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A CONTRIBUTION TO THE DEVELOPMENT OF A CONGESTION RESPONSIVE GENERALISED COST FUNCTION

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ABSTRACT: *The form of generalised cost function used in travel choice modelling is typically a simple function of travel time and distance, and bears little direct relationship to the level of traffic congestion. Such a specification does not allow us to either model or evaluate the effect of the many transport systems management schemes which result in smoother traffic flow conditions and yet do not significantly alter average travel times. This paper presents a conceptual framework for the incorporation of congestion effects into disaggregate travel choice modelling, primarily through a revision of the generalised cost function. The form of the congestion index required is placed in context by reference to transport supply considerations. A specific advantage of the framework presented is that it does not require any major revision of existing network manipulation programs.*

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INTRODUCTION

It is the aim of this paper to focus attention upon the role of traffic congestion can play in behavioural travel modelling through its influence upon the form and components of the generalised cost function. Historically, congestion has been accounted for only in an aggregated traffic engineering sense through the use of volume-delay curves to relate traffic flows to *average* vehicle speeds for different classes of roads. Such average speeds are then used to derive the generalised cost of travel along the various links within the simulated transport network as part of the process of matching traffic demand (vehicle flows) with supply (road space). In this situation the volume-capacity ratio is used as what we may call a 'macro-level' indicator of congestion.

From the evidence that is available, and which will be discussed later in this paper, it is apparent that the volume-capacity ratio is not *in itself* a sufficient descriptor of traffic congestion. Rather, it needs to be supplemented by a 'micro-level' indicator of congestion, namely some measure of travel speed 'variability'. This second dimension to congestion is particularly important if we are to effectively consider Transport System Management (TSM) schemes within our established network simulation framework. This is because such schemes generally aim to provide smoother traffic flows for all vehicles (or particular groups of priority vehicles) and yet may not significantly alter overall average vehicle speeds. A further example of where this second dimension is important is in being able to model the observed travel choice of drivers selecting longer (in distance) but less congested routes, even though no travel time savings are obtained.

In this paper we do not attempt to answer many of the side issues associated with disaggregated travel choice modelling. Rather, we try to present a framework for incorporating existing knowledge (on the influence of traffic congestion upon travel behaviour) into the established transport modelling process without making the considerable investment in existing network simulation programs and data banks redundant. It is recognised that the framework we shall present in this paper will require some refinements to be made to existing network simulation procedures, as well as some empirical work to establish the form of particular relationships proposed. However, it remains to be seen as to whether such efforts are justified in terms of increased predictive accuracy of modelling procedures.

In presenting our framework we will first turn our attention to the concept of generalised cost and its application in travel choice modelling. Following this we will discuss the available evidence on the effects of traffic congestion upon the components of generalised cost (i.e. upon travel behaviour). We can then move on to consider the role of both macro- and micro- level measures of congestion within travel 'supply', before concluding with a summary presentation of our basic proposal and what its application may entail.

DEMAND AND GENERALISED COST

If the generalised cost of travel (C), is expressed as a linear function of the factors determining the total disutility (or cost) of such travel (denoted by X:); then we can express the quantity of travel demanded (Q) as follows:

$$C = \sum_i \beta_i X_i \qquad (1)$$

where the β_i's are co-efficients of the cost function;

and $$Q = f(C) \qquad (2)$$

where C can be either monetary or, infrequently, time units. In Australia monetary units are used, and this practice will be followed throughout the paper.

Williams (1977) examines the theoretical requirements for consistency of several common variations of the sequential approach to travel demand modelling, including the most common approach in Australia, that of post distribution modal choice or G-D-MS-A (Generation-Distribution-Modal Split-Assignment). Using this approach, which is followed throughout the rest of this paper, Williams shows that the appropriate modal choice model(1) is:

$$M_{ij}^{nk} = \frac{\exp\left(-\lambda^{n}\left(c_{ij}^{k} + \delta^{nk}\right)\right)}{\sum_k \exp\left(-\lambda^{n}\left(c_{ij}^{k} + \delta^{nk}\right)\right)} \qquad (3)$$

where the subscripts i, j, k and n refer to:

i	the trip origin,
j	the trip destination,
k	the mode, and
n	the person type;
c_{ij}^{k}	is the generalised cost for mode k;
δ^{nk}	is a modal bias term, for person type n, to capture the combined effect of all intangible factors influencing modal choice;
M_{ij}^{nk}	is the modal share; and

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[1] Unfortunately, Williams was not able to find, or propose a *route choice model* which is rigorously consistent with the fundamental assumptions of the G-D-MS-A approach.

λ^n is a scaling parameter associated with the propensity of individual of type n to travel.

Equation (3) is exactly the same as the more commonly expressed modal choice model:

$$M_{ij}^{nk} = \frac{\exp U_k}{\sum_k \exp U_k} \tag{4}$$

where U_k is the utility (disutility) associated with mode k, and is also a linear function of the X_i's. The Williams' approach of equation (3) facilitates an understanding of the choice mechanism; which is based on the combination of an individual's propensity to travel, λ, and his behavioural interpretation of the generalised costs involved in any such travel, c_{ij}^k and δ^{nk}. In fact λn, δ^{nk} and the β_i's of c_{ij}^k are not estimated directly, but obtained by interpreting equation (4) in the manner of equation (3).

A major misinterpretation of generalised cost is that equations (1) and (2) constitute an *indeterminate set.* In particular it is assumed that equation (2) cannot be estimated unless equation (1) has been predetermined (i.e. unless all the β_i's are known, *a priori*). A practical illustration of this can be drawn by reference to the generalised cost functions used for the re-estimation of the trip distribution models for Melbourne using the 1964 survey data (Don 1975):

$$c_{ij}^1 = 2.5\ ta_{ij} + 1.0\ t_{ij} + 4.0\ s_{ij} + P \tag{5}$$

$$c_{ij}^2 = 2.5\ ta_{ij} + 2.5\ tw_{ij} + 1.0\ t_{ij} + F \tag{6}$$

where c_{ij}^1 = generalised cost of car travel (¢)

c_{ij}^2 = generalised cost of public transport travel (¢)

ta = access time (usually walking time), (minutes)

tw = waiting time, (minutes)

t = travel (or in-vehicle) time, (minutes)

s = travel (or in-vehicle) distance, (kms)

P = parking charges (¢)

F = fare (¢)

(Note: all monetary values are expressed in 1964 prices).

