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A MODAL SPLIT MODEL FOR LONG DISTANCE TRAVEL

by

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ABSTRACT

A modal split model is put forward that contains a description of the transport system available for long distance trips between a set of regions. Each journey is treated as being of three parts: 1. access: the departure from a specific origin area in one region to an access point to a main haul mode between the regions: 2. main haul: the trip between the two regions on a specific mode: 3. egress: the last leg of the journey, from the terminal in the city region of the destination to the destination itself. A simplified network model has been constructed on this basis, and contains a geographical representation of the transport alternatives. Every link in this network is a different alternative method of travel between the points it links, and the travel time, waiting time, and travel cost along that link summarises the main characteristics of the set of travel choices that it represents.

The travellers of a given income bracket are assumed to have a specified valuation of travel time, and the generalised (time and money) cost of a trip along every given link will differ for each income bracket. The travel demand for each class of traveller is distributed over the different alternatives on the basis of the generalised cost, and all the classes of travellers summed to give the modal splits between the main haul modes.

This model is suitable for assessing the effect of introducing new modes of transport between the regions, and can also be used to assess the effect of different terminal sitings.

1. INTRODUCTION

The problem of forecasting or reproducing modal choice between different transport alternatives may be approached in a large number of ways, depending on the specific purpose of the study. The work reported in this Paper was required to simulate the changes in market shares that might be produced by the introduction of new or improved modes of transport operating over long distances between city regions. The model was proposed by Urban Transport Section, and the work was carried out in collaboration with the Transport Research Assessment Group (TRAG). The mode selection behaviour of the travellers is based on a generalised cost of a complete trip. This generalised cost includes both time and money costs, and by characterising each alternative mode in terms of travel time, fare, and frequency of service, ensures that the model can be applied as well to any future modes of travel as it can be fitted to the present range of modes. This type of model is well suited to the assessment of the operating economics of mixes of new modes by examining the effects of geographical and service characteristics on the market shares of each mode as a function of the fares charged.

2. MATCHING THE MODEL TO THE OBJECTIVES

The basic problem of any inter-city model is that a great deal of detail is usually required if any adequate geographical representation is to be achieved. Some measure of geographical detail is necessary as journeys are made from place to place, and not just (for example) from railway terminus to railway terminus. If any investigation of alternative terminal locations is to be made possible, journey origins and destinations must be differentiated from the termini of the main haul modes.

The model is concerned with passenger traffic, and it is therefore necessary to model the behaviour of various classes of traveller, taking into account all the information about each mode which they use in making their choices. In practice this must be limited to the two most important factors, namely the money cost and total time (including waiting time) of the journey, but in principle other factors such as comfort and reliability could be included if sufficient information were available to quantify their effect on modal choice. Frequency of service is a particular case of a factor which is believed to influence modal choice; it has an effect on the waiting time and is therefore included in the model to some extent, but the relationship is not fully understood.

It is taken as axiomatic that the factors influencing modal choice should not be mode-specific - for example, an irrational fear of aircraft cannot be included in the model. Unless this assumption is made the model cannot be used for forecasting the effect of a new mode such as a Tracked Hovercraft because it would not be possible to estimate its mode-specific features. In a general model this would be no limitation, because all factors influencing modal choice would be included. Taking the example above, one of the factors would be "element of fear", which would have a large value for aircraft and small values for other modes. The value of this factor would then need to be assessed for a new mode. In the limited case of a model confined to cost and time, neglect of other factors can cause difficulty because some groups of travellers appear to make irrational choices of mode, and it is necessary to make some allowance for this effect.

People in different income groups behave in different ways when faced with a possibility of saving time at increased cost, and if we are to be able to analyse the effects of different fare structures and service intervals by using our model, we must allow travellers in each income group to form their own individual choices based on their particular view of cost versus time savings. In a more general model it would similarly be necessary to make separate calculations for groups having different valuations of comfort reliability, etc.

These requirements define the form of our model:

(1) it must represent journey origins, journey destinations, and main mode termini separately and as distinct points;

(2) it must contain information on travel time, waiting time, and travel cost for each modal alternative for each part of a trip;

(3) the mode selection part of the model must respond to the views formed by different classes of traveller of the travel alternatives offered.

3. DESIGN AND CONSTRUCTION OF A SET OF GEOGRAPHICALLY-ORIENTED MODELS

The discussion of Section 2 showed that a large amount of detail would be required to represent adequately the travel choices offered between any specific pair of regions, and also that a considerable number of origin/destination areas (known as "zones") would have to be defined in each region. If a full (NxN) matrix of travel demands and trips made between these N zones were to be retained, the size of the problem would become unnecessarily large.

As we are interested only in trips between pairs of regions, we can eliminate all those elements of the matrix corresponding to trips between zones in the same region. This gives a very substantial saving in space when compared with other transportation network models covering both short and long travel movements in a single model, but it still retains a high level of geographical detail at the start and end of each journey without sacrificing information relevent to the inter-regional journeys.

In order to retain the necessary geographical detail each trip is broken down into three stages:-

Access: movement from the origin of the trip to a main haul terminus (which could be a motorway access point when considering car travel).

Main Haul:- movement between terminals of a main haul mode in the two regions

Egress:- movement from the main haul mode terminus in the destination region to the actual destination of the trip.

Each part of the trip may be made by different means, but in order to specify them for the model only the money cost, travel time and waiting time need be determined since, as already explained, the model does not include any mode-specific features. This representation of long-distance travel has also been used by other workers(1).

Fig. 1 shows the abstract 'model' view of two city regions linked by two main haul modes. In this illustration trips are made only between the city centres (denoted by circles), and the terminal points to the main haul modes are shown as squares. There may be many such terminals in each city region, and inside the city region there may be many different distinct ways of getting from the centre to any specific main mode terminal.

The model is built up from units of the type shown in Fig. 1 and thus forms a network consisting of access, main-haul and egress links, where every link has three characteristics (travel time, excess time and cost). There are two types of nodes: origin/destination zones and mode terminals. By splitting the journey into three constituent parts we no longer need to keep details of NxM journeys (between N zones in one city and M in the other), and need only retain details of T_N x T_M journeys (between T_N terminals in one city and T_M in the other) plus NxT_N and MxT_M journeys between terminals and zones. This again gives a substantia reduction in complexity.

