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The Demand for Passenger Transport

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1. Introduction

Transportation planning is basically concerned with the establishment of a stable relationship between the demand for, and the supply of traffic infrastructure and transport services. In the recent past and in the current situation the relationship between supply and demand has been somewhat one-sided in many European countries in the sense that (commodity and person) transport growth and demand for transport services have outstripped both investments outlay and institutional ability to deal with the complexity of the problems attached to the renewal and expansion of transportation infrastructure. This strong contrast between traffic growth and infrastructure investments since the 1970s has resulted in transport bottlenecks in many countries and regions (see Nijkamp et al. 1990).

In this chapter focus is laid on passenger transport or travel demand. The legacy of more than three decades of travel demand analysis is a large, rather diverse and often disparate body of information. No longer is research into travel demand to be focused narrowly on the theme of forecasting, the need for understanding travel behaviour itself became a prominent theme. This broader debate has resulted into a flux of new ideas, methodologies and techniques which proved as stimulating transportation researchers, but might have frustrated transportation practitioners seeking to identify the state-of-the-art in the field.

This contribution is primarily concerned with passenger travel models and especially with those applied within an urban context. Various aspects relating to the development of travel demand models are discussed and some views on outstanding research issues are offered. The discussion will be at a relatively general level, and while the material is wide-ranging, it is inevitably selective. In structuring the discussion it is convenient to refer to three broad classes of models which characterise the development and progression in the field:

- the **traditional four-stage transportation models** associated with the large Urban Transportation Studies (UTS) and characterised by an aggregate and descriptive use of data,

- the **micro-economic approach of travel choice behaviour** underpinned with random utility theory and emphasising explanation of behaviour at the level of the individual, and

- the **activity oriented approach** based on more holistic research styles and viewing travel behaviour as daily or multi-day patterns of behaviour, related to and derived from differences in life styles and activity participation among the population.

Accordingly, the chapter is divided into three major parts. Section 2 considers the more traditional research style of the aggregate four-stage approach, while in section 3 more recent theoretical issues and research requirements relating to the micro-economic approach are analysed. Activity based studies have been emerging in the 1980s as a challenge to the established travel demand techniques. Major aspects of the conceptual foundation and methodological developments of the activity based approach are discussed in section 4. In the final section some research and development priorities for the 1990s are being sketched.

2. The Traditional Four-Stage Transportation Approach

In this aggragate approach, the focus is on zones as generators of travel and as destinations for travel. Such a focus is appropriate for the kind of large-scale, long-range transportation planning which dominated planning in the past.

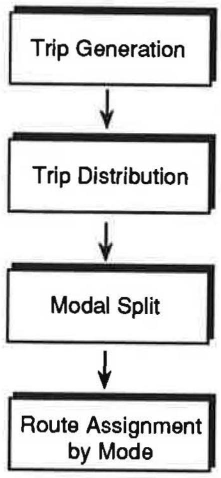
2.1. The Demand Forecasting Process

Most large-scale travel demand studies in an urban context - not only in the 1960s and 1970s, but also in current planning practice - are built around the classical four-stage travel demand forecasting process outlined in figure 1 (for more details see, e.g., Sheppard 1986). They basically rely on the following passenger demand model approach (see Williams and Ortuzar 1979):

$$T(k, i, j, m, r) = G_i^k \; T_{ij}^k \; M_{ij}^{km} \; R_{ij}^{kmr} \qquad (1)$$

in which the number of trips T(k, i, j, m, r) by persons of type k, between locations (zones) i and j on mode m by route r is expressed in terms of the attributes of the transport system. G_i^k is the total number of trips made by persons of type k generated in zone i, T_{ij}^k is that proportion attracted to zone j, M_{ij}^{km} denotes the proportion of T_{ij}^k associated with mode m (for example, car, bus, rail), while the route share R_{ij}^{kmr} is similarly defined. The four quantities G_i^k, T_{ij}^k, M_{ij}^{km} and R_{ij}^{kmr} correspond to the four stages of demand forecasting: Trip generation, trip distribution, mode choice and network assignment, designed to predict traffic flows on links of a transportation network from knowledge of land use, car ownership, economic, population and travel conditions.

Figure 1: The Four-Stage Model of the Demand Forecasting Process



Trip Generation

Trip generation is the first submodel of the conventional four-stage model sequence. Trip generation models attempt to predict the total quantity of travel, i.e. G_i^k, measured in terms of the number of trips of a certain kind (usually home-based work trips) leaving a zone i during a fixed period of time (usually peak or off-peak hours) and based upon attributes of that zone. Two types of methodologies, linear regression and category analysis, are generally used for modelling the generation of trips.

Trip generation models may be critisised due to several limitations. The most severe one is their evident inability to predict the hidden demand which is released by transportation improvements. The interrelation between the transportation system and land use patterns is not captured in this type of models.

Trip Distribution

Trip distribution models link the origin and destination ends of the trip generated by the trip generation model. That is, a trip destination model predicts how many trips made by persons of type k and originating in zone i (i = 1,..., n) will terminate in zone j (j = 1,..., n), i.e. T^k_{ij}. A variety of trip distribution models have been proposed, including classical gravity models, intervening opportunity models and entropy models (see, e.g., Wilson 1969, 1970). How different these models are, they all contain three basic elements to model the distribution of trips: the number of trips generated by a zone i of origin, the degree to which the in situ characteristics of a particular zone j of destination attracts trip makers, and the inhibiting effect of separation (distance, generalised costs).

Modal Split

Modal split or mode choice is concerned with the prediction of the number of trips from each origin to each destination which will use each transportation mode. Thus, the objective of modal split or mode choice analysis is the prediction of M^{km}_{ij}, the number of trips made by persons of type k from i to j by mode m, given a prediction of the number of trips T^k_{ij} Mode selection is usually seen as choice between just two broad categories: private cars [and trucks] on the one side, and public transport on the other. Certain groups of travellers can be virtually eliminated before considering modal split. Passengers who cannot afford or cannot drive a car must generally take public transport. Thus, the first step in modal split is to identify the public transport-captive fraction of population of each zone and to allocate these subpopulations to the one mode which they use.