The weightings of 2.5 and 1.0 on the travel time components reflect the *pre-assigned* values of travel time (i.e. β's) which were in fact 'borrowed' from the results of work in Denver, USA (Don 1975). The 4.0 weighting on 's' is the average car running costs in ¢/km (averaged over all roads, and operating conditions for Melbourne). These weightings have since been drastically revised (Transport User Study Team, 1977) in light of the performance of the transport models; but they are still determined *a priori* rather than from the actual data being analysed.

Domencich and McFadden (1976, p 158) outline the derivation of generalised cost functions for a modal choice model specified in the manner of equations (3) and (4), through the use of binary logit techniques. Following their example it becomes a simple matter to solve for λ^n, δ^{nk} and the β_i's by using the fact that β_i for an actual money term (eg parking cost) should be exactly 1.

A further misinterpretation, often going hand in hand with the first, is that of including in eqn (2) a set, or vector, of socio-economic factors, E, such that:

$$Q = f\ (C,E) \tag{7}$$

The theoretically correct procedure to adopt in this case is to estimate eqns (1) and (2) *separately* for each homogeneous socio-economic group. In other words, to allow the weightings attached to each component of generalised cost to vary between socio-economic groups and different travel purposes. Hence the subscript 'n' in some equations to denote a family of cost and choice functions for different population subgroups.

Form of Generalised Cost Function

From eqns (5) and (6) we have that the form of the generalised cost function typically adopted within Australia, is a simple linear function. Concentrating our attention upon the major components of generalised cost, namely in-vehicle travel time and operating costs, we can simply rewrite eqn (5) as follows:-

$$c_{ij}{}^1 = a^1\ t_{ij} + b^1\ s_{ij} \tag{5a}$$

By removing subscripts for clarity, and dividing through by travel distance (s) we have that:-

$$\begin{aligned} g^1 &= {}^{c^1}/_{s} \\ &= a^1\ {}^{t}/_{s} + b^1 \\ \text{or}\quad g^1 &= {}^{a^1}/_{v} + b^1 \end{aligned} \tag{8}$$

where	g^1	is the generalised cost per unit distance for car travel;
	v	is the average speed;
	s	is the journey distance;
	t	is the journey time;
	c^1	is the generalised cost for the car journey;
	a^1	is the average value of travel time for car travellers;
and	b^1	is the average car operating costs per km.

Current Australian behavioural modelling practice (and also for project evaluation) is to assume that the parameters a^1 and b^1 are constants, and the average value of travel time (savings) is the same for all modes (i.e. $a^1=a^2=a$).

In addition to any proposed revision of the generalised cost function to take congestion effects fully into account, it is also apparent (particularly in project evaluation context) that the form of the operating cost component (i.e. b^1 in eqn 8) is also in need of major revision. Evidence presented by ARRB (1973) and Dawson and Vass (1974) clearly shows that a more realistic form of operating costs would be:-

$$b^1 = b_0 + b_1/v + b_2\ v^2 \qquad (9)$$

where b_0, b_1 and b_2 are constants

and v is the average speed:

(the shape of such a relationship is illustrated in Fig 1).

As such, eqn (8) would become:

$$g^1 = {}^{a}/_{v} + b_0 + {}^{b_1}/v + b_2\ \ v^2$$

$$\text{or} \quad g^1 = b_0 + \frac{1}{v}\,(a+b_1) + b_2\,v^2 \qquad (10)$$

Hence, if we attempt to estimate the parameters of our generalised cost function (i.e. the β_i's of eqn 1) directly from our data it is important to ensure that the form of our cost function is 'realistic'. This point is also made by Metcalf and Markham (1974).

Before continuing it is important to highlight the two key areas of transport planning where generalised costs are employed. Namely, in the evaluation of alternative projects or policies, and in the modelling of individual travel behaviour. In this paper we are primarily concerned with the application of generalised cost in the behavioural context, although our comments will also have direct relevance to evaluation.