The multiple city situation of Fig. 2 reduces to Fig. 1 for each pair of zones considered, and a specific route between main mode terminals can be specified. If we wished to generalise the network structure still further, we need only add links between terminals of different modes located in the same city, to allow for journeys involving more than one main mode. This extension was not used for the work reported here, however.

We have now reduced our multimodal geographical model to a manageable size, and have retained all the transport information that we need to operate a model of modal choice based on generalised cost. We have yet to represent the different groups of people and the trips that they wish to make. We carry a set of trip matrices for trips between zones in different towns and retain a different matrix for every income group that we wish to distinguish. These matrices are further broken down into business and non-business trips, and to those travellers who do and do not have a car available. In practice these last stages are difficult to achieve, as the quality of available data will not usually support this level of fine detail, and some averaging is necessary.

The modal choice procedure is carried out separately for each of these matrices. The reasons for this are:-

(1) the members of each income group and each journey purpose behave as if they valued time savings at a different rate;

(2) those without cars available do not have the choice of the car mode.

The effect of differing time valuations is to present a different balance between the fixed set of modal services offered, so that the travellers' view of the choices available to them must be re-evaluated for every trip matrix considered. For a given income distribution of travellers the matrix describing their trips must be further split into a matrix of business trips and a matrix of non-business trips.

The model compares the available routes from origin to destination on the basis of a generalised cost, which is a measure of the disutility to the traveller of travelling on the route. The generalised cost should in principle contain all the factors which influence a traveller in his choice of mode; these include money cost, journey time, frequency of service, comfort, possibility of returning the same day, and many others. Each traveller would then choose the mode offering the least generalised cost, but since different travellers would make different assessments of the relative importance of these factors not all travellers would choose the same mode.

In practice most of the factors are unquantifiable and there are insufficient data on which to base an evaluation of their relative weights in the generalised cost function. It has been necessary therefore to restrict the range of factors to the two most important, namely money cost and total journey time (including waiting time). Because of this limitation not all travellers choose the mode which has the lowest generalised cost as calculated by the model - for example, although it may be both quicker and cheaper to travel by rail, some travellers choose car because it is more convenient for carrying luggage or because they need a car at their destination.

To allow for this effect the model distributes travellers over the available modes by means of a relation which tends to allocate most travellers to the mode of least generalised cost but does in fact assign some to the other modes. The relationship which is used is:-

$$S_{ij}^{k} = \frac{\exp(-\alpha \phi_{ij}^{k})}{\sum_{r} \exp(-\alpha \phi_{ij}^{r})} \qquad \text{.......................} \qquad (1)$$

where:

k = modal selection for travel between i → j

i = origin of trip

j = destination of trip

ϕ_{ij}^{k} = generalised cost of trip from i to j via mode k

S_{ij}^{k} = share of the trips between i and j gained by mode k

r = dummy index for summation.

The parameter α characterises the degree of approximation in the calculation of generalised cost. As α tends to large values, the relationship above degenerates to a least generalised cost model.

This particular form of modal choice equation arises naturally from both discriminant analyses of modal choice[2], and also the entropy maximising models of Wilson[3].

Wilson deduced a trip distribution equation of the general form:-

$$T_{ij}^{k} = A_{ij} \exp(-\alpha \phi_{ij}^{k}) \quad \text{.......................................} \quad (2)$$

where A_{ij} is an accessibility and attractiveness variable which may depend on the characteristics of the available modes. T_{ij}^{k} is the number of trips made by mode k between i and j, and the modal split relation (1) above follows directly. A second result can be obtained by summing equation (2) for a set of modes K:-

$$T_{ij}^{K} = A_{ij} \sum_{k} \exp(-\alpha \phi_{ij}^{k})$$

$$= A_{ij}^{*} \exp(-\alpha \phi_{ij}^{*}) \quad \text{.......................................} \quad (3)$$

where $A_{ij}^{*} = N . A_{ij}$

and $\exp(-\alpha \phi_{ij}^{*}) = \frac{1}{N} \sum_{k} \exp(-\alpha \phi_{ij}^{k}) \quad \text{.......................................} \quad (4)$

N is the number of modes k in the set K.

Equation (3) is in the same form as equation (2) and shows that a set of modes can be represented by a single generalised cost ϕ_{ij}^{*} as defined by equation (4). This combination rule can be useful for example in determining an average cost of access from a zone to a terminal, so that it is not necessary to include every available access mode in the model. Furthermore, provided elements ϕ_{ij}^{k} have similar values, ϕ_{ij}^{*} is close to their arithmetic mean.

The combination rule can be applied one stage further, and a cost C_{ij} that characterises movements between i and j found by combining the ϕ_{ij}^{k} values for each main mode between k and j. This characteristic cost can now be used to estimate changes in travel demand that occur as a result of changes in the service provided, using a relationship:-

$$T_{ij} = D_{ij} (C_{ij})^{-\beta} \quad \text{.......................................} \quad (5)$$

Equation (5) represents a demand curve with constant elasticity β. The calibration constant D_{ij} is deduced from a specific case where the number of trips T_{ij} and the overall generalised cost C_{ij} are known, and the elasticity β is determined by observing the change in the number of trips caused by a change in C_{ij}. At the present time there is a lack of suitable measurements of changes in numbers of travellers, and any form of demand curve more complex than one with constant elasticity cannot be justified. The assumption of constant elasticity also simplifies the interpretation of the results of any economic assessment of changes in the level of travel demand (Fig. 6).

The complete model developed for this work can therefore be summarised:-

1. $$S_{ij}^{k} = \exp(-\alpha \phi_{ij}^{k}) \Big/ \sum_{r=1}^{n} \exp(-\alpha \phi_{ij}^{n}) \qquad \text{(1) (repeated)}$$

2. $$\exp(-\alpha C_{ij}) = \frac{1}{N} \sum_{r=1}^{n} \exp(-\alpha \phi_{ij}^{r}) \qquad \text{(4) (repeated)}$$

3. $$T_{ij} = D_{ij} (C_{ij})^{-\beta} \qquad \text{(5) (repeated)}$$

No great importance has been attached to these trip generation aspects of the modal choice problem, as the model was intended mainly for use to determine market shares, and was not set up to assess or predict the size of the market.

