.5
Vehicle parameters[c]	α	$Mb_1\beta_1$	$b_2\beta_1$	$M\beta_1$	$M\beta_2$	$M\beta_1$

[a]These components also include the fuel required to overcome engine drag.
[b]aR_1 component includes effect of increased engine drag during acceleration and inefficient use of fuel during periods of high acceleration.
[c]Vehicle parameters are summarized here and described in detail in Refs. 2 and 3 including values for the "typical car." α = idle fuel rate (0.444 ml/s); M = vehicle mass including load and occupants (1,200 kg); b_1, b_2 = drag-related parameters [0.333 kN and 0.00108 kN/(m/s)^2]; and β_1, β_2 = vehicle efficiency parameters relating energy to fuel consumption [0.090 ml/kJ and 0.045 ml/(kJ m/s)^2].

models are interrelated, using the same set of vehicle parameters and they cover the general range of traffic analysis applications. These models are described and numerical examples are given in a guide to fuel consumption analysis in urban traffic management by Bowyer, Akcelik, and Biggs (3).

The components of fuel consumption due to engine operation, rolling and air drag, inertia, etc., and the effect of vehicle characteristics on these components were estimated using the instantaneous model and on-road second-by-second speed, acceleration, and grade data collected over 1,500 km of driving in Sydney. The percentage contributions of each component for the central business district (CBD), other urban and nonurban driving for a fairly typical car and the vehicle parameters that affect each component are given in Table 1. The effect of changes in particular vehicle parameters can be estimated using this table. For example, a 10% increase in mass, M, will increase total fuel consumption in the CBD by $(16.2 + 9.2 + 8.1 + 0.9) \times 10/100 = 34\%$. Engine capacity is not a parameter in the energy-related model but, as discussed later, it is strongly related to some of the vehicle parameters.

Average Travel Speed Model

The average travel speed model, as given by Lam, is:

$$F = A + \frac{B}{V} \qquad (1)$$

where F = fuel consumption per unit distance (ml/km); and V = average travel speed (km/h). The various aggregate (but detailed) fuel consumption functions derived from the instantaneous fuel consumption model indicate that:

1. Parameter B, coefficient of the speed term in Eq. 1, should be taken as the idle fuel rate (fuel to maintain engine operation).

2. Parameter A, the constant term in Eq. 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 by the driving environment.

Lam suggests that the average travel speed model can be extended to include a V^2 term:

$$F = A' + \frac{B'}{V} + C'V^2 \qquad (2)$$

and that the coefficient A' in this equation, should be the same as the coefficient A in Eq. 1. Our findings do not support this suggestion. In fact, B and B' should be the same and $A' + C'V^2$ in Eq. 2 accounts for the same components of fuel consumption as A in Eq. 1.

Engine Capacity and Mass

The engine capacity of a vehicle has the greatest effect on the idle fuel consumption rate. Fig. 1 shows the relation between idle rate and engine

