Personal travel in towns: the development of models that reflect the real world

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INTRODUCTION

In studies of personal travel in towns, recourse is frequently made to transport models. A transport model can be defined as an approximate representation of some aspects of the real world, usually by a set of mathematical equations but sometimes by a set of intuitive non-quantitative statements. This paper is concerned with the development of demand models for personal travel that accurately reflect our increasing knowledge of travel patterns in urban areas, and which can be used as an aid to answering some of the increasingly complex questions raised by policy issues that cover transport, land use, and social factors.

The fundamental purpose of these demand models is to predict how travel patterns will alter in response to changes in land-use patterns and in the supply of transport, or changes in other relevant factors such as levels of car ownership, working hours or schooling arrangements. There are several ways in which this predictive task can be approached. One method is to consider in detail the travel decision process for individuals or small groups of people, and then estimate the travel demands for larger groups of people by an aggregation process from the predected behaviour of many small groups. This is the basic concept of disaggregated modelling. A very different method is to observe empirical relationships (such as the variation in the total travel time per person per day with age, income or employment category) and patterns of movement that appear to be relatively stabel over time and which are constant or predictable between different communities and different social groups. The conventional method, used in the great majority of transport modelling to date, is not unlike the first method, except that disaggregation is not taken very far. The population is disaggregated geographically into a set of zones, and socially into a few very broad categories (for example into car-owning and non car-owning households, and possibly into a few income bands). The behaviour of each category is accounted for by a simple semi-empirical model, usually only containing a rate of exchange between the time and money costs of travel. The model is calibrated on average data, often aggregated over whole zones, before being used to make predictions.

This conventional type of model has been used, in various forms differing only in detail, to plan most almost all recent large British transport projects and in some respects constitutes a satisfactory predictive tool. It effectively provides an extrapolation of existing experience, and is suitable when the proposed transport or other changes are not very great and when prediction is required for the reasonably near future. However, as more information on urban movement is accumulated it is becoming clear that in some respects these models can be improved; on the one hand to reflect the more detailed knowledge of the travel decision process provided by the disaggregate type of model, and on the other to take account of increasing knowledge of the broad relationships and movement patterns already mentioned.

Some typical examples of these relationships and patterns will be described in detail immediately after the initial section of the paper, which sets out the requirements for transport models. These examples use data from travel surveys in specific British cities and from the (British) National Travel Survey. It has been found that the existing transport models have problems both in representing these patterns and in predicting the behaviour of particular groups of people; some of the improved techniques that are being studied or developed are described later in this paper. Mention is also made of some of the problems of long term forecasting and planning, and of the interaction between transport investment and land use.

THE REQUIREMENT FOR MODELS

Transport models are required to provide an input to planning the development of transport systems, and indeed, of urban areas. In the field of strict transport modelling, they are needed for three different purposes, which are:

(i) To predict the future traffic flows and to indicate whether it will be necessary to do something to avoid problems forecast to arise in the future.

(ii) To predict the changes in traffic flows that would be caused by different policy decisions.

(iii) To estimate the costs and benefits of different projects, so that alternatives can be ranked and decisions taken on whether a project is worth carrying out.

It is well known that the emphasis of transport modelling has shifted from predicting flows of vehicles to predicting flows of people on public and private transport, to enable complete transport systems to be evaluated. The greater attention that is now being paid to the social effects of transport and planning decisions is leading to a continuation of this change of emphasis to include all travel in an urban area, particularly those journeys made on foot. In addition, transport studies are increasingly considering the travel of different groups of people and the opportunities for access to different activities available to people of different social groups. The consideration of measures of accessibility is becoming more important as urban areas become more diffuse and as the differences between the opportunities accessible to car-users and non-users increase.

A further class of models should also be considered, which provides the necessary inputs to the transport models. The most important of these is the forecasting model used to predict future levels of car ownership. There are also important inputs from planning models, to provide estimates of factors such as population and employment.

URBAN MOVEMENT IN THE REAL WORLD

In the earliest studies of urban movement in Britian, made using models of the conventional type described above, it was assumed or deduced that people travel more when they get cars, that private and public transport are alternatives between which travellers can be switched by changes of costs and level of service, and that all members of car owning households have the choice of car travel when they need it. More recent studies of urban travel and transport experiments are suggesting that these early concepts were not wholly correct, and that they could lead to transport investment decisions that would not achieve the results desired.

Number of trips

There is growing evidence that provided all trips are counted, including short walks, then the number of trips per person per day is stable over time and is only slightly affected by car ownership. It is, however, influenced by the employment category (employed, retired, housewife, student) of the persons concerned.

For example, Figure 1 shows the variations of household home-based trip rates with household size and car ownership, based on surveys in the town of Reading in 1962 and 1971 [1]. Trip rates have changed little with time, are almost linear with household size and only vary by about 2 to 3 trips/day between no-car households and multi-car households.

Similarly, Table 1 gives the variations with car ownership of the total number of journey stages [1] per day by all modes by different groups of people. It can be seen that the rate is almost invarient with car ownership for employed persons, but not for retired people, housewives and "others". The number of journey stages per person per day (about 4) is rather higher than the number of trips implied by Figure 1 (about 3). This difference is due to differences of definitions and the inclusion of non-home-based journey stages in Table 1.