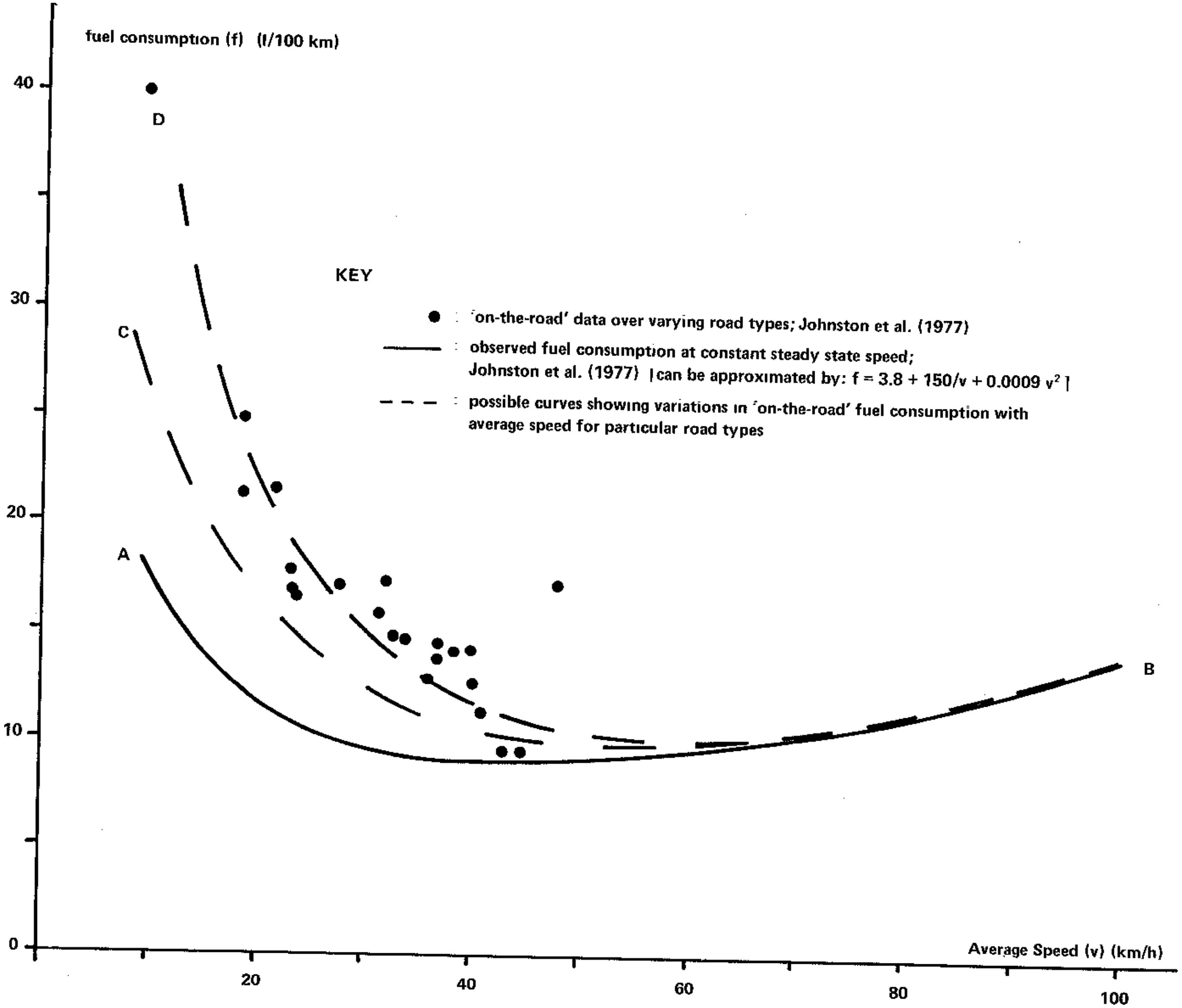

Fig. 1 – Fuel consumption and speed; the effects of congestion

If we find that there are errors in either the form of the generalised cost function, or in the values of its co-efficients (or in both) we cannot expect rational transport planning decisions. Rather, we will be in a situation of mis-evaluating incorrect forecasts of travel behaviour. Bamford and Wigan (1974) clearly demonstrated this point in relation to the values of the parameters employed in the generalised cost function (their work also adopted a functional form along the lines of eqn 10 rather than eqn 8).

TRAFFIC CONGESTION, VEHICLE OPERATING COSTS AND THE VALUE OF TRAVEL TIME SAVINGS.

Operating Costs

As noted in the previous section (see eqn 5 and 5a) current Australian practice is to assume a fixed average cost per unit distance of travel. Eqn (9), as adopted for the UK (Dawson and Vass 1974), gives us a more 'realistic' description of variations in vehicle operating costs but only in relation to *average vehicle speed*. Evidence collected in Australia (Pelensky 1970) and supported by work overseas (Claffey 1971, Winfery 1969, Dawosn and Vass 1974) clearly shows the effects of road and traffic flow conditions upon fuel consumption(1) and other components of vehicle operating costs. Traffic speed variability is seen to have a significant effect upon fuel consumption with the most frequently used proxy for this being the number of stops recorded per km (Pelensky 1970, Claffey 1971).

These results are basically supported by the later work of Johnston, Trayford and Wooldridge (1977) who found that under extreme levels of congestion the fuel consumption of their test vehicle more than doubled, as compared to stable flow (i.e. constant speed) conditions

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[1] Fuel consumption (inclusive of tax, as appropriate for behavioural modelling purposes) constitutes approximately 50 per cent of total car *operating* costs (oil petrol, tyres, maintenance and depreciation). For the purposes of this paper it is reasonable to assume that overall *operating* costs vary in a similar manner to fuel consumption for a car under varying traffic conditions, and in particular under different levels of traffic congestion. This assumption is generally supported by the evidence put forward by Claffey (1971), and Pelensky (1970); and also by the equations for UK (car) fuel and operating costs put forward by Dawson and Vass (1974):-

(i) fuel costs/km (gross) $= .41 + 21.4 \left(\frac{1}{V}\right) + .000053\,V^2$

(ii) operating costs/km (net of time)
$= 1.29 + 26.5(\frac{1}{V} + .000063\,V^2$

where V = average speed in km/h

with the same overall average speed. Fig 1 illustrates the experimental results of Johnston *et al.* (1977). Curve AB depicts variations in fuel consumption against average speed where there is no speed variation; whilst curves BC and BD depict what we might expect as speed variation increases.

Whilst there is clear evidence to show that actual vehicle operating costs vary with traffic congestion (among other things) it is more difficult to show that car users 'perceive' such cost variations, although the proposition seems intuitively correct. For example, when people quote the fuel consumption rate for their vehicle they often draw the distinction between 'around town' (with its relatively congested roads) and 'in the country'. It is also quite possible that they further perceive that their 'around town' fuel consumption is worsened by travelling in the peak hours on heavily congested roads.

An example of the effects that TSM schemes can have upon actual operating costs (as opposed to perceived costs) is reported in Easingwood-Wilson, Nowottny and Pearce (1977). In this case a 'floating car' equipped to measure fuel consumption was placed in the traffic stream of Glasgow while the traffic signal control strategy was altered from minimising delays to minimising number of stops. As a result of this the 'fuel consumption decreased by 5.8 per cent while the average journey time increased by only 0.3 per cent'.