Two basic model types have been used to predict M^{km}_{ij} modal split models and mode choice models, where the former term refers to aggregate and the latter to diaggregate model forms. The core of disaggregated logit-type choice models (see section 3) in the context of mode choice modelling is accepted practice today. The modal split stage of the travel forecasting model provides useful informations for transportation policy in general and in particular for decisions such as, for example, to whether to invest in a new subway system; to implement an exclusive high-occupancy-vehicle lane for buses and/or car pools, etc.

Trip Assignment

The final step in the conventional four-stage model sequence is generally referred to as trip or traffic assignment (route choice). The rationale behind trip assignment is based on the assumption that all trips between zones follow the 'best' route, best being defined in terms of travel time or generalised cost. It is implicitly assumed that travellers are sufficiently familiar with the network for making their optimal route choice, an assumption which is quite reasonable for work and shopping trips, but questionable for recreational trips. Network assignment models (such as all-or-nothing assignment, multipath assignment and constrained assignment) contain two components: a tree building process for searching out the 'best' route for each interzonal movement in a network and a procedure for allocating the interzonal modal trip volume among the paths.

2.2. Criticisms of the Approach

Many conceptual, methodological and technical problems have been identified in the aggregate four-stage sequential approach. One is the absence of any feedback between the various stages ot the travel demand forecasting process. The submodels are applied in a uni-directional way. Errors in submodels are compounded in any foreward linkage.

More significantly, the traditional research style of large-scale modelling has been strongly criticised in academia in the 1970s to be

- descriptive rather than explanatory in nature,
- theoretically deficient and in particular lacking in a behavioural rationale,
- subject to ecological fallacies and aggregation biases,
- policy insensitive and unresponsive to exploratory new policies in the context of transportation system management, and
- expensive to develop and operate.

At the same time aggregate models have been improved considerably by introducing household- and individual-based category analysis for trip generation, incorporating the generalised cost concept (with micro parameters) within the entropy maximizing based trip distribution stage, integrating disaggregate logit-type models in the context of mode choice and interrelating the stages of the travel demand forecasting process. The SELNEC transportation model developped by

Wilson et al. (1969) and its descendents are prominent examples of aggregate models which anticipated elements of the disaggregate modelling philosophy and are free from some of the above mentioned criticisms. Thus, in many respects the distinction between aggregate and disaggregate models is becoming blurred (see Williams and Ortuzar 1982).

There is no doubt now that travel demand models whether aggregate or disaggregate should be based on a well specified behavioural representation of the travel decision process. It is possible to develop aggregate travel demand models derived from a realistic representation of travel decision making at the micro level. Thus, the clearest remaining distinctive feature between the two classes of travel demand models is the level of data analysis. Each model type has a distinct role to play in transportation planning and policy (see Jones 1983). Aggregate models provide important insights into the working of the (urban) transportation system as a whole and are appropriate for the sort of large-scale, long-range transportation planning while disaggregate models can provide insights into the nature of the travel decision process and are more suited for the type of transportation planning and policy which became more important since the late 1970s, the finer-scaled, shorter-time frame and low-capital cost planning epitomized by transportation system management (see Hanson and Schwab 1986).

3. The Micro-Economic Approach of Travel Choice

The disaggregate approach takes individuals or households rather than zones as the units of observation and analysis. There are three major reasons for shifting the focus of research away from zones to individuals or households. The first is related to theory building and derives from the desire to explain how and why traffic flow patterns emerge. There is now consensus that the decision making unit is the adequate level at which to build travel choice theory. The second refers to the potential of increased policy sensitivity at a much finer scale of analysis. The third is more technical in nature and relates to the potential for a greater statistical efficiency of data requirements (see Hanson and Schwab 1986).

The specific focus in this section is on the random utility based discrete choice approach of travel choice behaviour which has proved a great stimulus to the promotion of disaggregate travel choice models. Its essential conceptual contribution lies in its explicit treatment of the processes making perfect predictions of travel choice behaviour unattainable. Before progressing to the choice-theoretic framework we first introduce some basic notions such as travel choice behaviour, and characterise the travel decision process in some detail.

3.1. The Travel Decision Making Process

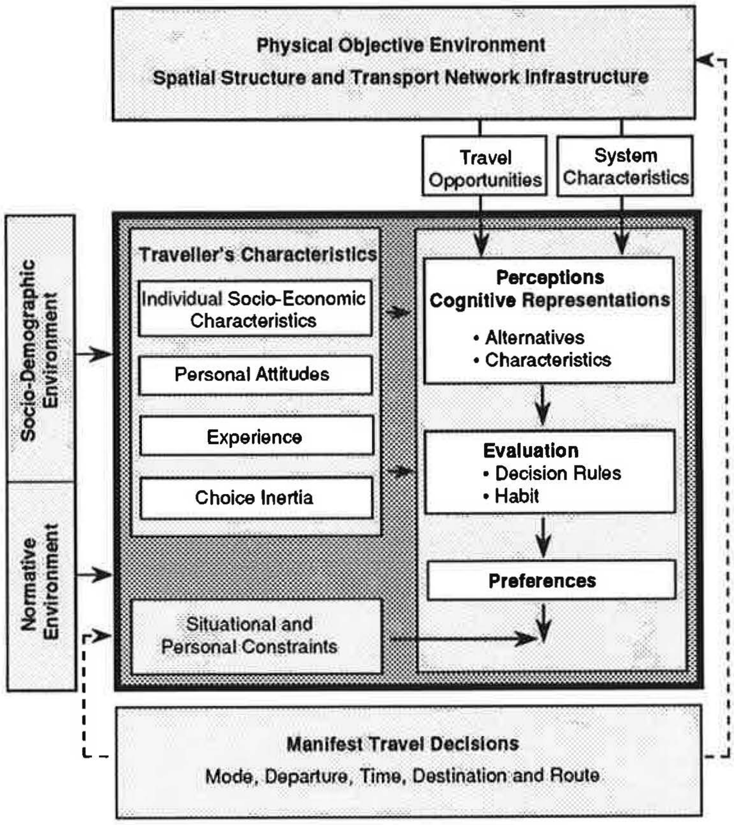
The need to travel arises at the level of the individual and at this level choices about travel are important. The term individual choice refers to the selection decision by an individual between commodities which are discrete in nature, such as, for example, mode of travel to use. Travel behaviour is reflected, among other things, by pre-trip decisions consisting of destination, mode, route and departure time choices, and enroute decisions which may consist of decisions such as diversion of alternate routes or rescheduling of intended trips (see Khattak 1991). Figure 2 describes the decision making problem in a simplified manner with which the traveller is faced. According to this framework travel choice is principally concerned with two givens:

- the **individual** in question with his/her subjective needs, travel experience, preferences, perceptions and attitudes, influenced by both the socio-demographic environment in which the individual lives (including, for example, his/her household, car ownership, age and other individual characteristics) and the normative environment including the set of norms and values derived from society, and

- the **physical environment** (including the built-up surroundings, the transport network infrastructure, etc.) determining the objective-travel opportunities and their characteristics.

The decision making process itself is viewed to consist of the formation of perceptions and cognitive representations of travel opportunities and their characteristics, and attitude formation (i.e. learned predispositions to respond to a situation in a consistent way) (see Golledge and Stimson 1987, Bovy and Stern 1990). In route choice contexts - quite in contrast to other travel choices - the set of choice opportunities may be quite extensive and complex. The traveller has only limited knowledge (cognition) of all the opportunities available. Cognition is associated with his/her experiences and the kind of acquiring information. There is a growing body of literature confirming the widely held view that in travel choice contexts individuals act under restricted knowledge of alternatives and their attribute values. The traveller may have - to a certain degree - a distorted image (cognitive representation) of the actual situation. There may be constraints which preclude certain alternatives, especially in the context of route choice and destination choice behaviour (see Bovy and Stern 1990).

Figure 2: The Decision Making Process: A Simplified View



The perceived choice options are likely to be evaluated consciously in unfamiliar choice contexts and subconsciously in routine contexts. For example, travellers may get into the habit of taking a certain mode and route through a familiar network. Inertia or habits may play a role in so far that certain thresholds in the evaluation need to be crossed before changing (attitudes towards) routine behaviour. Situational and personal constraints along with preferences determine observable choices then.

The decision making process outlined in figure 2 indicates that travel choice is by no means a direct and simple derivative of observable attributes of the traveller and of the transport network. The black box in figure 2, the so-called traveller's world, may be considered as a complicated system of filters through which choice-relevant information is selected and transformed. Two types of filters are of central importance in the choice process: Perception/cognition filters and evaluation filters. Through perception filters the universal set of choice options is narrowed into feasible choice sets, i.e. sets of choice alternatives which are known to the individual and actively considered in the choice process. The individual receives a certain cognition of the existence of choice options and a certain perception of the characteristics of these alternatives while through evaluation filters these perceptions are transformed into a desirability (utility) scale (Bovy and Stern 1990). The decision making problem is also characterised by dynamic components. Perception/cognition filters as well as attitudes are likely to change via learning processes due to discrepancies between anticipated and actual experience. Finally, it is worthwhile to mention that strong individual differences in travel behaviour may occur which cannot be easily derived from observable personal characteristics such as sex or age. This diversity is caused by the filter functions (perception, cognition and evaluation) which differ from individual to individual.

3.2. The Discrete Choice Framework and Random Utility Choice Models

Classical travel choice theory explains individual behaviour as the outcome of a two step recursive process. First, exogenous forces pose a travel choice problem, i.e. an individual decision maker and an associated choice set. Then, with the choice set well defined, the decision maker chooses among the available travel options. In general research on travel choice theory has focused on the second stage of the decision process, the characterisation of classes of decision rules, formalisation of choice set structure and analysis of the attributes of the outcome when decision rules of a given class are applied to choice sets of a specified structure.

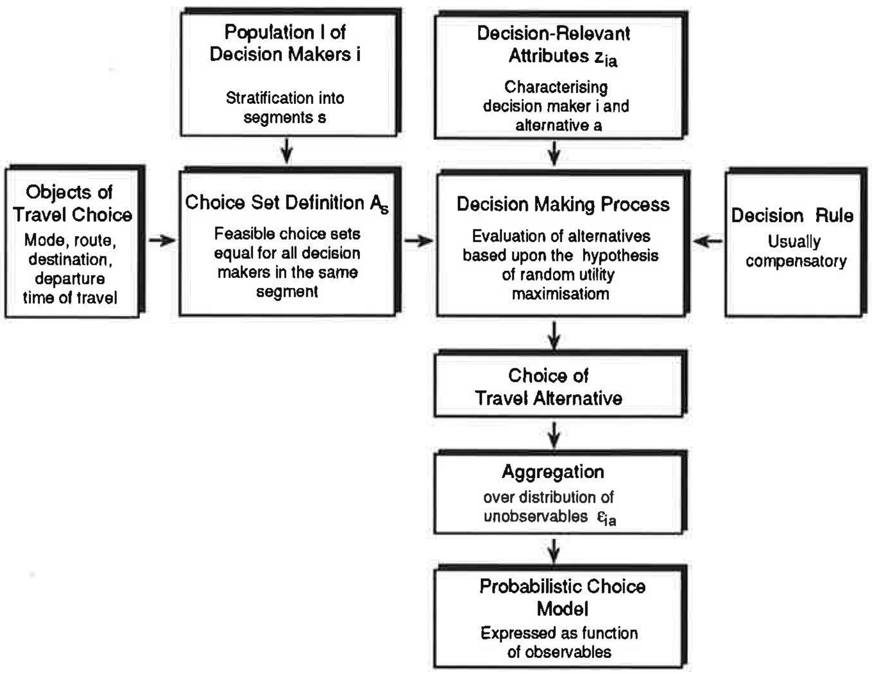
Random utility choice theory is based upon the hypothesis of preference (utility) maximisation which postulates that the distribution of demands in a population is the result of individual preference (utility) maximisation, with preferences influenced by unobservable variables. Utilities are treated as random variables not to reflect a lack of rationality of the decision maker, but to reflect a lack of information concerning the characteristics of alternatives and decision makers on the part of the observer/researcher.