Table 1 - Total number of journey stages per day per person by all modes (including walking)

Employment category / Cars	Full Time	Part Time	Retired	Housewife	Other	Total Population
0	4.87	4.34	2.21	2.43	3.50	3.58
1	4.76	4.35	3.09	3.02	4.12	4.24
2	4.89	4.29	2.83	3.76	4.66	4.55
3+	5.10	4.69	2.88	3.55	5.33	4.75
All Car owning	4.79	4.34	3.06	3.13	4.27	4.30
TOTAL	4.82	4.34	2.43	2.76	3.88	3.98

(Source, National Travel Survey 1972/3)

Goodwin has shown that the number of stages per day does not vary much with the population density of the travellers home area (Fig 2), but the variations in the number of stages by each mode and total distance travelled are significant and systematic [2]. The lower the density, the more cars are used and the greater the total distance travelled.

Travel time budgets

There is some evidence that the total time a person from a particular employment category (employed man, housewife, retired) is prepared to spend travelling each day is rather constant. Zahavi has shown this for vehicular travel in the USA [3], and Bullock has found that in a British town travel time was relatively unaffected by car ownership (see Table 2), although in this instance car ownership did affect the number of trips [4].

Table 2 - Total time per day spent in travel (survey in Reading, 1973) (hours)

	Men	Employed women	Housewives
With car	1.59	1.47	0.81
Without car	1.51	1.42	0.93

In Britain the total travel time per day does not vary much with the population density of the traveller's home area, but an analysis by Goodwin of National Travel Survey data does suggest that travel time is a little higher for car owners than non-car owners, and that it increases with increasing income up to an income of about £ 1500 per person per year (Fig 3). There is some variation with age, but this appears to be largely due to variation with age in the distribution of employment categories [2].

There is some evidence also that people choose the distance that they are willing to travel on the basis of the time it takes using the most convenient mode available to them. The travel time to different activities is more constant than is the travel distance, and travel distances by different modes appear to be adjusted to keep the travel time approximately the same (Fig 4) [5].

Trips by different modes and for different purposes

When all trips, including short walks, are recorded it is found that walking accounts for some 41 per cent of all journeys in Britain [5]. When the modes used for different trip purposes are compared it is found that trips to work and for social purposes are most likely to be made by car, while trips to school, to shopping and for day trip/play are most likely to be made on foot (Table 3). This is not surprising - most of these latter journeys are made by women and children who are relatively unlikely to have

Table 3 - Modal Split for Each Trip Purpose (per cent)

Trip Purpose / Modal Split	Train/ Tube	Bus	Car	Bicycle	Walk	Motor-cycle	Total	Proportion of *all* trip purposes
Work	4.5	20.4	45.3	5.4	22.0	2.5	100	20.8
In course work	1.8	4.5	79.6	0.8	12.8	0.4	100	3.8
Education	1.1	18.0	10.2	3.1	67.4	0.2	100	9.9
Shop	0.5	13.7	27.4	2.2	55.8	0.3	100	10.2
Personal business	0.8	10.9	44.3	2.0	41.4	0.4	100	7.8
Eat/drink	0.7	7.1	41.5	0.4	49.7	0.7	100	4.1
Entertainment	1.1	16.7	46.0	1.6	33.6	0.9	100	4.6
Social	0.9	11.5	51.8	2.6	32.3	0.9	100	14.2
Day trip/Play	1.0	3.5	28.1	2.7	64.5	0.3	100	5.9
Escort	0.4	3.2	66.2	0.4	29.6	0.3	100	5.9
Other	2.0	9.9	52.6	3.9	31.1	0.5	100	2.8
All purposes	1.6	13.2	40.7	2.8	40.9	0.9	100	100.0

Source: National Travel Survey 1972/3

the use of a car. The journey purpose for which the bus is most likely to be used is work, but even for this it only carries 20 per cent of all trips. The three modes, bus, car and walk, together carry over 94 per cent of all trips in Britain. The majority of trips are short, with 50 per cent less than 3 km, 70 per cent less than 6 km and 90 per cent shorter than 16 km. As would be expected, shopping and education trips are shorter in distance than work and social trips, though the difference in travel time was not large (Figure 5).

Table 4 - Driving Licence-holding by age and sex

Age group	Per cent holding licence in 1965	1972/73
Male		
17-20	29	35
21-29	60	72
30-39	68	79
40-49	62	74
50-59	54	68
60-64	41	60
65-	19	31
All 17 or over	50	63
Female		
17-20	6	13
21-29	15	32
30-39	18	34
40-49	13	27
50-59	9	19
60-64	6	10
65-	2	4
All 17 or over	10	21

Notes 1. National Travel Survey data
2. Data refer to full licences for driving cars

Availability of private cars

In Britain at the present time there are 0.25 cars per person, or 0.34 cars per person old enough to hold a driving licence. 45 per cent of households do not own a car, 45 per cent own one and 10 per cent own two or more cars. Ownership varies markedly with income and socio-economic group; the probability of the households of managers or professional workers owning a car is about twice that of the households of semi- and unskilled manual workers. About 63 per cent of adult males held a driving licence in 1972, compared to 21 per cent of adult females. Within each sex the numbers holding driving licences varies considerably with age (Table 4) and also with the socio-economic group of the household. Overall there are about 1.3 driving licences per car. When cars are available they tend to be used by male members of the households, and to be used for work journeys and for social purposes rather than for school or shopping trips. There is thus a number of identifiable groups of people who either do not have the use of a car at all, or do not have one without making complicated arrangements. The travel needs of these groups are largely met by the use of buses and walking; Table 5 shows that lifts in non-household cars only account for some 6 per cent of all journeys by people in non-car owning households.