This evidence together with that from many sources (such as Pelensky 1970 and Winfrey 1969), clearly shows that speed variability directly affects *actual* operating costs(which is appropriate for project evaluation)and can also be expected to affect perceived costs and hence affect travel behaviour.

Value-of-Travel Time

In addition, there is increasing evidence becoming available which suggests that the 'behavioural' value of time (savings) is also related to the level of congestion being experienced. Heggie (1976) in what he called 'a diagnostic survey of journey-to-work behaviour' - i.e. he did not base his analysis on modal choice modelling - found that 'congestion ..... affects marginal time values and that the effect increases with the level of congestion', Heggie concluded that the effect of congestion was 'not large enough to warrant estimating time values as an explicit function of congestion', but suggested that this was possibly attributable to the generally low level of congestion experienced by car users in Vancouver, the city under study. The authors suggest that in a city such as Sydney the effects of congestion on the value of travel time (savings) may be much more marked. Heggie's original graph is reproduced here as Fig 2.

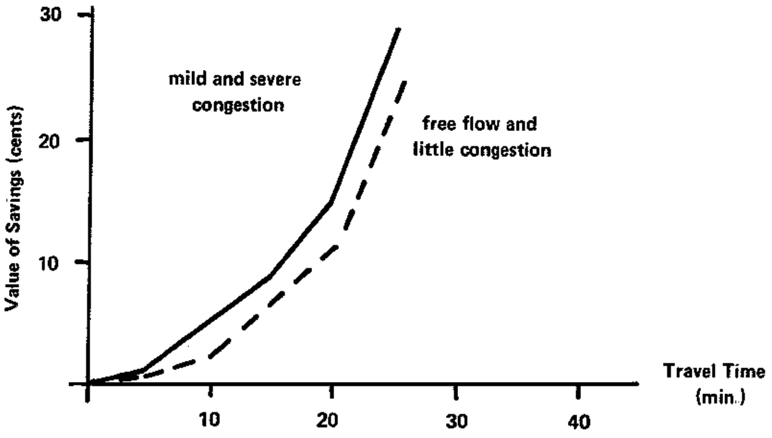

Fig. 2 — The effect of congestion on the value of travel time (savings)

In a study using Sydney data Hensher and McLeod (1977) found *inter alia*, that the differences in the number of stops per unit in-vehicle time (one of many possible quantitative measures of congestion) was a significant explanator of (binary) modal choice. As Hensher claims in a later article 'The separation of in-vehicle time into moving time and stop time *is a fist step*(1) in recognising the differences in disutility between a constant speed journey and a fluctuating speed journey' (Hensher 1979). Hensher goes on to claim that managing congestion so as to even out speed variation is beneficial to the user.

Bowyer (1978) in an analysis of the Victoria Road transit lane in Sydney found that bus users perceived an improvement (i.e. a benefit) in the service upon the introduction of the transit lane, yet the average travel time for their overall journey did not alter significantly. What did happen though, was a marked reduction in the standard deviation of their journey times, or put another way, a significant improvement in the reliability of the bus service. Engineering approaches to the theory of traffic flow have long recognised that reliability of travel time decreases with increasing congestion (Haight, 1963). It is therefore possible to interpret Bowyer's results of these perceived benefits accuring to bus travellers as being due to their placing a higher value on their travel time under relatively unreliable (i.e. congested) travel conditions.

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[1] Authors' emphasis.

Such 'benefits' are intuitively reasonable and are well illustrated by an example drawn from Richardson (1978). Let us consider an employee who is allowed to be late for work only once in every fortnight (i.e. 10 working days), otherwise deductions are made to his pay. As a result the employee must schedule his journey-to-work so that the 90th percentile of his travel time distribution will get him to work in time (allowing him to be late 1 day in 10 and, yet, be early on the vast majority of occasions!). Here we can see that if the employee allocated simply his average travel time to the journey-to-work he would probably get dismissed, and hence positive benefits could be derived from reductions in the variance of his travel time distribution even if the mean travel time remained the same.

INCORPORATION OF CONGESTION INTO THE GENERALISED COST FUNCTION

For the sake of simplicity we will continue to consider only the in-vehicle components of generalised cost (i.e. travel time and operating costs) and adopt the functional form typically employed in Australia today (i.e. eqn 8)(1).

From the arguments presented in the previous section of this paper we have indicated that both operating costs, b^1, and the value of time (savings), a, are increasing functions of some measure of *congestion*(2) (denoted by z). Further, it would seem reasonable to assume that these relationships are linear:

$$a(z) = \alpha_0 + \alpha_1 z \tag{11}$$

and

$$b^1(z) = \beta_0 + \beta_1 z \tag{12}$$

Where α_0, α_1, β_1 and β_1 are parameters of the equation; with α_0 and β_0 representing the 'free-flow' (i.e. steady state speed) values of time and operating costs per km, and α_1 and β_1 represent the increases in these 'base' values resulting from unstable flow conditions (i.e. slower and more variable traffic speeds). The parameters a and b^1 of eqn (8) can therefore be thought of as the *average* values obtained from eqns (11) and (12) under a typically observed range of traffic conditions.

Combining eqns (8), (11) and (12) results in -

$$g^1 = (\alpha_0 + \alpha_1 z)\frac{1}{V} + \beta_0 + \beta_1 z \tag{13}$$

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[1] The following arguments hold equally well if we had adopted the alternative form outlined earlier by eqn (10).