Basic Concepts and Conceptual Considerations

Figure 3 illustrates the general strategy adopted by the micro-economic approach to accommodate various aspects of the travel decision making process characterised in figure 2. The approach requires four primary ingredients:

- a population I of decision makers i which may be partitioned into population segments s = 1,...,S defined by some socio-economic descriptors,
- objects of travel choice (such as routes, modes, destinations or times of travel) and a set A_s of travel options available to $i \in s$ (known as choice set definition),
- decision-relevant characteristics z_{ia} of both, the decision maker i and alternative a, and
- a decision rule for combining them.

Figure 3: Major Elements of the Micro-Economic Random Utility Based Approach



The hypothesis of random preference (utility) maximisation plays a key role in modelling the travel decision making process and assumes that there exists a mathematical function U, called (indirect) utility function, such that decision maker i prefers travel option a to option a' if and only if $U(z_{ia}) = u_{ia}$ (the value of the utility function corresponding to the attributes of the pair (i, a)) exceeds $U(z_{ia'}) = u_{ia'}$ (the value of the utility function corresonding to (i, a')). In other words, decision makers are assumed always to choose the utility maximising alternatives, i.e.

$$U(z_{ia}) > U(z_{ia'}) \qquad \text{for all } a' \neq a, \; a' \in A_s \tag{2}$$

It is generally recognised that not all the attributes characterising the decision makers and the alternatives which are relevant to choices among travel alternatives are known to the researcher, and that it is usually not feasible to measure or observe the values of all the known attributes. Moreover, there may be unobserved taste variations in a population (segment) influencing measurement errors (see Horowitz 1986, Ben-Akiva and Lerman 1985, Fischer and Nijkamp 1985).

In random utility travel choice models, these inherent uncertainties are dealt with random utility functions of the following form

$$u_{ia} = U\,(f_1\,(x_{ia}),\; f_2\,(x_{ia}),\; f_3\,(\varepsilon_{ia})) \tag{3}$$

where u_{ia} is the overall utility (or preference) of alternative a, $U(\cdot)$ denotes the utility function (for the s-th population segment), $f_1\,(x_{ia})$ is the function measuring the average (systematic) taste of decision makers within s, $f_2\,(x_{ia})$ a random function representing the idiosyncratic variations in taste (random taste variation), and $f_3\,(\varepsilon_{ia})$ a random disturbance term capturing the effects of unobserved, but decision-relevant attributes of both the decision-makers and the alternatives. x_{ia} is a vector of observed characteristics of the pair (i, a). In applications it has generally been assumed that the utility values, e.g. for alternative a, may be expressed as

$$u_{ia} = x_{ia}\,\beta + (x_{ia}\;\delta_i + \zeta_{ia}) = v_{ia} + \varepsilon_{ia} \tag{4}$$

where the first term v_{ia}, at the right side of (4) is referred to as the systematic (deterministic) component of utility, while the second term, ε_{ia}, denotes the random component. This component consists of two parts. ζ_{ia} is a random disturbance term capturing the effects of unobserved attributes of the decision maker and the choice alternatives, while $x_{ia}\;\delta_{ia}$ represents the idiosyncratic tastes of i. β is a vector of the deterministic component of utility and δ_i the taste variation parameter vector. This linear-in-the-parameters and additive form is not so restrictive as it might look at the first glance, as nonlinearities and nonadditivities may be readily accommodated.

In typical travel choice applications, observed attributes of decision makers might include automobile ownership, income, and household size. Unobserved attributes of individuals might relate to social status (except income), occupation, health and schedule commitments affecting travel choices. Observed characteristics of alternatives typically involve travel times and costs, and employment and population levels, if the alternatives are locations. Unobserved attributes of alternatives typically include reliability and comfort, if the travel options are modes, and the prices, quality, and variety of available goods and services if the alternatives are locations (see Horowitz 1983).

Random utility travel choice models specify the probability p_{ia} that a randomly selected travel decision maker i chooses alternative $a \in A_S$:

$$p_{ia} = \text{Prob}\,(u_{ia} > u_{ia'}, \quad \text{for all } a' \neq a,\; a' \in A_S) \qquad (5)$$

conditional on the matrix $\mathbf{x}_i = (x_{ia}, a \in A_S)$ of observed attributes characterising i's choice problem and an unknown parameter vector θ including parameters of the utility function U (i.e. β and δ_i) and parameters of the distribution F of the random components $\varepsilon_i = (\varepsilon_{ia}, a \in A_S)$. The choice probabilities are assumed to fulfill the conditions that they are nonnegative, sum to one, and depend only on the measured attributes of travel options and individual characteristics.

Functional Forms

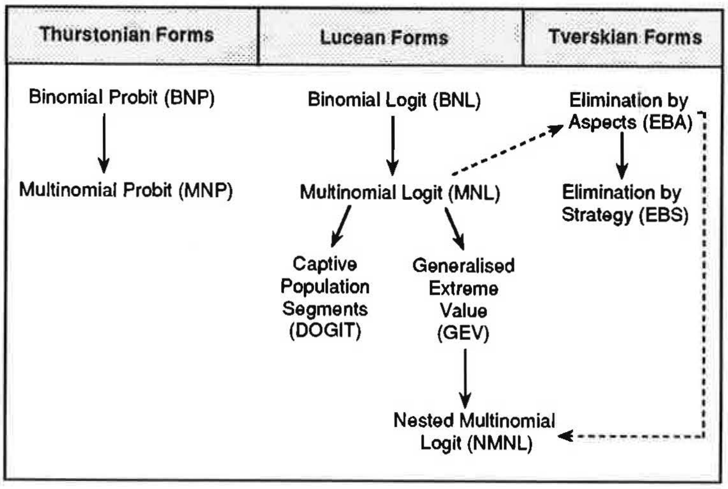
The primary issues in selecting a functional form for the choice probabilities in (5) are computational practability and flexibility in representing patterns of similarity across travel options. Three major classes of concrete functional forms for random utility travel choice models may be distinguished. These are logit models based on the work of Luce (1959), probit models based on the work of Thurstone (1927), and elimination models based on the work of Tversky (1972 a, b) (see McFadden 1981 for more details). Figure 4 outlines these classes as well as their most important members.