Table 5 - Travel by bus, as a car passenger, and on foot. Percentage of journey stages made by each mode. (NTS 1972/73 seventh day - short walks included)

Household cars	Local Bus			Passenger in Non-Household car			Passenger in Household car			Walk		
	Men	Women	Child.	Men	Women	Children	Men	Women	Children	Men	Women	Children
0	17	19	13	6	7	4	0	0	0	60	69	77
1	4	9	6	3	5	4	2	17	19	33	52	61
2	1	5	6	3	5	4	3	14	29	27	36	49
3+	2	4	0	3	9	7	3	13	36	24	39	43
All Car owning	3	9	6	3	5	4	2	17	21	32	49	59
TOTAL	8	13	9	4	6	4	1	9	13	42	58	66

Choice between public and private road transport

It appears that, except in the larger cities, very few people use buses from choice, and many do not use them at all. Table 6 shows the proportions of people of different socio-economie groups [2] who did not use a bus during the week of the 1972/73 National Travel Survey. Overall, 58 per cent of the population did not use a bus even once during the week.

Table 6 - Percentage of each SEG who did not use a local bus during the week of the NTS 1972/73 survey

SEG category	Men	Women	Children	Adult total	Total
A (Senior non-manual)	80.0	61.7	67.5	70.9	70.0
B (Junior non-mánual)	70.1	46.1	60.8	56.7	57.5
C (Skilled manual)	65.9	44.7	60.8	55.5	56.9
D (Unskilled manual)	56.9	37.1	53.2	47.0	48.4
Total	67.8	46.9	60.8	57.2	58.0

Table 7 - Diversion from car to bus

Service	Percentage of car occupants diverting to bus	
	Car drivers	Car passengers
Dial-a-bus (Harlow)	0.5%	2.3%
Dial-a-bus (Dorridge & Knowle)	0.7%	2.3%
Subscription service (Stevenage)	3.0%**	9.0%**
Subsidised conventional service (Stevenage)	8.0%**	20.0%**
Park and Ride (Oxford)	5% (7% in peak hour)	
	Diversion from complete car trip	Diversion from car previously used for access to station
Rail feeder (Formby)	0.9%*	9%*

* Work trips only.

** Work trips only. Percentage is given in terms of car trips to same destination as that served by bus.

Several experimental bus services have been provided in Britain in recent years to determine the potential for attracting passengers to public transport. These experiments have covered subsidised, high-frequency, conventional services; dial-a-bus; rail feeder services; park and ride services from peripheral car parks and subscription services to employment centres. In addition, one New Town has a segregated bus-way along which houses are clustered. This allows the provision of an exceptionally high level of service.

One of the conclusions from these experiments is that although it is possible to attract passengers on to new bus services, very few of these use the bus instead of a car. The two dial-a-bus experiments each attracted about $1/2$ per cent of the car driver trips and $2^1/2$ per cent of the car passenger trips that potentially could have transferred to bus. Other experiments using subsidised conventional services and park-and-ride services attracted a few per cent of the potentially transferable car trips (Table 7). The reason for this inability of buses to attract passengers from cars is almost certainly that on any measure - travel time, generalised cost, or even marginal money cost - the best practicable bus services are much less attractive than the private car.

Other factors

People are extremely good at modifying their travel to make the best use of the opportunities available to them. Thus if congestion occurs, then the times at which some journeys are made will be shifted to less congested times. Journey times are also shifted to allow car-sharing, and journeys for different purposes are combined into multi-purpose, multi-leg trips. Destinations may be changed, and in the long term people will move home, if travel on journeys which must be made regularly becomes too difficult. These complex effects are not covered to any significant extent by transport models at present in use.

TRANSPORT MODELS AND THE REAL WORLD

Definition of a model

The word "model" is used to describe an approximate representation of a part of the real world by a set of mathematical equations. These equations require an input in the form of various descriptive parameters of the part of the world being examined; in a transport model these would normally be quantities such as travel costs and times, levels of car ownership, and the distribution of population and activities. Some of these input parameters, such as future levels of car ownership, may in turn have been derived from the output of other kinds of model. The outputs from the equations that comprise the models are of two types; those that are, in principle, directly observable and which therefore can be checked experimentally, and derived results which are intrinsically not directly observable and so can only be estimated by the use of a model. Examples of the first type are trip numbers between various places and modal split; and example of the second type is the estimation of benefits resulting from a change in the provision of transport.

The word "model" has frequently been used to refer simply to the set of mathematical equations, but it is felt that this usage is too narrow and that the definition of a model should include a description of its overall concept. An important practical point is to keep a transport model as simple as possible in order to reduce the computational effort required to obtain the desired outputs. It is of course pointless to strive for apparent accuracy which is better than that of the input data. Simplicity is also desirable so that it is possible to retain a clear view of the fundamental concepts on which the model is based, and to ensure that all the implicit assumptions and approximations remain valid in any particular application.

Calibration

With current knowledge it is not yet realistic to construct a transport model entirely from theoretical considerations. All models therefore contain a number of arbitrary constants, the value of which must be found by a calibration process. In practice the mechanics of this are usually complex and involve much statistical theory, but in principle the process consists of adjusting the various constants in the model until, when values for the input parameters which represent the existing situations are inserted, it produces results that agree closely with the conditions known to exist.

There is a natural tendency to equate goodness of fit with goodness of model, but the aim of the model is not to describe an existing situation, which can be done adequately by a survey without any need for a model. The aim is to predict what will happen in some future situation when the input parameters are changed. A complex model may well calibrate to describe an existing situation, but totally fail to predict; experience in other fields suggests that the more complex the model the more likely is this to be the case. An important practical point in model design is that the input parameters should be confined to items for which the values can reasonably be forecast for as far into the future as predictions will be required. Many of these difficulties could be reduced or avoided if calibration could make use of time series data; in practice to date transport studies have used a single survey and calibrated their models on cross-sectional differences.