[2] That is, travel-speed variability or micro-level congestion.

or alternatively

$$c^1 = g^1 . s = (\alpha_0 + \alpha_1 z)t + (\beta_0 + \beta_2 z)s \qquad (14)$$

To determine the cost of a given car journey (c_{ij}^1) we can consider the trip to comprise of a series of discrete links (l) each with its identifiable link length (s_l), level of congestion (z_l) and link travel time (t_l); giving us:-

$$c_{ij}^1 = \sum_l (\alpha_0 t_l + \alpha_1 z_l t_l + \beta_0 s_l + \beta_1 z_l s_l) + OVC_{ij}$$

$$= \alpha_0 t_{ij} + \beta_0 s_{ij} + \alpha_1 \sum_l z_l t_l + \beta_1 \sum_l z_l s_l + OVC_{ij} \qquad (15)$$

where $t_{ij} = \sum_l t_l$ = total journey time from i to j;

$s_{ij} = \sum_l s_l$ = total journey distance from i to j;

and OVC_{ij} = total Out of Vehicle Costs for the trip between i and j.

Using the modal choice model of Williams (1977), i.e. eqn 3, we can directly estimate the parameters of eqn 15 (including those related to OVC components) *within the framework of existing network manipulation programs:* provided, of course, that z can be suitably quantified. The statistical significance of α_1 and β_1 in am empirical study would help verify whether the hypotheses implied by eqns (11) and (12) are correct.

In undertaking any empirical work it would obviously be possible to test alternative functional forms for eqns (11) and (12), and to also consider variations in the form of the 'behavioural' operating cost function (for example we could develop eqn 10).

INCORPORATION OF CONGESTION INTO 'SUPPLY' CONSIDERATIONS

The basic relationship in traffic-engineering describing the effects of congestion upon traffic flow condition is the 'speed-flow' curve (Fig 3*a*). This relationship forms the basis of the 'operating characteristics' curve (Fig 3*b*) used to simulate the effects of vehicle interaction upon travel speed for aggregate travel demand modelling. Typically, transport planning agencies would adopt a range of such curves, each being for a different road type: Fig 3*b* illustrates a set of such curves empirically derived and commonly used in Melbourne.

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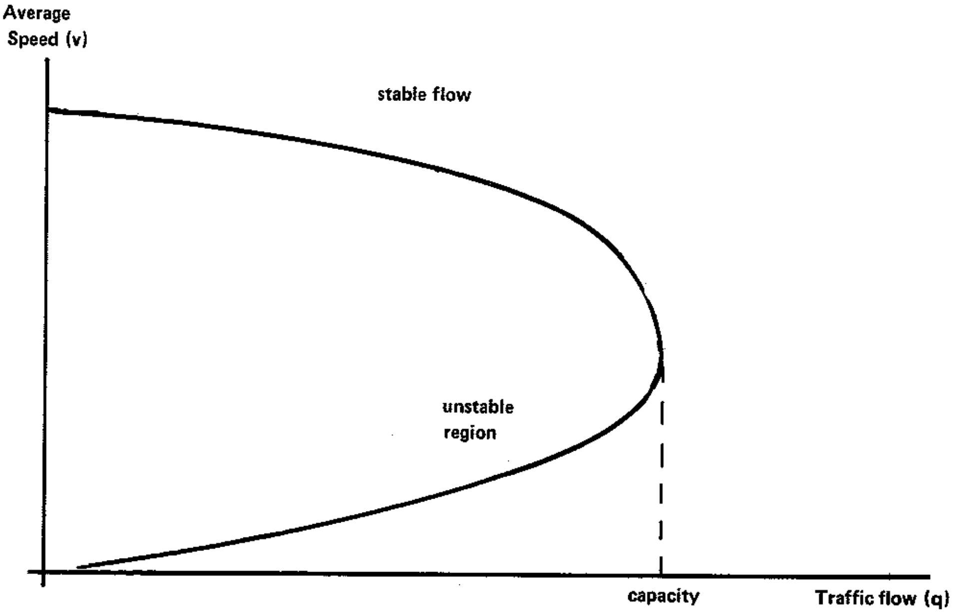