One disadvantage of the form of the model expressed in equation (1) is that the number of available modes must be specified. This can lead to difficulty when different services of the same mode are available, for example, train departures from different stations, as it is not clear whether such services should be represented in the model as separate modes or whether they should be included as a single mode with an averaged generalised cost derived from the combination rule (equation 4). A new mode such as vertical take-off and landing aircraft (VTOL) also presents the same difficulty, since it may be regarded as the same mode as a conventional aircraft or not, and different results are obtained in the two cases. No clear solution has been found to this problem which is due to the inclusion of a probabilistic element (the parameter α) in the model.

4. CALIBRATION OF THE MODEL AND APPLICATION TO EXISTING MODES OF TRANSPORT

The first calibration and subsequent application of the model was carried out on data obtained during 1969 for a long route between two city regions in the UK. The only information initially available was the modal split between rail and air for each income group, with no further detail on purpose of journey. This allowed a straightforward calibration of "α" to be made on the basis of valuation of time saving equal to the income rate.

The approximate calibration was used to gain experience with the model, and results from this work have been published elsewhere[4]. Wigan, in an unpublished Report, has described the technique used to set up the computer versions of the necessary models. The way in which the programming was organised allowed rapid modification and extension of the models in use, and provided a means of trading off numbers of origin/destination areas against other dimensions of the model. The amount of information that must be held for a given run of the model is very large, and with these facilities it is possible to use the same computer programe to study the different situations of interest.

When more detailed information became available, allowing us to distinguish between journeys made on business or otherwise, a better method of calibration (due to Dr. R.J. Balcombe) was worthwhile. Let us recast the modal choice equation (1) into the following form for two modes only:-

$$\log \frac{N_1}{N_2} = -\alpha(\phi^1_{ij} - \phi^2_{ij}),$$

where N_1 = number of travellers by mode 1 at cost ϕ^1_{ij}

N_2 = number of travellers by mode 2 at cost ϕ^2_{ij}.

Let us assume that the generalised cost ϕ^k_{ij} is a linear combination of its constituent parameters, i.e.

$$\phi^k_{ij} = a_1 x^k_{ij1} + a_2 x^k_{ij2} + \ldots..$$

where the x's are the parameters (cost, time, comfort, etc.) and the a's are weighting coefficients appropriate to a given group of people. The linearity assumption simplifies the analysis and need not give any loss of generality because the x's could be functions of the parameters, for example logarithms of cost and time.

With only two parameters (cost f and journey time t) the generalised cost equation can be written

$$\phi^k_{ij} = f + \lambda t,$$

where λ is a weighting coefficient expressing the valuation of time savings in money terms, and where the weighting coefficient for cost has been set equal to unity because the generalised cost is measured in money terms.

Thus

$$\log \frac{N_1}{N_2} = \alpha.\delta f + \alpha.\lambda\,\delta t \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (6)$$

where δf, δt are the differences in money cost and journey time between the two modes.

When the observed values of $\log (N_1/N_2)$ from the survey data are plotted as a function of household income (Fig. 3a), it is found that they approximate to two straight lines (one for business travel and one for non-business). An assumption consistent with this observation is that α is independent of income and λ is directly proportional to income and by comparing the observational lines with similar lines calculated from the model, the following values of α and λ can be deduced:

For business travel:

$\alpha = 0.088\ £^{-1}$, λ = £1.05 per hr per £1000 of annual household income

For non-business travel:

$\alpha = 0.31\ £^{-1}$, λ = £0.29 per hr per £1000 of annual household income

Although these values were deduced from two modes only, they are insensitive to any assumptions made about other modes. They were also deduced from data about travel on one particular route, and should not be applied indiscriminately to travel on other routes.

The reproduction of the market shares current at the time of the survey requires us to run the model for business and non-business travel for each income group, and for car-owning and non-car-owning travellers. The results obtained are shown in Fig. 3b. The current size of the bus market is the least precise of the data, but data and model are in agreement within this uncertainty. The car share is fairly sensitive to the value used for the perceived cost of car travel, and the procedure adopted was to adjust this cost until the number of car travellers predicted by the model agreed with that observed. The perceived cost thus obtained was 0.86 p/km per passenger.

By 1972 95% of the 'main haul' road route between the two regions will be served by motorways, and a simple illustration of the behaviour of the model is given in Fig. 3(c) by applying toll charges of various levels to each mile of motorway.

5. APPLICATION TO POSSIBLE MIXES OF MODES IN THE FUTURE

The model was calibrated as described in the previous section, using a network of 52 origin/destination zones in one city and 22 in the other, and with the travelling population divided into 14 income groups, for each of two journey purposes (business and non-business) and for those with and without cars.

A value of the elasticity-of-demand parameter was deduced from Evans' survey[5] of the increase in rail travel on the London-Midland line after electrification. A value $\beta = 1.9$ was obtained, but this is a very approximate result due to some deficiencies in the survey (it did not examine business and non-business travel separately for example). Furthermore the assumption of constant elasticity is really only justifiable when only small changes are contemplated, and the applicability of the trip generation function to cases where new modes are introduced is open to question.

Some examples of the application of the model to situations involving new modes are shown here. The market shares are quoted as a percentage of the market before the new transport proposal, and therefore because of the generative effect the final market shares add up to over 100% of the initial market.

Care must be taken that the value of β used is not too large, otherwise absurd effects can occur such as an increase in car travel due to a reduction in rail fares. This has not happened in the examples shown here however; the increase in car travel shown in Fig. 4 is due to a reduction in journey time produced by the opening of the M1 - M6 motorway link.

Fig. 4(a) shows the effect of upgrading the rail service to provide a service typical of the proposed Advanced Passenger Train (HSR), at different fare levels. The effect of the new mode is to increase the whole travel market but only high speed rail itself is strongly affected by the fares chosen.