Philosophy of predictive modelling

In the Introduction a broad distinction was drawn between transport models based on the decision processes of individuals or small groups of people, and models based on broad empirical relationships which appear to be stable over time, and constant or predictable between different communities. Most conventional transport models are related to the first method, but use data aggregated and averaged over fairly large groups. Category analysis trip generation models belong to the second group.

The other major division in modelling concepts is between those using empirical curve fitting methods and those based on behavioural hypotheses. The empirical method (various forms of regression or classification analysis) effectively takes the input parameters which could reasonably be expected to have an influence on the output results, postulates some functional relationship between input and output, and then carries out a multiple regression or classification analysis in order to evaluate the arbitrary constants in the functions and determine the relative importance of the various input parameters. The method has been used successfully when predicitions have involved relatively minor changes in the input parameters, but cannot always be considered reliable where major changes in the scenario are involved.

The behavioural hypothesis method involves certain assumptions about human behaviour, and using these as a foundation on which to build up a theoretical structure until a complete transport model evolves. The behavioural constants of the model will stil require calibrating, but the potential advantage of the method is that once evidence has accumulated that the initial assumptions or theories appear to fit the real world, then a model developed in this way can be extrapolated to new and untested situations with much more confidence than one developed by empirical methods. The method has not been used much in practice, though recently it has been used successfully in the development of new modal split models to deal with the problems presented by the existence of more than two main modes.

As in many fields of science, the empirical projection of observations is being succeeded by theories that attempt to represent mathematically the pattern of the observed data. There is as yet little sign of progress in the further stage of determining the physical or psychological laws that are the actual cause of the observed patterns. (In the field of astronomy, for example, the fitting of a complex set of circles and epi-cycles to planetary orbits was succeeded by the appreciation that they were actually ellipses. This in turn was succeeded by the theoretical prediction of orbits using Newtonian mechanics and the law of gravity). If progress in the direction of greater fundamental understanding is possible, it should initially reduce the amount of data needed to build a model and increase the transferability of a model from one place to another; ultimately it could permit the construction of transport models on theoretical grounds alone.

It is not suggested that the behaviour of human beings can be explained by laws as simple as the inverse square law of gravitation. Any behavioural law must be statistical and be limited to predicting the average behaviour of a large number of people, since there is no suggestion that it will ever be possible to predict the behaviour of a particular individual. A statistical method has already been applied with some success to problems of modal split and trip distribution. In these applications it has been possible to draw conclusions on traveller's behaviour by making very simple assumptions about their decision making processes, and about the variability in their perception of travel costs. The step that has not yet been taken is to link assumptions on behaviour with observations of broad empirical relationships which are relatively invariant with time or location.

Current experience of predictive modelling

Since 1962 some 100 transport studies have been made in Britain for areas with populations between 10,000 and 8,800,000. It is only now that sufficient time has elapsed to allow an assessment to be made of the predictive accuracy of the earliest studies, and in practice comprehensive assessments of complete studies have not yet been made. The accuracy of parts of the transport modelling process have been checked individually by TRRL, and some of these are mentioned below. Similarly, some examination of the results of studies for complete urban areas have been made by the local authorities concerned (notably the Greater London Council), but these examinations have been largely for their own use and have not been published. Inevitably, repeat surveys tend to be used to update transport plans rather than to look back to previous studies.

The TRRL forecasts of car ownership that were based on data up to 1960 have to date been justified by events (Figure 6). Forecasts issued in the mid- to late- 1960s tended to overestimate the actual growth of car ownership. The most recent forecasts, [8] issued in 1975 and based on data up to 1972, predict a range of levels of car ownership within which current levels still lie.

A study has been made of the stability and forecasting ability of trip generation models [1]. An initial travel survey of the town of Reading in 1962 was followed by a repeat survey in 1971. The results of the 1962 survey were used to predict zonal trip generations in 1971, and the estimates were then compared with the actual measurements. Good agreement was obtained, demonstrating that the trip generation model was stable with time, at least over a nine year period. It was also demonstrated that trip generation was not sensitive to the location of a household within the town.

The accuracy of a conventional modal split model has been tested by using it to predict the patronage on an experimental dial-a-bus service in Harlow. The actual effects of the bus service were measured by comprehensive surveys, and were compared with the predictions [6]. Considerable care was taken to make the model represent the real world as accurately as possible, and the results were surprisingly good in terms of the number of trips predicted for different times of day and different purposes. However, the total ridership (by travellers included in the model) was overestimated by about 30 per cent, and the proportion of trips diverted from existing car use was also overestimated. Another comparison of the predicted and measured patronage of a bus service has been made by Papoulias and Heggie for a park-and-ride service in Oxford [7]. Again, the prediction overestimated the actual patronage by between 20 and 30 per cent, while achieving a reasonable representation of the distributions of trip purposes.

TECHNICAL PROBLEMS OF CURRENT MODELS

In this section of the paper a range of current problems in transport modelling is discussed. Although these are of necessity considered as a number of separate topics (not necessarily in order of importance), it should be understood that in practice many of the problems are related and may be part of the same fundamental difficulties.

Trip generation

From a theoretical standpoint the trip generation sub-model using disaggregated household data can be considered as one of the most satisfactory components of current transport models, though one in which many detailed developments are still being made. As already indicated earlier total trip generation rates appear to be stable with time and to be almost invariant to household data other than employment status. It must be stressed that this only applies when walk trips are included in the total, and that the split between different modes can vary markedly with circumstances.