By far the best known functional form, the multinomial logit (MNL) allows easy computation and interpretation, but has a very restrictive pattern of interalternative substitution

$$p_{ia} = \exp\,(x_{ia}\,\beta) \;/ \sum_{a' \in A} \exp\,(x_{ia'}\,\beta) \qquad (6)$$

derived from the assumption that the random terms ε_i are independently and identically (IIP) distributed with the Gumbel Type I extreme value distribution. In the MNL no allowance is made for random taste variation. The values of the parameter vector must be estimated by fitting the model to data consisting of observations of the choices and measurements of the attributes for a random sample of decision makers. Usually the maximum likelihood procedure is used for this purpose. The most significant feature of MNL is the independence of irrelevant alternatives (IIA) property - a property which implies that the relative choice probability of any two alternatives depends exclusively on their systematic components - and can give rise to somewhat odd and erroneous predictions when the travel options are clear substitutes for each others.

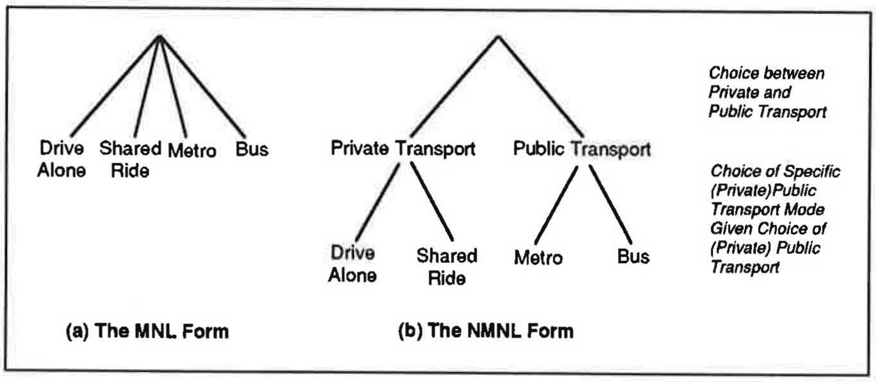
Figure 4: Three Major Classes of Functional Forms (see McFadden 1981)



Because of its simplicity, the MNL model form has been a primary focus of attempts at functional generalisations to transcend the limitations inherent in the IIA property of MNL. The most general ones are Thurstonian forms which can be derived by assuming the errors to have a multivariate normal distribution (see Hausman and Wise 1978). These model forms allow the random components of the travel options to be correlated, to have unequal variances, and also permit to incorporate random taste variation across decision-makers. For binary choice this yields the binomial probit model (BNP). The primary difficulty in applying the multinomial probit model (MNP) is the lack of practical, accurate procedures for approximating the choice probabilities when the number of alternatives is large as it is usually the case in destination and route choice contexts.

The most promising and widely adopted generalisation of the MNL form is the nested multinomial logit (NMNL) model which can be obtained as a special case of the generalised extreme value (GEV) model form by choosing appropriate values of the parameter of the GEV distribution (see, e.g., Sobel 1980, Ben-Akiva and Lerman 1985). To illustrate the NMNL model, a simple journey-to-work mode-choice context may be considered as displayed in figure 5 in which four travel options are distinguished: drive alone, shared ride, metro and bus. Using the MNL model, one would treat the four modes as distinctly independent alternatives and assume that each individual selects one particular mode following a simultaneous evaluation of all four. In contrast, using the NMNL model one would treat the trip decision process as a recursive sequential choice structure where results of the decision on the lower decision level feed into that of the higher level. The NMNL form has the advantage of retaining the desirable computational and other characteristics of the MNL model, embodies more general properties of cross-substitution, but is less general than Thurstonian forms.

Figure 5: Alternative Decision Structures and Model Forms for a Simple Travel-to-Work Mode Choice Example



All the functional forms considered so far belong to the family of compensatory choice models assuming that the travel decision making process is compensatory in nature, in other words that individuals 'trade off' attributes of the travel options in the decision process. Non-compensatory models employ other decision rules. The most prominent examples are the elimination-by-aspects (EBA) models (see figure 4) where lexicographic and satisfaction rules are combined (see, e.g., Recker and Golob 1979). Choice is viewed as a process in which the attributes are hierarchically ranked by the importance associated to them, and alternatives are eliminated from the choice set until a single alternative remains.

These models, however, are more complicated than the MNL model and require considerable a priori information. Thus, empirical practice confines itself to the exclusively used Lucean forms in general and the MNL model in particular. Their domain of applicability has been steadily extended from binary mode choice to simultaneous choices over complex choice sets in a destination or route choice context (see for example, Kern et al. 1984, Borgers and Timmermans 1986).

Revealed versus Stated Choice Models

Traditionally travel choice models have been based on data obtained by direct observation of travel behaviour or in surveys asking for actual travel behaviour (i.e. revealed (preference) data). Such data, however, have some limitations which restrict their general suitability. First, it might be difficult to obtain sufficient variation in the revealed preference data to analyse all variables of interest. Second, there may be strong correlations between explanatory variables of interest (especially travel time and cost) which makes it difficult to estimate model parameters reflecting the proper trade-off ratios. Third, the revealed preference data approach can not be used in a direct way to evaluate demand under conditions which do not yet exist (such as new forms of public transport, new regulations affecting the use of cars, etc.). In view of these problems the use of stated (preference) or experimental data became an attractive option in travel demand analysis (see Louvière and Hensher 1982, Kroes and Sheldon 1988).