Fig. 4(b) introduces a VTOL (vertical take off and landing) service, moving between several strategically located points in each city at high speed in place of the ordinary (CTOL) air services presently running. Again the effect of increasing fares is similar to that seen in Fig. 4(a). Here the competition between rail and air is highlighted.

Fig. 4(c) introduces a high speed high frequency service, operating between points close to the city centres. The effect of adding this further alternative is to fragment the market, and puts VTOL on direct terms with HSR for the upper income market, while bus services are largely unaffected. This small effect on bus travellers is directly due to the low mean income of bus travellers, and the fact that those who value time savings highly were already using other modes in 1969. It is interesting to see that the private car also has its own well-defined market share on this route, and is fairly well insulated from the competition provided by these newer modes of transport.

6. THE EFFECTS OF GEOGRAPHICAL DETAIL ON MODAL CHOICE

The models that we have discussed include a fair amount of geographical detail: the route discussed in Section 5 is not typical in that it is longer than most in the UK, but the effects of geographical detail in the origin/destination regions can be illustrated by varying some of the model parameters. If we averaged over all the origins and destinations in each city and replaced all the detailed o/d-to-terminal links by a single link with these averaged parameters, then the effect on our modal choice prediction is as illustrated in Fig. 5(a) to (c). The effects are systematic but small, and are clearly the result of throwing away the differential ease of access to each mode from different o/d zones.

The differential geographical effect of the small change in VTOL service frequency shows up only on VTOL and car: i.e. on the mode of direct interest (VTOL) and the mode with most flexible access/egress capabilities (car). Again, these effects are small in this example where the length of the journey and the time taken to move between each city region by each main mode dwarf the geographical and service variations. The general effects of these parameter variations can however be seen in this example.

7. CONCLUSIONS AND DISCUSSION

This model of inter-urban travel can be calibrated on limited information to give a fairly good representation of the travel market, and the effects of terminal location, new mode mixes, and service alterations can be simulated effectively by its use. This model is well suited for the evaluation of new modes of transport and it was for this purpose that it was produced. Simply by allowing links between mode terminals, a full network of services can be simulated in greater detail, and modal interchanges represented. This extension together with an improved trip distribution and generation model is the next logical step in the development and application of this work.

The model which has been described represents an attempt to simulate the modal-choice decision process of real travellers. It uses only a small number of parameters to reproduce the travel behaviour of a group of people drawn from the travelling population who have similar characteristics - namely income, journey purpose and origin and destination. Not all the reasons for which people make certain choices can be included in the model, since these are as varied as the travellers themselves, and inevitably some simplications must be made, but the model is able to reproduce the broad trends of the data.

It is not easy to take the next step and test the model. In order to do this a prediction would need to be made of the modal split in some situation other than that which was used for calibrating the model. Unfortunately no suitable data exist to check such a prediction on the route used in this study, although it is not impossible that such data could be collected. Data do exist for other routes, but it is not clear whether the calibrated values deduced on one route can be applied to another; preliminary studies indicate that this is not the case.

These remarks are particularly relevant when applied to the trip generation model. Only one known measurement, that of Evans[5], exists of the increase in traffic due to a change in service on one mode, and this permits the calibration of the generation constant β. Therefore, not only is it unjustifiable to conceive a generation function with other than constant elasticity, but it is not even possible to check the calibrated value against a different situation. In any case, such checks could only serve to verify the behaviour of the model when predicting the effect of a change in the service offered by an existing mode. It is unlikely in the foreseeable future that any check could be made on the prediction of the effect of the introduction of a new mode, because no new modes are likely to be introduced on any route in Great Britain until the advent of VTOL aircraft or Tracked Hovercraft.

However, some degree of confidence in the forecasting ability of the model can be gained from its internal consistencies. The number of bus passengers travelling at the time of the survey is estimated correctly within the observational error, and the perceived cost for car travel which must be used to give the correct number of car travellers is of the same order as the marginal cost of operating a car. It was possible to make the simple joint assumption of λ proportional to income and $\propto$ independent of income. The former is a common assumption in urban studies, and the latter may indicate $\propto$ is a fundamental characteristic of groups of people, although this conclusion must be treated with great caution until borne out by other evidence because it could be affected by the method by which the analysis was carried out. But such internal checks are a poor substitute for an independent prediction of a modal split on a surveyed route, and there is a pressing need for suitable measurements to be made.

8. ACKNOWLEDGEMENTS

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The route data on which the model was calibrated was supplied by G.R. Leake of Leeds University, and we are grateful for the helpful co-operation of Leeds University, the then Ministry of Technology, the British Railways Board and British European Airways in allowing us to use this information.