The practical problems of trip generation modelling are concerned with the form and structure of the disaggregated model, and the difficulty of forecasting the planning inputs to the model. With regard to data handling, for example, it is still not clear whether it is better to base the model on households or individual persons. Recent work suggests that it should be possible to reduce considerably the size of survey required to estimate trip generation rates. The problem of forecasting planning inputs in terms of the future number of households in an area and the distribution of household types is a serious one, as errors in the predicted total number of trips made is directly proportional to errors in predicting the number of persons available to make trips. Further consideration of this problem is outside the scope of this paper.

Interaction between modal split and trip distribution

As well as the problem of trip generation (shall I go somewhere?), transport models are concerned with questions of trip distribution (where shall I go?) and modal split (by what mode shall I travel?). Some models treat these last two problems sequentially, while others carry out both calculations in a single stage. Both methods give rise to problems, and it is doubtful whether either is a very good representation of the actual decision making process of individual travellers. One of the complexities of the real world is that this is not necessarily even the same for different types of trip. For trips to work the distribution pattern can be considered as fixed, at least in the short term, and the only choice open to the traveller is the selection of travel mode. For non-work trips, on the other hand, the choice of mode may well be restricted, but there may be a wide choice both of destinations and of times at which the trip can be made.

One current suggestion [2] is that in many travel situations choice of mode may be more restricted than it is represented to be in most transport models, and that the apparent modal split seen in the real world is in fact simply the effect of overlapping trip distribution patterns of several different populations of travellers, each of which is constrained to using a single specific mode. Another possibility is that trip destinations are selected on the basis of the door to door travel time by the quickest mode that is economically available to the traveller. [5]

The practical effect of this may be very significant when an attempt is made to influence modal split by deliberately altering the characteristics of one or more modes. If modal choice and trip distribution are linked, as appears to be the case for many trip purposes, then either the actual change in modal split will be less than that predicted by most models, or associated changes in trip destinations will occur.

Red bus/blue bus - the multi-mode problem

Various methods have been devised to extrapolate the well established two mode modal split model to cater for more than two modes. Unfortunately these mostly fail to overcome the red bus/blue bus anomaly. This is the colloquial description of a defect of multi-mode models which causes them to give results which vary as the way in which the competing modes are described varies. For example, consider a particular journey for which a conventional model predicts that the two modes, train and bus, each attract half the travellers. If the front doors of the buses are painted red and the rear doors blue, and the buses are regarded as two modes (red bus and blue bus, depending on which door is used), then the same conventional modal split models applied to the three modes would predict the bus patronage as 2/3 of the travellers (1/3 red bus, 1/3 blue bus) and the rail patronage as 1/3 of the total. This superficially trivial example shows one way in which the results from conventional modal split models can be altered by factors which in reality would have no effect on modal choice. Indeed, it is only a specific example of the more general difficulty, that the results from these models are sensitive to rather detailed assumptions, such as whether the choices between several modes are made simultaneously or sequentially, and if sequentially, in what order. Recent work has clarified the cause of the red bus/blue bus problem and has produced models which successfully overcome the anomaly [9,10,11].

Availibility of different modes

As described in section 5.2 above, evidence is growing that the choice of modes available to a traveller is probably not as wide as is usually assumed. It is now known, for example, that knowledge of whether or not a traveller lives in a car owning household is a poor guide as to whether the car mode is actually an available choice for any particular trips. Similarly, bus travel is not realistically available to some motorists because of lack of knowledge of routes and time-tables. There are many other complex interactions between different travellers and different activities that can affect the availability of travel mòdes to any specific individual.

Walk and cycle modes

Until recently walk and cycle trips have generally been omitted from transport studies. This has been partly because of their presumed lack of importance, either as a section of the transport system or as a determinant of road capacity, and partly because of the difficulty of including them within the existing modelling framework (because of the multi-mode problem). It is now realised that they make up a very significant part of the total urban movement pattern, and that for short distance trips they are important competitors with public transport. For example, diversions to or from the bus mode following changes in service levels or in fares are likely to be mainly with walk or cycle trips, with very little diversion from or to the car mode.

The value of time

This appears in models in two ways. The first is the "behavioural" value of time, and represents the trade off that an individual is prepared to make between time and money costs of travel, while the second is the "social" value used in benefit evalution, which represents society's valuation of time saving in money terms. There are considerable doubts about how one should measure the behavioural value, how constant it is for any particular individual under different circumstances, and whether the spread of time values for different individuals is important and should be included as a modelling parameter [12]. In any case, it appears that the behavioural value of time derived from the calibrations of actual transport models is a proxy for a complex set of factors, so it is not surprising that the values deduced from simplified observations vary considerably.

The connection between the behavioural value perceived by the traveller and the social value poses difficult questions of equity, and in the end must be based on political judgement. Different organisations have taken different views on this.

Compatability of demand and benefit estimation models

As mentioned briefly above, a major problem in estimating the value of benefits arising from transport changes is that these cannot be actually measured on the ground; they can only be estimated in terms of the output from some form of model. It is much less easy to check that the model is producing the right result than it is for an output such as trip distribution or modal split which can at least be checked by comparison with observations of the real world at the model calibration stage.

It is therefore particularly important to ensure that the model is internally consistent, so that the benefit estimation process is, as far as possible, consistent with the methods used to estimate trip distribution and modal split. This has not always been the case with models used in the past.