Stated (preference) data relate to observations of choices made by individuals in laboratory choice experiments carried out in hypothetical environments. A key feature of the stated data approach is that individuals are exposed to a set of choice experiments generated by some controlled experimental design procedure (e.g., full or fractional factorial design) so that the independent variables can be made truly independent. A crucial issue in the design is the definition of the variables (factors) of interest and the values (levels) of the factors which need to be evaluated by the respondents. The last few years have seen an increasing attention devoted to computer integrative procedures to increase the reliability of the behavioural responses of the respondents.

Choice models based on revealed data are termed revealed choice models, while choice models based on stated data are called stated choice models. Revealed and stated choice models have complementary advantages and disadvantages. Revealed ones have high external validity in the sense that they are calibrated to real data. This advantage, however, may be considerably diluted by the difficulty of defining the choice set in destination and route choice contexts, and by the concern about the accuracy of the data actually used in making the choice. Stated choice models have several advantages over the revealed choice models in analysing travel behaviour. The most important one refers to the controlled nature of the choice experiments which allows greater freedom in defining travel choice contexts, alternatives and attributes as well as direct comparison with the responses accross individuals. With these advantages comes the liability that the success of the stated preference approach largely depends on the consistency of the hypothetical alternatives and the corresponding sets of attributes with their perception in actual choice situation (see Wardman 1988). Stated choice models are becoming increasingly employed in academic studies (especially in destination and route choice contexts) and in policy analysis to analyse how people would adjust their behaviour under radically different alternative futures (e.g., new forms of public transport, new regulations affecting the use of cars, etc.).

3.3. Range of Applications of Random Utility Models

Revealed and stated choice models have found an increasing range of application in travel demand analysis in the past two decades. They have been used simply to replace the forecasting components of aggregate models. But often inflexibility in the large scale aggregate frameworks has restricted the benefits obtained. Most success has been found in specialised policy analysis. For example, car pooling has been studied by Ben-Akiva and Atherton (1977), the elasticity of gasoline taxes, parking taxes, transit fares and housing taxes to finance public transport by Anas (1982) and the effectiveness of ride sharing incentiveness on work trips to reduce congestion and air pollution by Brownstone and Golob (1992).

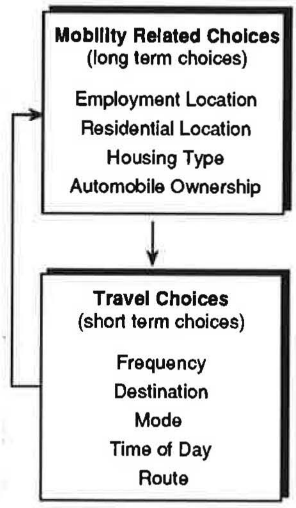
The early applications were confined to mode choice in the urban area for work trips. The choice of mode for travel to work has been analysed extensively, using different types of data from widely differing urban areas (see, e.g., Domencich and McFadden 1975, Ben-Akiva and Lerman 1985). Initially satisfied with identifying those attributes characterising the system and/or individual which significantly affected one's choice decision, transportation researchers have since broadened their scope to include virtually every aspect of an individual's choice of travel mode. Consequently, considerable efforts have been devoted to the valuation of traveller's time, uni- and multidimensional procedures for obtaining an index of vehicle safety, comfort and other qualitative aspects, procedures which attempt to minimise aggregation biases, due to spatial or socio-economic groupings, etc. These and other isssues have been analysed both in isolation and together with related individual decisions such as trip purpose, time of day of travel, frequency of travel and residential and employment location choice.

Although still dominated by mode choice studies the application of discrete choice models now includes departure time (see, e.g., Abkowits 1981, Brownstone and Small 1989), route choice (see, e.g., Bovy and Stern 1990), automobile ownership and use (see, e.g., Hensher et al. 1989), travel frequency (see, e.g., Domencich and McFadden 1975), multi-destination travel or trip chaining (see Horowitz 1979). Most of the studies assume trip decisions are being made independently. However, some also explore relationships between decisions, such as, e.g., between mode, destination and frequency (see Domencich and McFadden 1975); mode destination and trip chaining (see Horowitz 1980); frequency, mode, destination and time of day of travel (see Charles River Associates 1967), shopping mode and destination choice (see Ben-Akiva and Lerman 1985).

Work has also progressed on applying discrete choice models to intercity travel demand situations. Recently, Koppelman and Hirsch (1989) have developed an intercity travel demand model representing trip frequency, trip destination, mode and service class choice in form of a nested decision structure.

Changes in the transportation system are likely to have significant effects not only on travel decisions, but also on travel-related choices such as car ownership, employment and residential location etc. In turn, these decisions may have a significant impact on travel demand, since travel decisions of an individual are constrained by fixed employment and residential location as well as by fixed automobile ownership or availability. Thus, a fully successful travel demand model has to take into account the structural relationships between these decisions which directly or indirectly influence trip making behaviour (see Domencich and McFadden 1975). There are good reasons that the longer-run mobility-related choices are assumed to be intertwined with the short-run travel choices within each of both bundles of decisions a simultaneous structure may be assumed. Figure 6 illustrates one possible choice hierarchy in a travel and mobility-related context. Until the nature of the interactions between transportation services, travel and travel-related decisions is better understood, there is only little hope that travel choice models will provide reliable tools for long-term policy analysis.

Figure 6: A Simple Hierarchy of Travel and Travel-Related Choices
(see Ben-Akiva and Lerman 1979, 669)



With the exception of mode choice modelling, most transportation applications of random utility models have been carried out by individuals who are either mainly engaged in or closely associated with travel choice behaviour analysis. The ability of discrete choice models to represent broad ranges of travel choices and policies has not yet been fully exploited in transportation planning practice.

3.4. Criticisms and Limitations of Travel Choice Models

Random utility travel choice models represent an important advance over other operational modelling approaches and reflect an increasing awareness of the need to understand a wide range of travel and travel-related decisions. There has been much research and experience with random utility travel choice models during the last two decades. Strengths and weaknesses of the particular forms of models have been increasingly well understood.