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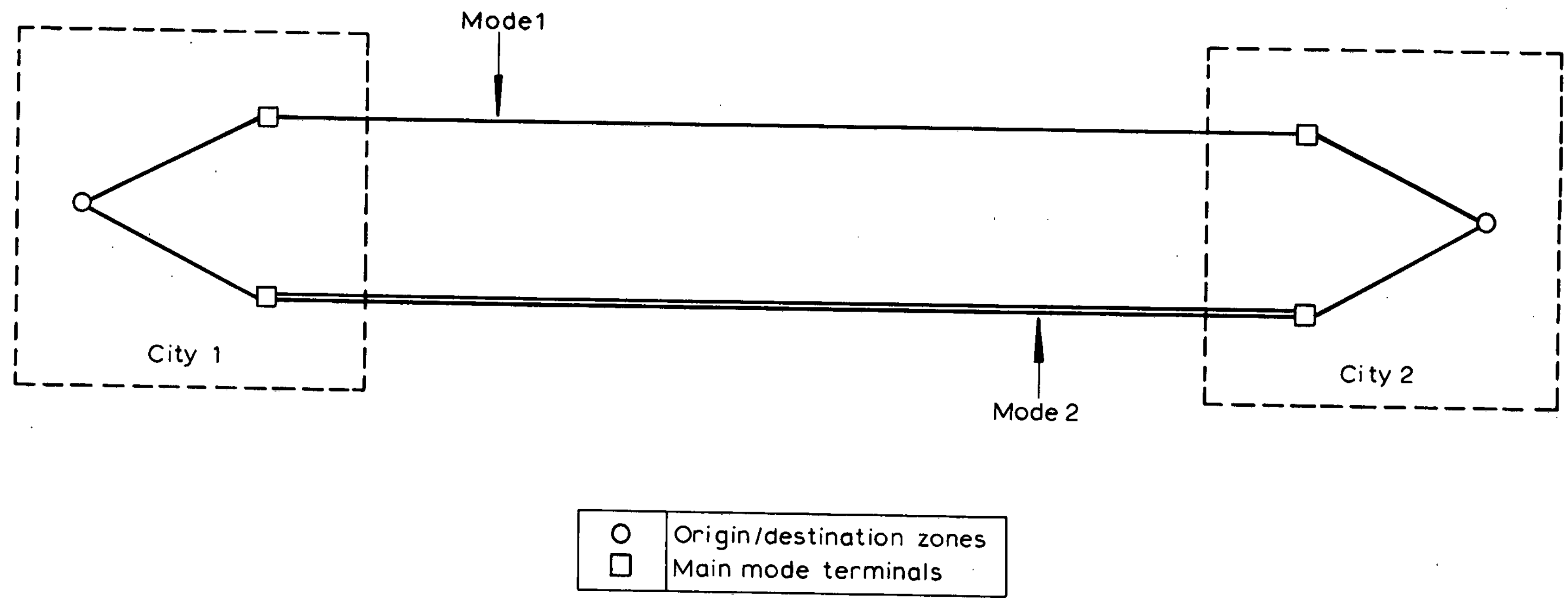


Fig.1. SINGLE ZONE, TWO MODE NETWORK.