It is also important to check whether, in any particular case, the estimation of benefits is sensitive to details of the methods of calculation used. Some calculations have been found to produce estimates of benefits (which cannot be checked) which are much more sensitive to small changes of assumptions or methodology than are the outputs such as patronage.

Interaction between transport supply and land use

When a traditional transport model is used for the prediction of future traffic levels it is usual to assume a certain pattern of future land use which is fixed regardless of the transport supply. This is in fact very different from the real world situation, where land use and transport supply interact closely with each other. In order to study the social and economic effects of various land use and transport policies, it is desirable to develop a dynamic transport/land use model which includes the effects of these interactions. Although several such models are in use in the USA, they have not yet been applied to any significant extent in Britain.

Spatial and temporal stability of models

The use of transport models for predicting future travel patterns involves an implicit assumption that the basic model and its calibration constants are stable with time. There is no reason to suppose that this assumption is untrue, but apart from the work on stability of trip generation models already referred to, there does not seem to have been much work done to investigate the matter.

The question of spatial stability is significant for both practical and theoretical reasons. In Britain almost every transport study carried out to date has involved an independent survey and calibration. Several different transport models have been used, which makes it difficult to compare the calibration from different areas. Even in cases where the same models have been used the calibration constants have been different between areas. In only a few studies (aspects of the West Yorkshire study, for example) has it proved possible to use calibrations from one area in models for another area. Spatial stability and potential transferability does appear to occur for trip generation, but has not yet been demonstrated for trip distribution. Some modal split expressions have been transferred from one model to another, usually when local data have not been available. There is at present little indication of whether the apparent variation of calibration constants reflects real differences between geographical areas or simply differences, between studies, of the model details and the choices of zone sizes and zone patterns.

The development of models that could be transferred from one area to another would be an important practical step towards cheaper and quicker transport studies. Such a development would also greatly increase confidence in the predictive abilities of models, for if they could be transferred successfully from one area to another it would be much more likely that their calibrations would still apply to the area being modelled when it has experienced the changes that the passage of time brings.

FUTURE IMPROVEMENTS IN MODELLING

Possible approaches to improvement

In this paper three possible ways of improving the art of transport modelling have been identified. The first is to take the existing conventional transport model as a basis and improve it to remove some of the current problems. The second is to extend the conventional model to enable it to answer new types of question, such as the interaction between land use and transport and the overall effect of changing long term policy in either field. The third is to take a completely new look at the problem, to see whether the conventional model provides the best method of providing information to aid policy decisions, or whether some radical new approach to modelling might be preferable.

These different approaches need not necessarily be viewed as exclusive alternatives. While the third approach may be a desirable long term objective, work on the first two is undoubtedly necessary to give immediate improvement to our forecasting methodology, and probably also forms an essential input to a proper appreciation of how to develop the necessary items to make the third approach practicable.

Improvements to the conventional model

(i) *Modal split models.* Understanding of the problems of estimating modal split between more than two modes has been improved by recent work at TRRL [9,10] and LGORU [11]. This has led to a new concept of multi-mode modal split models which fundamentally eliminates the red bus/blue bus anomaly. It has also provided further insight into the relationship between trip demand modelling and benefit estimation. The new model is based on consideration of the distribution of perceived costs (time and money, for travel by each mode) among different potential travellers, and the assumption that each traveller chooses the mode which, in his perception, provides the cheapest journey. The method originally developed at TRRL involved quite complex mathematics and lengthy computation, but it was subsequently shown that a very close approximation could be obtained by a relatively simple modification of the conventional logistic modal split model. The two-mode modal split model used in most conventional transport models is in fact a special case of this new, more general model.

Work is in progress on further developments of the concept to include the effect of distributed perceived values of time and other effects. It is hoped that this will help to solve problems occuring in the inclusion of walk mode in transport models, and in situations where two classes of travel are provided in a single vehicle.

(ii) *Combined modal split and distribution models.* It may be possible to extend the concept of models based on the distribution of perceived costs, to produce a combined modal split and trip distribution model. Cochrane [13] has already demonstrated a derivation of the conventional "gravity" trip distribution model using the concept, and Goodwin [2] has produced new ideas on trip distribution using the same basic concept, though not yet in a form usable in practical models.

(iii) *Estimation of car avialability.* It now appears that this is a major factor in the estimation of modal split between car and other modes. The Telford Transportation Study is an example of a recent attempt to include a better method of estimating car availability [14], with promising results. Interesting work in this field has also been carried out at the Cranfield Institute of Technology [15] and at the Transport Studies Unit of Oxford University (not yet published). It is clearly time to put major effort into this problem, and also into investigating practical problems of availability, or lack of availibility, for other modes; for example, is bus a practical mode for a mother shopping with young children?

Further uses for the "conventional" model

Various attempts have been made to bring land use effects into transport modelling, but much more work is needed before it will be possible to model the dynamic interactions between land use and transport supply [16,17]. The difficulties are both theoretical and practical. On the theoretical side the problem is the scale and complexity of the interacting systems which have to be considered, while on the practical side there is a shortage of data covering the time span required to calibrate and verify a dynamic model. Results in this field are mostly produced either on the basis of a step-by-step approach in which various sub-systems are developed in detail before the overall synthesis is attempted, or on the basis of using very simplified models of sub-systems, which in some cases may be thought to lack plausibility. In view of the tentative nature of work at present in progress in Britain it is not proposed to comment further in this paper.

Another obvious extension of the use of conventional transport modelling is to examine the transport energy and other resource implications of various transport and land use policies.