In the past decade various objections and criticisms have been directed at currently implemented probabilistic travel choice models. These have generally focused on limitations of the variants of the MNL model and have generated a whole range of extensions, generalisations and new approaches. More specifically, some of the objects of attention have been related to the incorporation of taste variability in a population, the investigation of alternative individual decision rules, the treatment of similar travel options in choice contexts, the incorporation of time-varying exogenous explanatory variables, unobserved variables with a general serial correlation structure and complex structural interrelationships among decisions taken at different times, etc. (see, e.g., Fischer and Nijkamp 1987).

A serious shortcoming of the discrete choice approach is the use of single trips as the basic unit of analysis, despite the widely recognised fact that travel is a derived demand. That is, demand for travel is derived from needs and desires to participate in various activities in space and time. Most operational travel choice models ignore the relationship between activities and travel, and, thus, are unable to provide meaningful information about how changes in the activities themselves may affect individuals' travel behaviour (see Recker et al. 1983b). In this context, studies of behaviour within an integrated activity-travel framework are of particular importance (see section 4).

A second major problem associated with current travel choice theory is its failure to explicitly consider the mechanism generating choice problems. Little work has been done up to now on relaxing the assumption of homogenous choice sets, on identifying systematic differences in the choice sets of individuals, specifying variables which define the individual's choice set, and on modelling endogenous choice set formation for appropriate types of individuals. Closely related is the problem of the proper specification of the individual's choice set, a problem far from trivial because meaningful choices can only be made from known and evaluated travel options. Although environmental, informational, personal and situational constraints delineate the set of feasible travel options to an individual; the models fail to identify these options which are perceived and actually considered by the individuals.

Applications of travel choice models have generally assumed that information about travel alternatives available to the decision maker is exogenous and subject to systematic inaccuracies. This classic assumption, however, is unrealistic. Individuals' information is not only imperfect, but also depending upon experience with the transport system and upon information-gathering activities (see Manski 1981). The integration of the dynamic relation between information and travel choice moves one away from the current cross-sectional to a dynamic framework where effects of experience, time-discounted preferences, learning processes, habit persistence etc. become central issues.

Finally, it has been argued that the underpinning theory, involving a perfectly discriminating rational (wo)man, endowed with complete information, is unacceptable for analysing travel behaviour (see, e.g. Burnett and Hanson 1982). Indeed, it is not too difficult to find examples of travel related situations in which the utility maximisation principle does not seem to apply, at least without some substantial conceptual modifications.

4. The Activity Based Approach

Activity based studies have been emerging in the 1980s as a challenge to the established travel demand techniques. The replacement of the trip-based view by a broader, more holistic framework in which travel is analysed as daily or multi-day patterns of behaviour is considered by many scholars to be essential for a deeper understanding of travel behaviour. The growing interest in this approach has been reflected in an increase in the number of studies undertaken in the recent past (see, e.g., Jones 1990) and in the wide range of issues which have been addressed by an activity orientation point of view.

4.1. Conceptual Foundation and Major Characteristics

The major conceptual foundations of the activity based approach can be traced back to two major schools of thought:

- the time geographic or Lund perspective resulting from attempts to develop a model of society in which constraints can be formulated in physical terms (see Hägerstrand 1970), and

- the transductive or Chapel Hill perspective which conceives activities in terms of the individual and his/her physiologically regulated and learned behaviour (see Chapin 1974).

The two perspectives are complementary in nature. The Lund group paid specific attention on understanding the operation of constraints on travel behaviour in space and time, while the Chapel Hill group primarily focussed on individuals' preferences, assessing the relative significance of role and personal factors preconditioning individuals to particular patterns, and the relative importance of motivations and other attitudinal factors affecting predisposition to act.

Much of the activity based work is descriptive rather than theoretical in nature and relates to a wide range of issues including activity patterns and rhythms of individuals and households, the scheduling of activities in time and space, the importance of space-time and other constraints on activity behaviour, interactions among persons (both intra- and inter-household), relationships between activity and travel choices, detailed timing and the duration of activites and travel, routine travel behaviour, etc. Despite the wide diversity of the studies, they share a common philosophical ground - not so much a clear common theoretical or methodological orientation - which results from their interest in patterns, linkages, trip timing and constraints.

Although difficult to characterise simply, the following characteristics may be considered to be of central importance (see Jones et al. 1983, 1990 and Jones 1991):

- The approach emphasises the need to consider travel within a broader context through the pattern or sequence of activities, undertaken by individuals at various locations in space during a period of time (a day, week or month). The way in which the concept of activity patterns has been operationalised differs greatly from study to study.

- Activities are undertaken to satisfy basic needs (e.g., sleeping, eating), institutional requirements (e.g., school, work), role commitments (e.g., child care, shopping) and personal preferences (e.g., specific leisure activities).

- There are various degrees of constraint on when activities can be undertaken, for how long, where and with whom to participate. Special emphasis is laid on spatial, temporal and interpersonal constraints and linkages.

- Emphasis is laid on decision making in a household context, taking into account relationships and interactions among household members.

- Travel is explicitly treated as a derived demand, representing a space-shifting mechanism by which people move around space to take part in a succession of non-travel activities at different points in time and space. Thus, travel results from activity participation and trip making. Individual trips are manifestations of activity needs and motivations, given perceptions of opportunities and constraints (see Golob 1985).

- The observed daily activity and travel patterns are viewed as outcome of a - widely routinised - activity scheduling and rescheduling process in which obligatory and discretional activities are fitted into an available period of time, given perceptions of opportunities and subject to various constraints due to physiological factors, institutional requirements, norms and rules of society and family life.

The activity based approach provides a more realistic, but also a more complex view of travel behaviour than the micro-economic approach does. The emphasis on complexity has deepened our qualitative understanding of travel decision processes, options and constraints, but also inhibited the development of a more comprehensive and rigorous theoretical framework and analytical methodologies up to now.

4.2. Methodological Developments

Several methodological developments have been motivated by or developed from the activity based approach which have been fundamental to activity based research and which have made important contributions to other approaches to travel behaviour research, covering aspects of survey data collection, analysis and modelling. This section is largely based on Jones et al. (1990), see also Kitamura (1988) for more details.