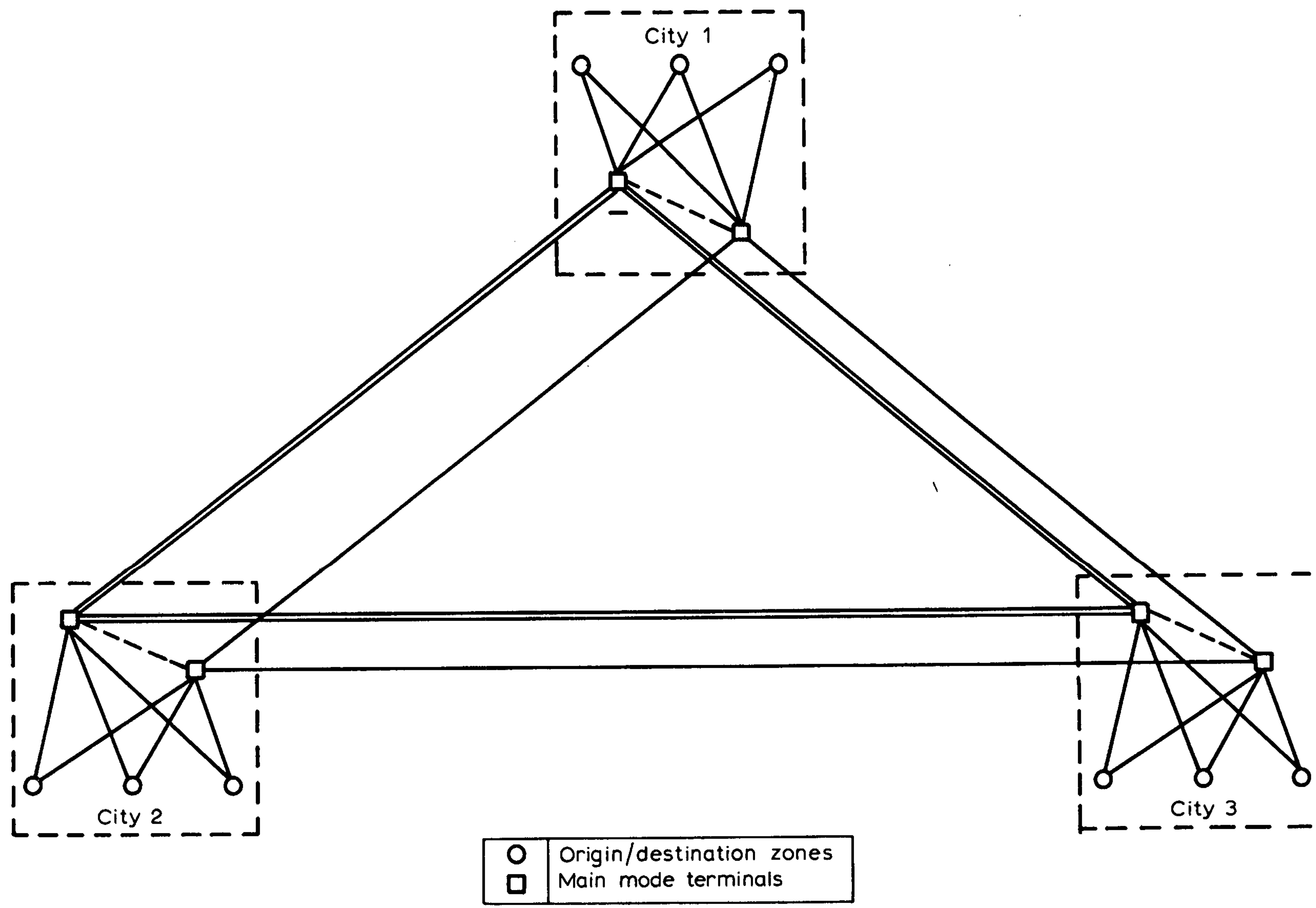


Fig.2. MULTIZONE NETWORK

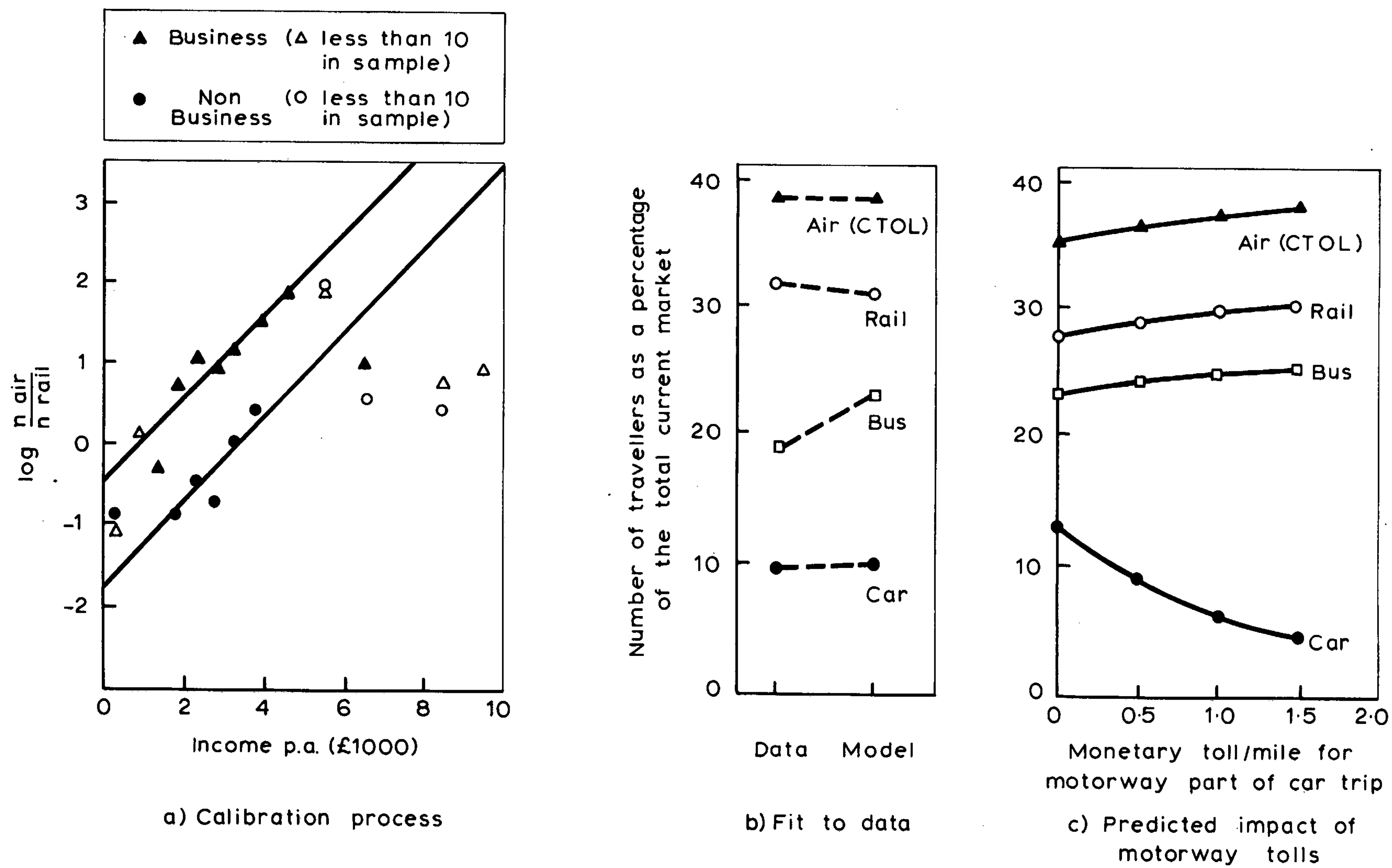
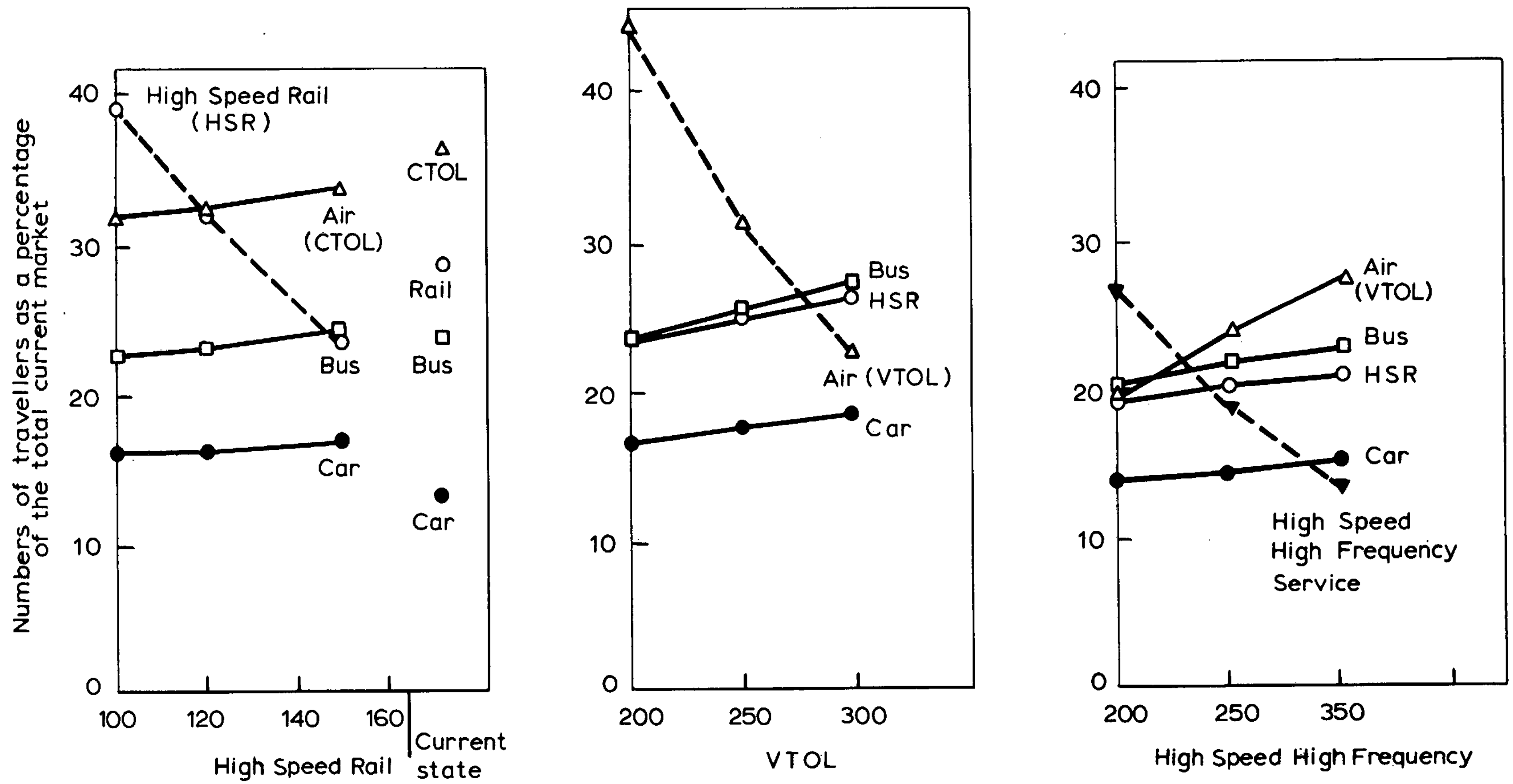