Fig. 3a – Typical speed-flow relationships

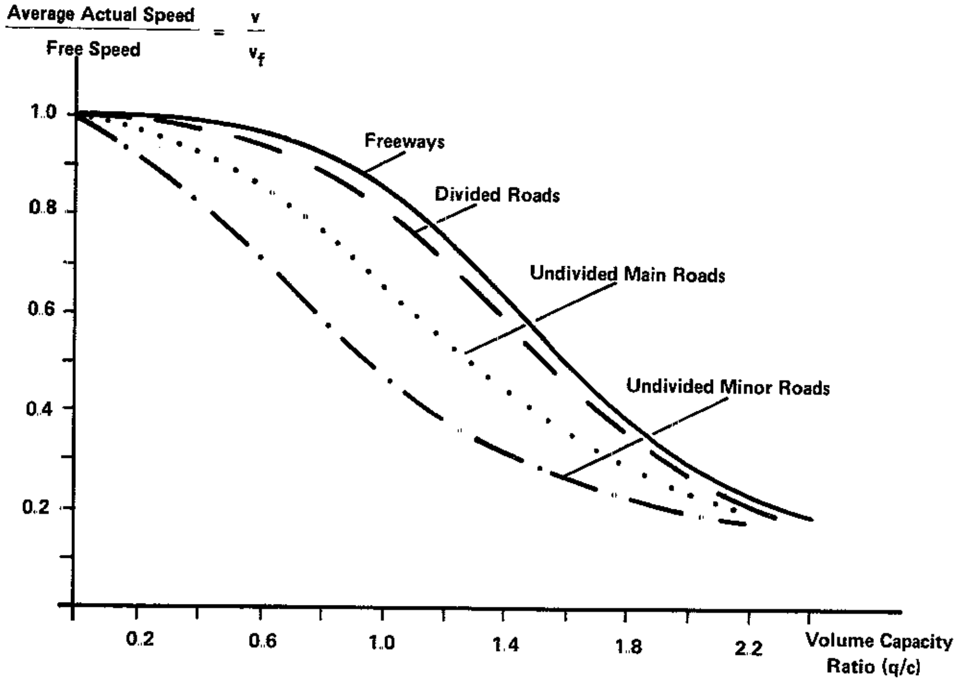

Fig. 3b – Typical 'operating characteristics' curves

It is important to realise that these relationships (i.e. Fig 3*b*) depict fluctuations in *average* speed with traffic flow; and a more realistic picture of operating conditions may be that depicted in Fig 4 where there is a 'band' of observed speed-flow combinations on a given road link. This band would be better defined if instantaneous measures of traffic flow and traffic speed were possible. That is to say, for any particular traffic volume there will be a degree of variability in observed traffic speeds, which manifests itself in the level of reliability of travel times. Further, it is quite likely that different roads may well exhibit the same *average* speed-flow relationship and yet exhibit differing levels of 'reliability' in the travel times encountered by travellers along these routes. As mentioned earlier, the level of reliability in travel times decreases as congestion increases (Haight 1963).

One of the more important features of TSM schemes is likely to be the improvement in travel time reliability. The manner in which individual travellers react to those improvements has already been discussed in the section on travel demand and generalised cost, but how to incorporate this into the supply side of network simulation must now be tackled. It should be emphasised that the following discussion refers to the supply characteristics faced by private car travellers; different supply functions may well have to be developed for adequately modelling transit lane users for example.

Historically, the use of speed-flow relationships (such as those in Fig 3*b*) has proved adequate for aggregate travel modelling exercises adopted to answer such questions as 'which new facilities should be built first?' In such cases, the volume/capacity ratio has proved to be a sufficient *macro-level* indicator of traffic congestion.

In the case of TSM schemes the volume-capacity ratio is in itself an insufficient indicator of traffic congestion and needs to be supplemented by some measure of travel time reliability to more realistically describe the *operating characteristics* of a particular section of the road network. This measure of travel time reliability would be the same as the micro-level index of congestion (z) referred to earlier as part of our proposed revision of the generalised cost function (see eqn 13).

For the practical application of our proposal it would of course be necessary to develop a suitable measure of travel speed variability which satisfied our dual objectives. Further, we would need to develop a set of (empirical) relationships linking this measure of *micro-level* congestion with the average operating speed for a range of road types and TSM schemes (see Fig 4). (This link with average operating speeds would enable existing network

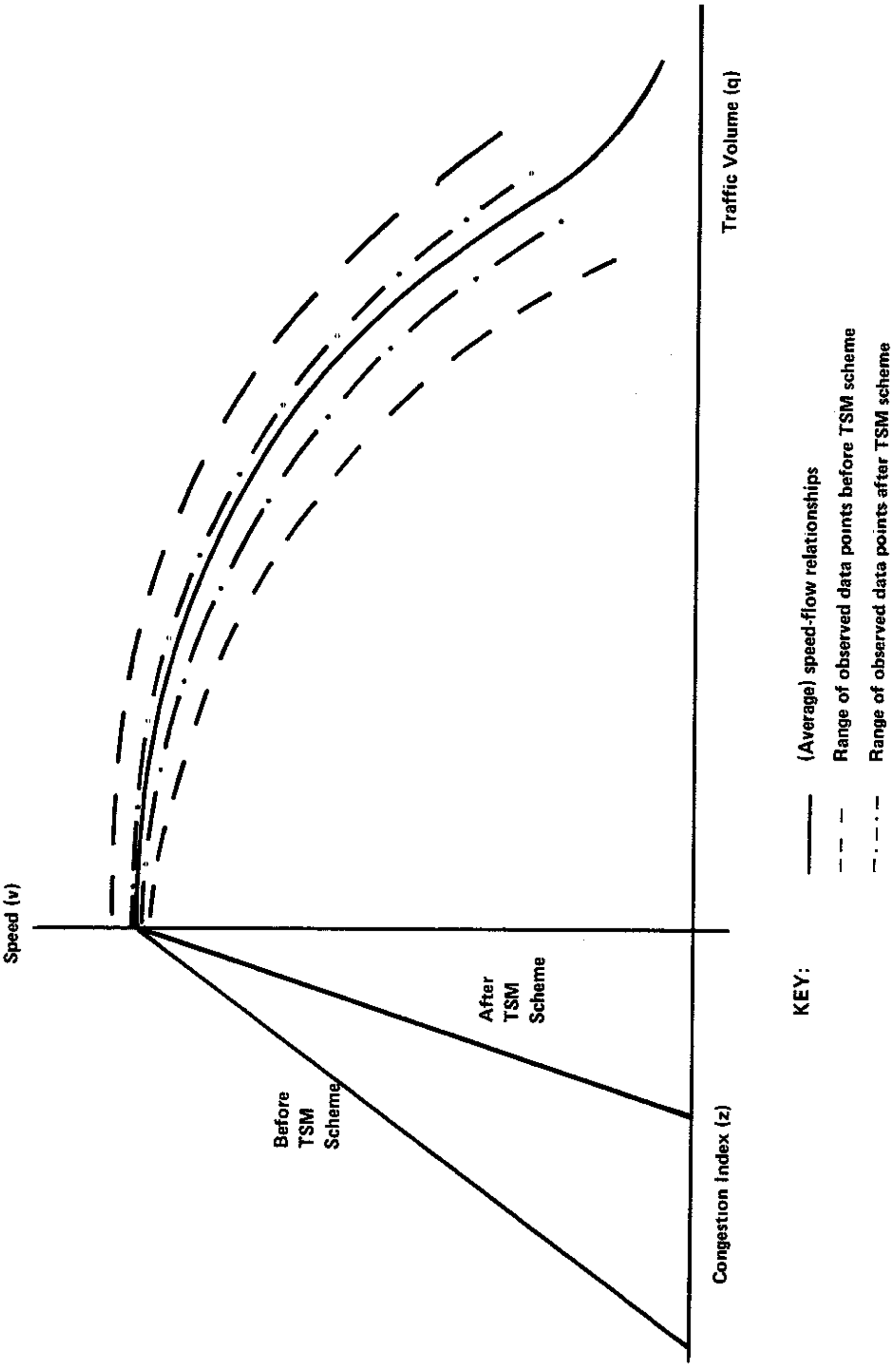

Fig. 4 — Operating characteristics for a particular road link

simulation programs to adopt our revised generalised cost function and operating characteristics, after appropriate minor revisions and finer specifications).