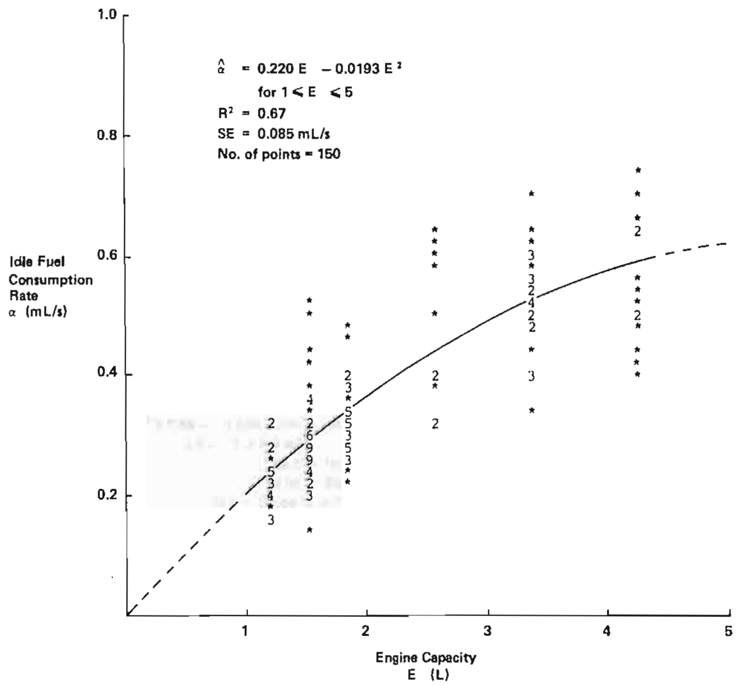

FIG. 1.—Idle Fuel Consumption Rate as Function of Engine Capacity (Source: Ref. 3)

capacity for 158 cars, typical of cars on the road in Australia in 1984. The idle fuel consumption rate, α, and therefore parameter B in Eq. 1 can be estimated from Fig. 1 for a given engine capacity E. A function of the form $\alpha = aE^b$, as used by Lam, could be used to relate idle rate to engine capacity. Post, et al. (5), found that a parameter related to the efficiency of the vehicle at converting fuel to tractive power (i.e., power to move the vehicle) had little relation to engine capacity, or vehicle type, size, or weight for over 150 cars tested. Thus, the vehicle efficiency parameters (β_1 and β_2 in Table 1) need not be adjusted for different engine capacities. Also, since engine capacity is not related directly to rolling resistance, aerodynamic drag, inertial and grade components of fuel consumption, a change in engine capacity alone should not affect parameter A in Eq. 1.

The writers have shown (2), that a linear increasing rather than a simple proportional relation, as suggested by Lam, exists between parameter A and the vehicle mass. The following expression can be given for the simple average travel speed model for a typical car with mass (M, in kg) as an explicit parameter:

$$F = \frac{f_i}{V} + 20.7 + 0.0443M \quad \text{(3)}$$

where f_i is the idle fuel rate (ml/h), and if unknown could be estimated

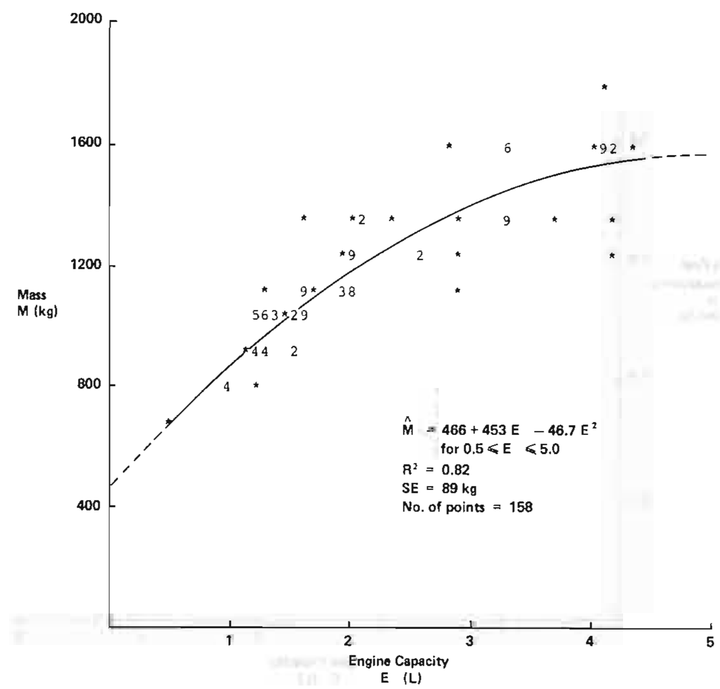

FIG. 2.—Relationship between Vehicle Mass and Engine Capacity (Source: Ref. 3)

as a function of engine capacity, E, from Fig. 1 ($f_i = 3{,}600\alpha$). Vehicles with high engine capacity tend to have a high mass and thus a high value of the parameter A. This relationship between engine capacity and parameter A is correlative, not causal. Fig. 2 shows the general relationship between engine capacity and mass and could be used to estimate mass from engine capacity if necessary. Again a function of the form used by Lam, $M = aE^b$, could have been used to estimate mass. Note that with fuel consumption estimated from Eq. 3, an increase in payload will affect the total mass, M, thus the A parameter, but not the B parameter (the idle fuel rate).