Fig. 3. CALIBRATION AND APPLICATION OF THE MODEL TO EXISTING MODES OF TRANSPORT

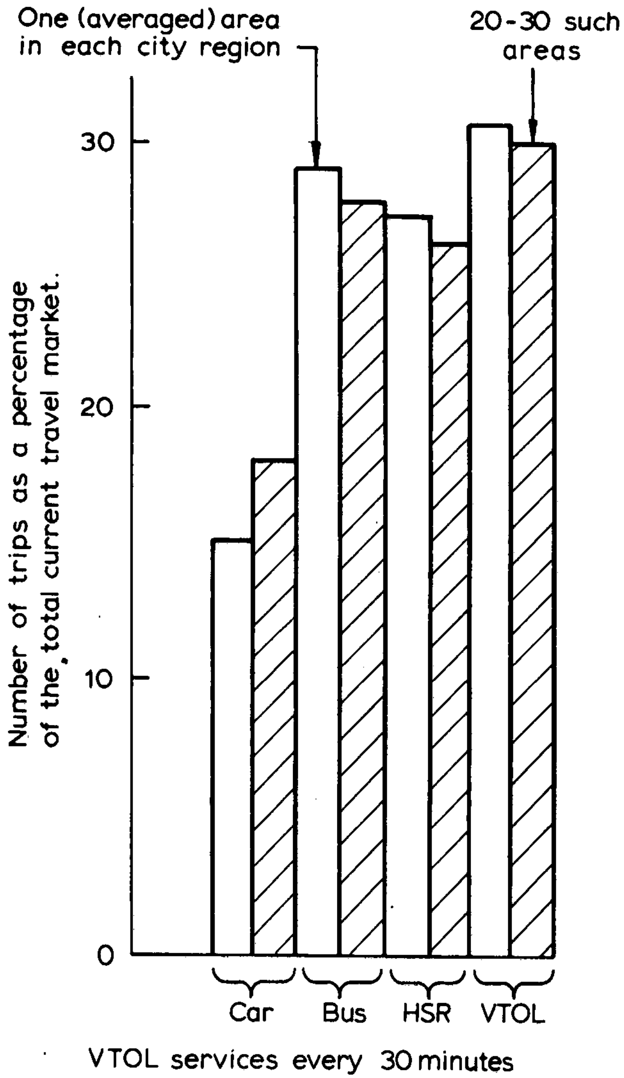


a) Effects of speeding up Rail at different fares

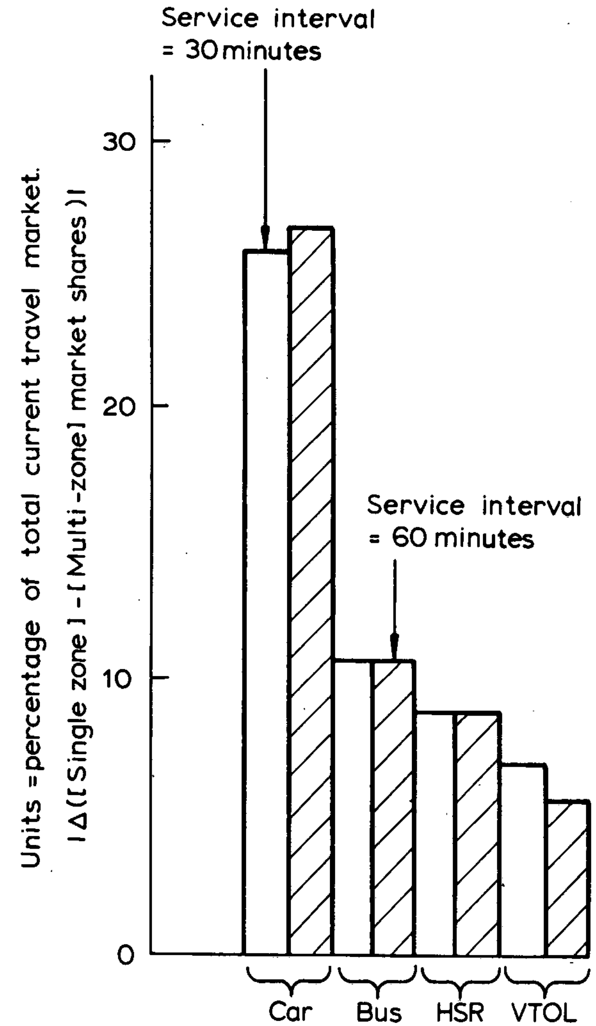
b) Effect of VTOL competition with High Speed Rail fare set to 150% current rail fare

c) Effect of a High Speed High Frequency service in competition with HSR at 150% of current rail fare VTOL at 250% of current rail fare