THE DEVELOPMENT OF A SUITABLE (MICRO-LEVEL) CONGESTION INDEX (Z)

So far we have developed a conceptual framework for the incorporation of a micro-level measure of congestion (z) into both the supply and demand sides of travel modelling; and have determined that 'z' should take the form of a measure of travel speed variability or travel time reliability.

One such possible measure, which is considered to be particularly appealing by the authors, is the 'acceleration index' developed by Johnston *et al.* (1977). In their experimental work a 'floating car' was fitted with a tacograph (among other things) to record the velocity-time path of a vehicle in the traffic stream. From the data collected an 'acceleration index' was derived, equal to the number of positive crossing of pre-selected constant velocity lines (0,20,40,60,80 and 100 kmh) by the velocity-time trace per km of vehicle travel. This index was then used to help predict the 'excess' fuel consumed for a given vehicle journey as compared to that which would have been consumed had the vehicle maintained a constant average speed.

The empirical relationship derived by Johnston *et al.* (1977) is given below:-

$$y = .765A^{0.512} \; (f/f^*) \qquad (16)$$

where y is the fuel ratio ($y.f$ predicts actual fuel consumption)

A is the 'acceleration index';

f is the fuel that would have been consumed travelling constantly at the average operating speed for a given trip; and

f^* is the minimum steady state fuel consumption rate, which from Fig 1 is at 40 km/h.

From the limited amount of data presented in Johnston *et al.* (1977) it would appear that there are relationships existing between average operating speed and the acceleration index recorded for different road types. Fig 5 shows some hypothesised relationships for a range of road types; as well as the 'best fit' curve obtained for urban arterial roads from the data in Johnston *et al.* (1977). Such relationships could be used to more completely describe the operating characteristics of a road, as illustrated in Fig 4.

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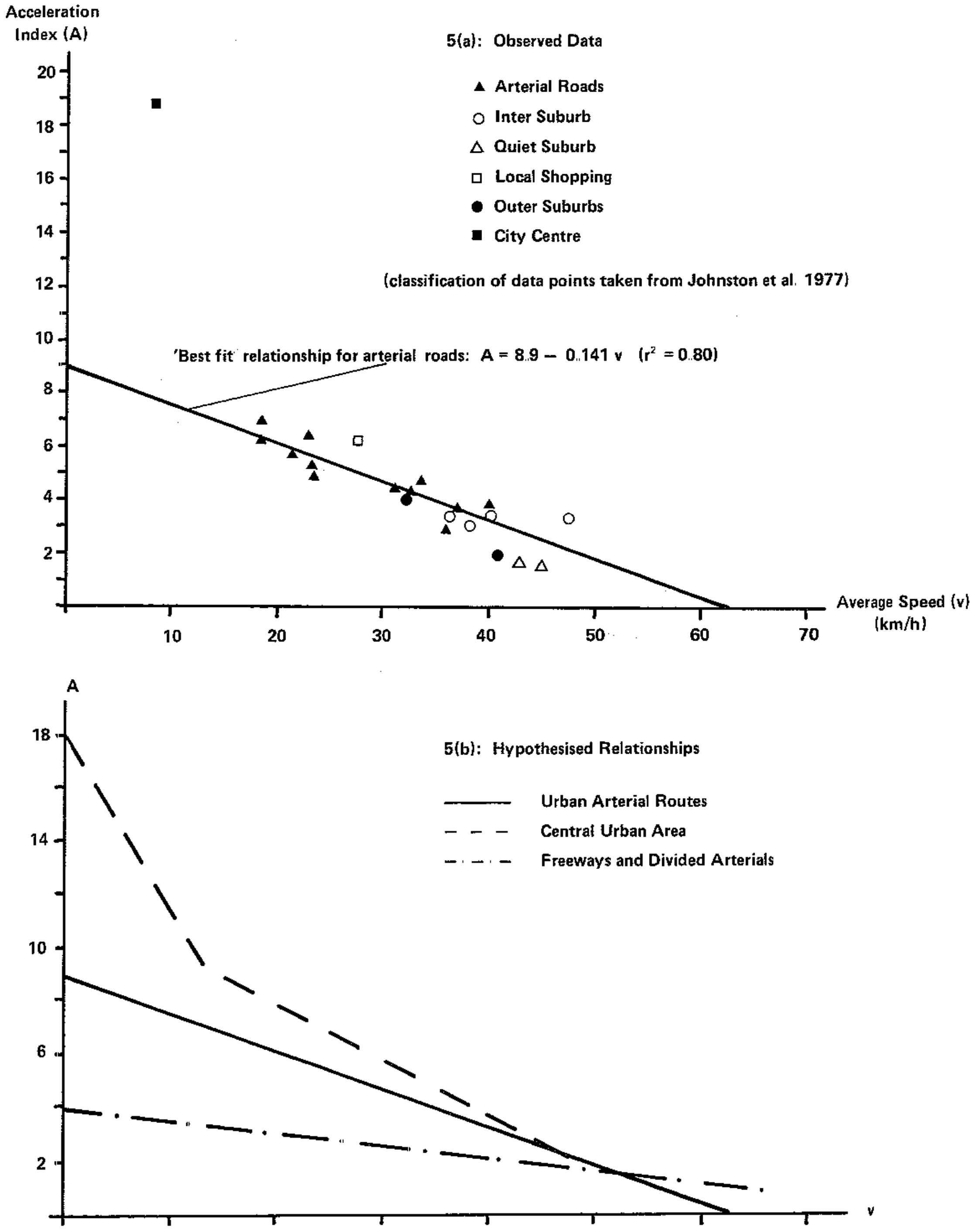

Fig. 5 — Relationships between Johnston's Acceleration Index and Average Operating Speed

Obviously, there are many potential variations of, and alternatives to, Johnston's 'acceleration index'. Experimental work would be required both to:

(a) develop the most suitable form of index for use in determining variations in both 'behavioural' (i.e. perceived) and 'actual' operating costs; and

(b) develop the relationships between such an index and average operating speeds for different road types (see Fig 5*b*).