To demonstrate our proposition that the engine capacity only affects fuel consumption via the idle rate (i.e., parameter B), let us consider the data given by Lam on the fuel consumption of vehicles of the same model and mass but with different engine capacities (Ref. 4, p. 345). These data are given in Table 2. The idle fuel rates included in Table 2 were estimated using Fig. 1. The average speed during the fuel consumption tests [assuming speeds are specified by the European Economic Community (ECE)-15 urban drive-cycle] is 18.8 km/h. Estimates of the excess fuel consumption rates for the vehicles with the larger engine capacity relative to the lowest engine capacity are included in Table 2. These were found from Eq. 1 assuming that parameter A for the one model of vehicle is the same for all engine capacities and that parameter B equals the idle fuel rate, f_i. Thus, the difference between the fuel consumption rates of the same model of car with different engine capacities, ΔF, is

$$\Delta F = \frac{\Delta f_i}{V} \quad \text{(4)}$$

where Δf_i is the difference in idle fuel rates of the two cars. The corresponding differences in fuel consumption rates estimated by the function given by Lam (Ref. 4, Equation 8) are also given in Table 2. Al-

TABLE 2.—Measured and Estimated Effect on Fuel Consumption of Increase in Engine Capacity for Two Cars

Car (1)	Engine capacity (L) (2)	Fuel consumption, ml/km (mile/gal) (3)	Idle rate[a] (ml/h) (4)	DIFFERENCE IN FUEL CONSUMPTION FROM CAR WITH LOWEST ENGINE CAPACITY ΔF (ml/km): Measured (5)	Estimated: $\Delta f_i/V$ (6)	Estimated: Lam[b] (7)
Escort	1.1	80.8 (34.9)	787	—	—	—
	1.3	92.8 (30.4)	912	12.0	6.6	9.1
	1.6	91.9 (30.7)	1,089	11.1	16.1	21.8
Cortina	1.3	100.7 (28.0)	912	—	—	—
	1.6	102.9 (27.4)	1,098	2.2	9.9	12.7
	2.0	111.0 (25.4)	1,306	10.3	21.0	28.2
	2.3	134.9 (20.9)	1,454	34.2	28.8	38.9
Mean difference				14.0	16.5	22.1

[a]Idle rate estimated from Fig. 1.
[b]Estimated from equation 8 of Lam (4): $F = 0.148E^{0.585}$.

though there is some variation, the measured and predicted effects of a larger engine capacity are similar when based on Eq. 4, given the approximate method of estimating the idle rate. These estimates are considerably better than those found by the function given by Lam. Thus the data generally supports the proposition that the engine capacity only affects fuel consumption via parameter *B*.

SUMMARY

In summary, we suggest that when relating fuel consumption to vehicle characteristics, it is best to start with a detailed model that includes all components that contribute to fuel consumption. The effect of vehicle parameters in the aggregate forms of fuel consumption models can then be found by integrating the detailed model over typical driving patterns. The components of fuel consumption will remain explicit in the aggregate forms of the fuel consumption model. The effect of individual vehicle parameters will therefore be clear. Using this approach, engine capacity is directly related to the coefficient of the speed term in the average travel speed model expressed in Eq. 1, and is indirectly related, via mass, to the constant term. Full details of this approach to fuel consumption modeling are given in Refs. 1–3. However, better estimates of the effects of vehicle parameters on fuel consumption can be found by applying the energy-related instantaneous model of fuel consumption to a detailed speed-time profile (e.g., a drive-cycle).

APPENDIX.—REFERENCES

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