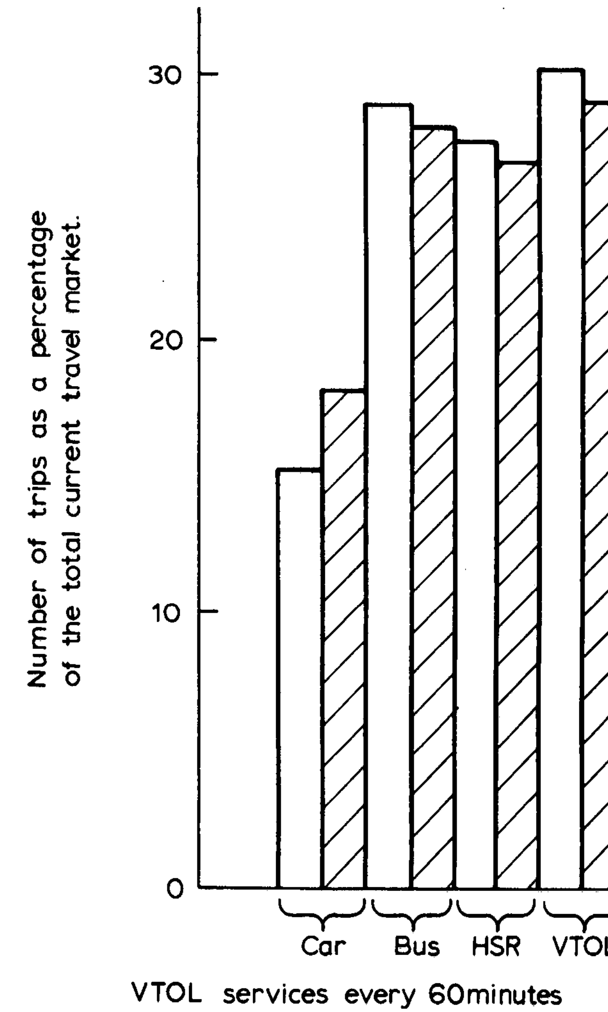
Fig. 4. APPLICATION OF THE MODEL TO THE INTRODUCTION OF NEW MODES OF TRANSPORT



(a) Effects of using detailed geographical data for trip origins and destinations.



(b) Differential effects of using detailed geographical data and different service frequencies.



(a) Effects of using detailed geographical data for trip origins and destinations.

Fig. 5 THE EFFECTS OF GEOGRAPHICAL DETAILS ON MODAL CHOICE

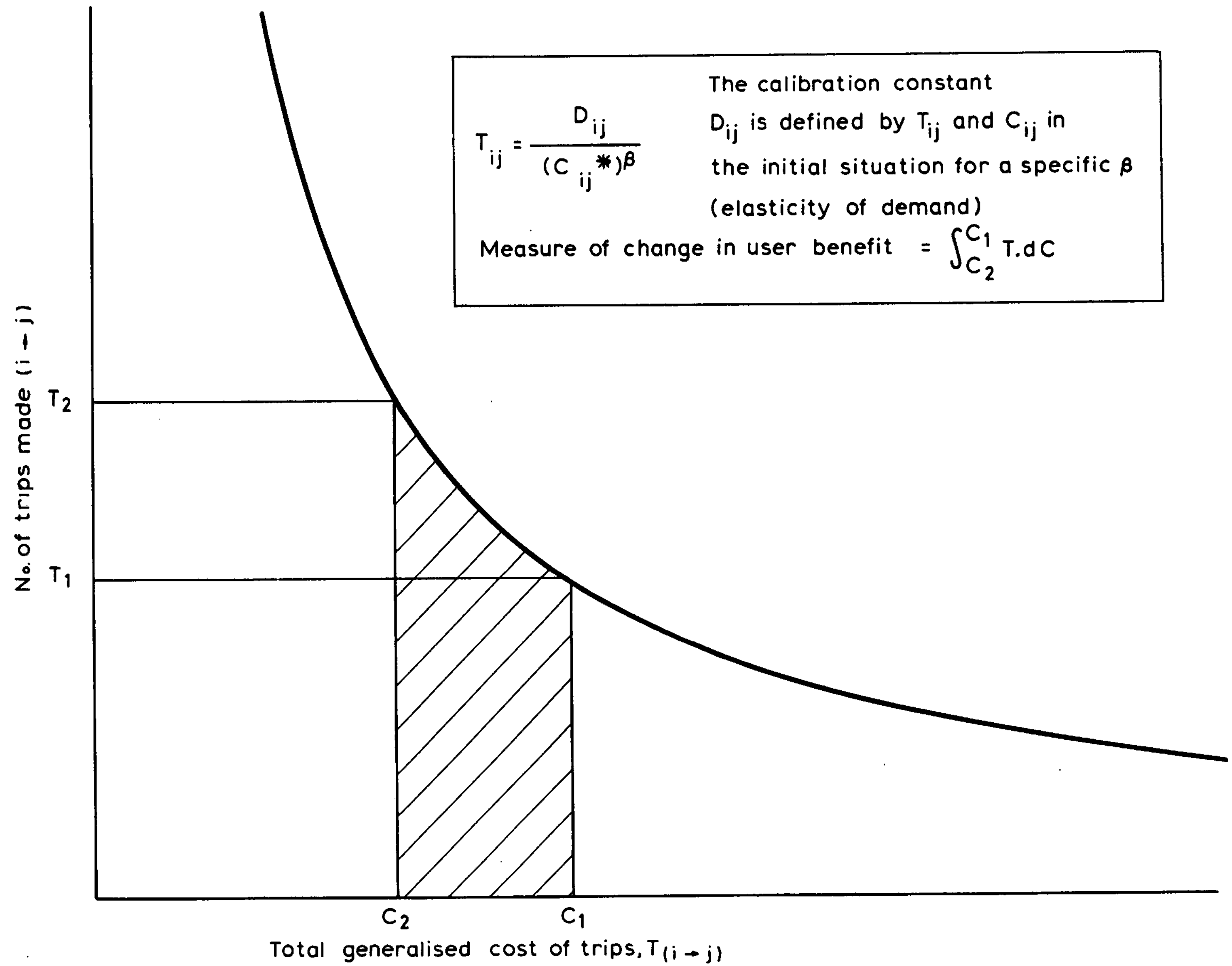


Fig. 6. CONSTANT - ELASTICITY DEMAND CURVE

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