New approaches to transport modelling

A recent development is the extension of the use of disaggregated data from the modelling of trip generation to the modelling of trip distribution and modal split. Such a model uses data at an individual or household level directly in the calibration process. This preserves the inherent variability of the data within a zone, which is lost when the zonal data is aggregated in conventional models.

Although disaggregated data has been used for model calibrations, when the model is used for predictive purposes this is usually done on a zonal basis, and input data for the model is supplied in aggregated form. Since the model calibration was made with disaggregated data, the variability within the zone of the input data has to be included in the prediction process. Where this intrazonal variability is important it can be represented by a statement of the statistical variation to be associated with the mean values of the inputs.

As well as allowing the modeller to get closer to the decision processes of individual travellers and so, hopefully, to produce a more accurate model, the use of disaggregated techniques is claimed to considerably reduce the amount of data needed for model calibration. It is not yet known whether the use of disaggregated techniques will produce model calibration constants which have less variability than those from conventional models. A thorough examination of the relationships between disaggregated and zonal models might well lead to a better understanding of the effects on calibration constants of changing zone size and distribution.

A disappointing feature of all current transport models, which the current disaggregated approach appears to have changed only in the case of trip generation, is that they neither predict nor make use of the invariant factors in actual travel patterns [3]. Any new form of transport model should take greater account of the various constraints which face real travellers than has been done in existing models. To achieve this it may well be necessary to break away completely from the traditional modelling framework, and make a fresh start. If it proves possible to develop the necessary mathematical tools to build such a new model, it is likely that under some circumstances its numerical predictions would closely approximate those produced by the current models. Indeed, one of the values of a model that accurately represents many aspects of the real world is to indicate which studies require sophisticated modelling and for which the simpler conventional models would be satisfactory. Eventually, it may become possible for much of the calibration to be done on a theoretical basis with only a limited requirement for local surveys: an interim stage would be to develop models which can be transferred from one area to another.

CONCLUSION

This paper has described the sort of trip patterns observed in the real world, and discussed some of the problems of transport models in both reproducing the current real world situation, and predicting future changes in personal movement. It is concluded that, while there are various problems in the existing models, they can in many cases usefully be used for prediction, provided that the changes between present and future are not too great.

However, deficiencies have been revealed in some areas, such as in the predicted substitutability of bus for car when car restraint is applied. Also, due to the lack of a solid theoretical basis, the reliability of prediction into the long term future must be suspect. A further cause for concern is that the models neither use nor predict some of the invariant factors in real world trip patterns, described in this paper, though a model under development at TRRL is using a fixed total number of trips.

Worthwhile improvements in the traditional type of transport model are currently being made, with the introduction of models using disaggregated data, and of new ideas for modal split modelling. However, even these innovations are to some extent only patching the existing model structures at the expense of added complications, and it is suggested that the time may be coming for more radical new approaches to modelling. These should be based on two concepts. The first is a mathematical approach on the traveller's decision making processes, including all the real world constraints applied to individuals; the second is the incorporation of the invariant factors in trip patterns, discovered by suitable analysis of survey data. There is probably a close connection between these two concepts, which the new models should try to exploit. Within the broad framework fixed by these concepts, an attempt should be made to tailor transport models more precisely to answer the questions actually posed by transport planners, without wasting time and effort on unnecessary complexity, irrelevant to current problems.

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FOOTNOTES

[1] Different surveys use different definitions of units of travel, and this can affect the numerical values of results. The definitions used in the surveys quoted above are:
National Travel Survey: Journey - Any travel for a single main purpose Journey Stage - A sub-division of journey required for each change in the mode of travel or each new ticket needed.
Reading Surveys: Trip - any travel for a single purpose.

[2] Socio-economic group is a classification based largely on the occupation of the head of the household.
Category A - SEG groups 1,2,3,4,13. Employers, managers, professional workers.
Category B - SEG groups 5,6,7. Intermediate & junior non-manual, service workers.
Category C - SEG groups 8,9,12,14. Foremen, skilled manual, self-employed manual.
Category D - SEG groups 10,11,15. Semi- and un-skilled manual, agricultural.

[3] A model under development at TRRL by Webster includes an invariant number of trips.

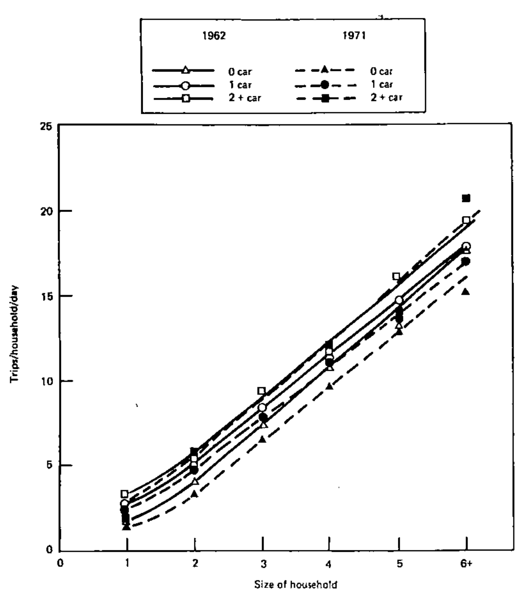


Fig. 1 - Household mean daily trip rates for all purposes by all modes (including walking)
(Source - Travel Surveys in Reading, 1962 and 1971)