One of the more commonly used measures of 'congestion' has been the number of vehicle stops per unit distance (or time). Fig 6 shows the empirical relationships derived by Pelensky (1970) between stops/km and average operating speed. These relationships are derived from all of Pelensky's data points and therefore represent averages over all traffic conditions. For our purposes it would be of interest to disaggregate the

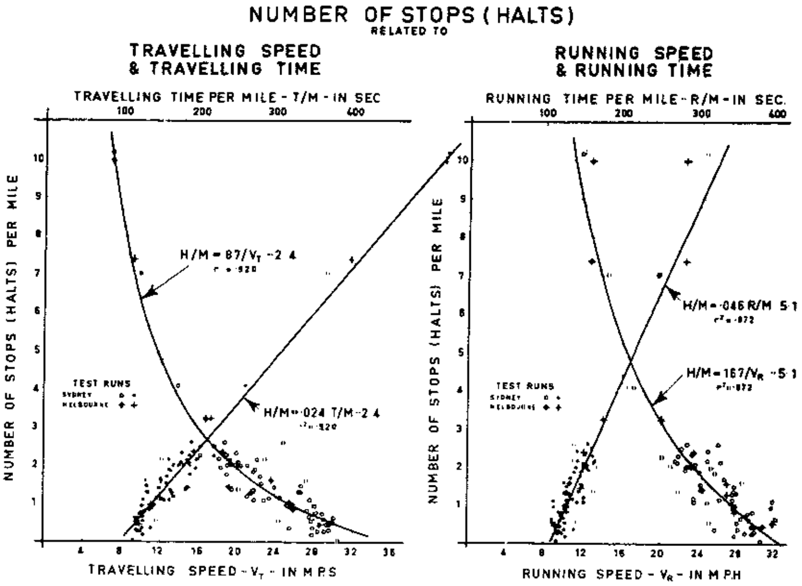

Fig. 6 — Number of stops against speed

data into 'road types' and estimate relationships for each.

CONCLUSIONS AND SOME UNRESOLVED ISSUES

In this paper we have underlined the need to incorporate traffic congestion effects into both the demand and supply sides of disaggregate travel choice modelling.

Several examples have been given of the effects of congestion upon both vehicle operating costs and the value of travel time (savings). To enable us to take account of these effects in travel demand modelling a simple revision of the current generalised cost function is put forward (eqn 15). It is recognised that the form of this equation (and also that of eqns 11 and 12) may well require revision to ensure that it is 'behaviourally realistic' in practice. However, the equation set presented in this paper does provide a good starting point in the absence of adequate empirical data.

The precise nature of the 'micro-level congestion' index that would be required in our revised generalised cost function, is placed in context by our review of supply considerations. The conventional 'operating characteristics' curve relating average speed to the 'macro-level' congestion indicator the volume-capacity ratio, is considered to be inappropriate for many disaggregate choice modelling situations. Given that many TSM schemes affect the reliability of travel times along a given route, rather than reducing the actual average travel time, it is important to expand the concept of road 'operating characteristics' to include some measure of travel time reliability (or speed variability).

The 'acceleration index' developed by Johnston *et al.* (1977) is put forward as *a possible*, simple to measure and intuitively appealing, index of 'micro-level' congestion (z): (there would appear to be several other potential candidates). If we can experimentally derive relationships between such an index and operating speeds for different road types and TSM schemes it would be possible to redefine both the generalised cost function (eqn 15) and the 'operating characteristics' of a road (as in Fig 4) and, hence, incorporate congestion effects into travel choice modelling *without* the need for any major *revision of established network simulation programs*.

In the paper we have presented several simplifications have had to be made and many relevant issues left unaddressed. These will almost certainly have to be resolved *before* travel models currently in use can be used to model TSM schemes. A brief statement of the nature of these issues would bring the paper to a satisfactory conclusion.

(a) *Choices.* A problem with behavioural travel modelling of late (in particular with the logit model) is that of how to correctly describe and define the choices open to individual travellers. With TSM schemes the range of choices is extended by the provision alternatives which have characteristics similar to each of the existng alternatives, compounding the above-mentioned dilemma further. As well, the choice structure (ie sequential choice of mode then route, or route then mode or the simultaneous choice of both) becomes extremely murky, as indeed does the definition of modes and routes.

(b) *Network specification.* This area is related to the first. It involves such issues as whether or not transit lanes for example should be coded as links separate to the rest of the lanes and indeed whether or not TSM schemes in general can be handled as a series of independent links at all, as highways have traditionally been handled by network simulation. For example, for the Inner London Bus Priority (ILBP) Study it was found necessary to formulate a junction delay equation for use along bus priority routes (Coombe, Buchanan, Rickard, Gower and Brown 1974).

(c) *Evaluation.* The issues of evaluation of TSM schemes remain unchanged by our proposal. The user benefits part of evaluation can still be handled by the standard Neuberger (1971) method, which is elegantly generalised by Williams (1977). However the problem of just what values to use, behavioural, 'accounting' (or 'engineering') or some other, for the value of travel time savings, etc. was not addressed in the paper, nor were the broader issues of evaluation of TSM schemes, which are left to others (e.g. Richardson and McKenzie 1976).

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