Survey Data Collection

The data requirements of the new approach are very demanding, reflecting the need for more comprehensive data on travel and activity patterns. These requirements have motivated the development of computer-based survey techniques (for example, the HATS and the IGOR techniques) based on the use of interactive measurement and/or gaming simulations to obtain travel preference and response data in the context of daily or weekly activity patterns and to identify the types of constraints within which travel-activity patterns are formed (see Jones 1991 for more details).

Analysis of Complex Travel-Activity Behaviour

An important issue in the analysis of travel-activity patterns refers to the development of methods which can be used to measure and analyse travel as a complex phenomenon by incorporating relevant linkages and interactions. Two general approaches to measuring travel patterns can be identified. The first one - usually adopted - decomposes the pattern into dimensions (such as timing, location, mode of travel, activity sequencing) and generates measures for each of the dimensions. The second one attempts to treat the patterns as a whole in form of a multidimensional space representation, to analyse the structure of the travel-activity patterns by means of classification procedures and to identify the relationships between travel-activity behaviour and hypothesised determinants of that behaviour. A prominent example is given by the work of Koppelman and Pas (1985). This approach involves defining a set of indicators that adequately characterise the travel patterns which itself involves considerable difficulty since activity and travel patterns evolve in a multidimensional space comprised of time, location, activity type, duration, trip attributes such as mode of travel, and other factors.

Quantitative Modelling of Travel Behaviour

Activity based travel research has played an important role in contributions to applied travel behaviour modelling in two ways. First, and more successfully, insights obtained by activity oriented studies have stimulated to refine and improve the specifications of existing random utility choice models. Second, but less significant up to now, there have been some first steps towards developing acitivity-based models (see Jones et al. 1990).

Studies using travel choice models have integrated the results of activity-based work in several ways, for example, by

- incorporating new types of explanatory variables, e.g., socio-demographic variables representing role, life cycle and life style which have been identified to be significant determinants of daily travel-activity behaviour,

- explicitly treating interdependencies (e.g., car availability at the intra-household level or inter-household interdependencies through ride sharing) via NMNL model forms,

- developing travel choice models with new kinds of dependent variables, such as the duration of travel.

There are several attempts at modelling activity participation, timing and duration with econometric tools developed for modelling single trip decisions. A practical illustration is Kawahami amd Isobe's (1990) one-day travel-activity scheduling model for workers. There have also been efforts to develop more comprehensive activity-based models of activity-scheduling based on combinatorial programming or computer simulation. They typically assume that the individual plans beforehand and predetermines his/her entire daily schedule of activities and trips through a simultaneous decision concerned with the daily schedule as a whole. Since the travel activity pattern evolves within a multidimensional space and, thus, the decision process is characterised by multidimensional aspects, the operational formulation of the decision process is far from easy, and involves discrete choices of activities and location as well as continuous allocation of time and financial resources.

Examples include CARLA (Jones et al. 1983) and STARCHILD (Recker et al. 1983b) which capture several important aspects of how people schedule their activities and represent a progression from a less to a more realistic conceptualisation (for an overview see Axhausen and Gärling 1991). The STARCHILD model involves a submodel of individual choice set formulation which includes both the effect of environmental/household constraints and that of individual limitations with respect to infomation processing and decision making. The model shows great promise as a means to handle complex adaptation processes (Recker et al. 1983b).

4.3. Shortcomings and Research Problems

The emphasis on patterns, constraints and linkages of activity and travel behaviour provides a more realistic, but also more complex view than the trip-based approaches do. Up to now the activity based approach, however, still lacks a clear methodological orientation and a unified theoretical framework. There is an urgent need to develop a more comprehensive theoretical framework and more adequate analytical techniques.

Development of such a theoretical framework requires the integration of concepts from several disciplines: psychology (perception of constraints, nature of activity participation needs, identification of attitudes, motivation and emotions for activity participation and travel), sociology (life style, life cycle and roles, interdependencies in social networks), geography (understanding of spatial aspects of travel and activity participation, nature of spatial cognition and spatial behaviour, acquisition of spatial knowledge, links between travel and residential mobility) and economics (role of time and money in activity participation and travel, utility derived from activity participation) (see also Jones et al. 1990). Equally important is a more explicit treatment of dynamic processes. Up to now activity based studies take dynamic effects only implicitly into account by looking at life cycle stages and transitions.

5. Outlook

The issues addressed in travel demand research have clearly broadened very considerably over the years. At the same time new innovative approaches have emerged. In spite of the progress made, we are still far away from understanding travel behaviour or from the development of sound theory underpinning travel demand.

Research and development priorities for the 1990s should be in two major directions. The first is to consolidate and make more widely available existing activity oriented and choice-theoretic modelling technologies to the practitioner-oriented environment and demonstrate their usefulness in the policy area. Both the discrete choice and the activity based approach to travel choice modelling offer a rich potential. The second is to improve our theories, refine the methods and integrate different strands of theoretical contributions. One major challenge will be to reconcile the activity based and the choice theoretic approach which widely differ in vocabulary and philosophy. Considering the power of discrete choice models on the one side and the limited activity modelling work to date on the other, it certainly seems appropriate to devote major future efforts to generalise and refine rather than to discard random utility based travel choice models. One obvious strategy is to define choice sets, constraints and explanatory variables in a more refined way.

Equally important is the need to shift the focus away from the dominating static to a more explicit dynamic perspective, from static cross-section to panel data sources, especially in a rapidly changing policy world. Static methods might provide biased forecasts of - for example - traffic growth, even if the estimates of input variables are correct, and may lead to wrong policy implications (see Goodwin et al. 1990). Methodologies and statistical techniques already exist to cope dynamically with discrete and continuous choices, aggregate and disaggregate data. The emphasis should be on the nature of behavioural adjustment processes inherent in travel choices, leads, lags, thresholds and uncertainties in travel decision making. The further development of dynamic concepts in travel demand analysis is crucial for the derivation of better and more reliable policy instruments.

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