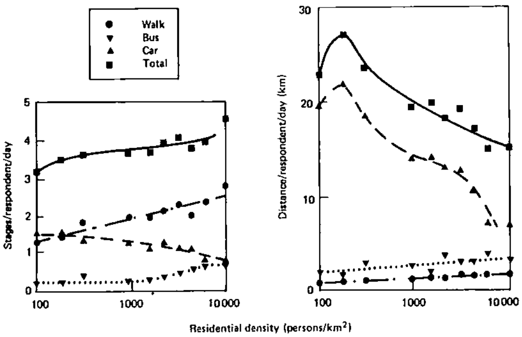


Fig. 2 - Variation of travel with residential density (National Travel Survey 1972/3)

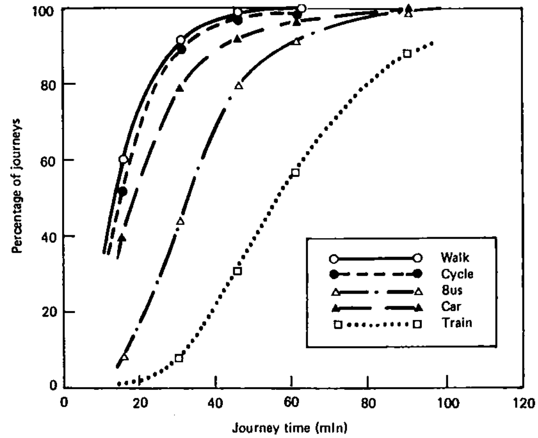


Fig. 4 - Cumulative distribution of travel distance and time for journeys to and from work (National Travel Survey 1972/3)

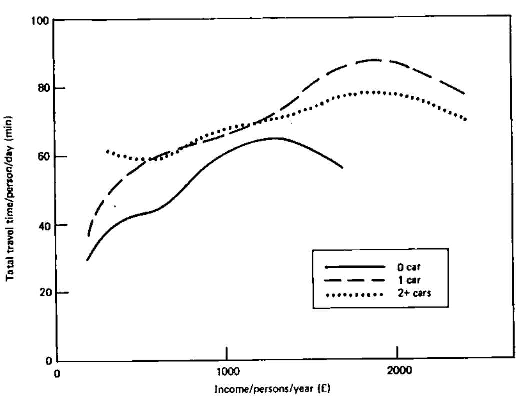
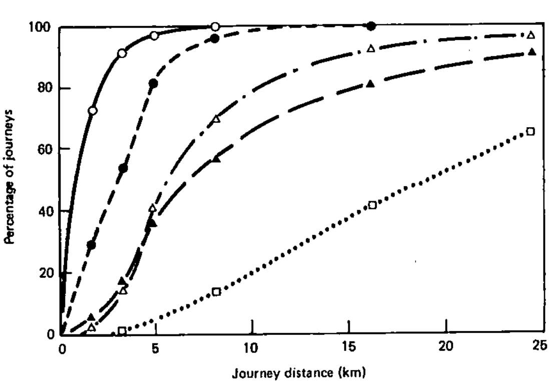


Fig. 3 - Variation of total time spent travelling with income and car ownership (National Travel Survey 1972/3)



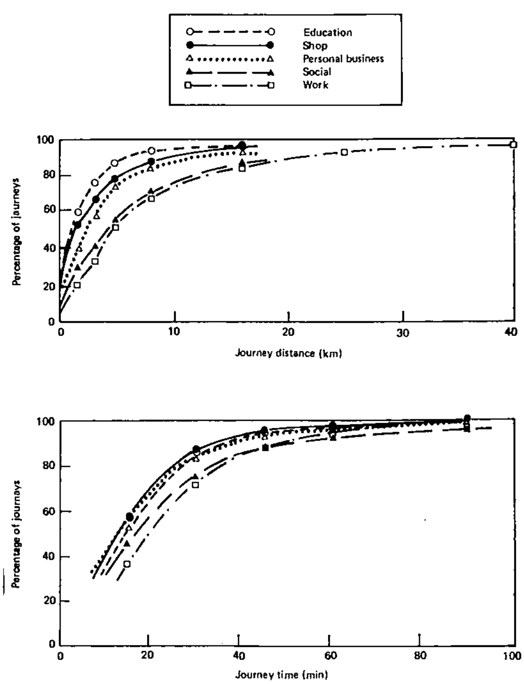


Fig. 5 - Cumulative distribution of travel distance and time for several journey purposes (National Travel Survey 1972/3)

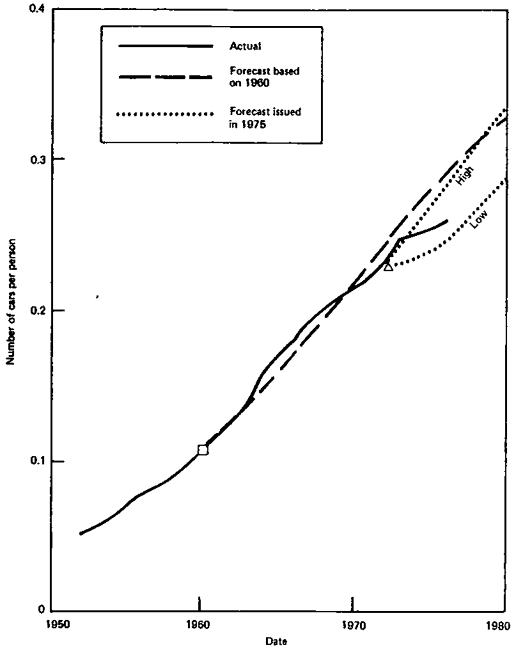


Fig. 6 - Comparison of forecast and actual numbers of cars per person in Britain