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RESIDENTIAL MOBILITY: POLICY, MODELS AND INFORMATION

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1. Introduction

The objectives of this paper are to review models of residential location and change in the context of their information needs and their contributions to public policy. Given the breadth of the topic, only a broad review is feasible and a somewhat polemical stance is adopted. In the next section, the policy context of this style of modelling is reviewed briefly and then follow two sections on modelling. In the first of these, the general characteristics of models in the residential field are examined and then a wide range of examples is presented. A number of preliminary conclusions are drawn in these sections and these are brought together more systematically in a concluding section together with a discussion of strategies for future work.

2. The policy context

It is often stated (for example, see Clark and Moore, 1978-B, Moore and Harris, 1979) that models of residential mobility have contributed little to public policy discussions. It is important therefore, to begin with a brief analysis of why this should be the case. There are probably two main reasons. First, the models do not contain variables which seem relevant to policy makers. It will be argued below that this is a situation which can be rectified as far as the models are concerned. Secondly, the public policy issues in the field are poorly articulated in spite of an enormous existing literature. On both counts, therefore, we need to examine how the policy context can be clarified.

Planning and policy questions arise from a variety of perspectives. From first principles, we would begin with people and

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households and their lifestyles. Planning can be seen as concerned with seeking ways of improving their packages of activities and opportunities (housing, transport, services, employment and so on). This involves surveys and predictions in relation to these topics and the identification of "problems". Planning and policy is then concerned with the resolution of these problems, or, more positively, with the achievement of various goals. There are always fundamental difficulties of procedure with this viewpoint: while it is often very easy to identify problems, and indeed solutions to problems, the resources are not usually available to implement solutions. There is competition for the available resources and their allocation can be seen as the outcome of class conflict. The nature of the competition and conflict varies across different countries and societies but is usually easily recognisable.

The argument can be extended from individual and household needs to community or social needs and this recognises the existence of groups of people who form pressure groups or whose interests may be represented by others - for example by planners. The same issues of competition and conflict will be present.

Planning and policy organisations formulate their own goals: they see themselves as representing particular groups in particular instances and possibly in trying to resolve conflicts. These organisations may be, in the broadest sense, resource based (and a housing agency may be taken as an example of this category) or place-based. For completeness, we should also note the policy ambitions and roles of a wide range of organisations whose functions are economic and they may be in both private and public sectors.

Broadly, then, we can argue that there are two types of policy question: those concerned with people or communities from first principles - the identification of problems and what can be done about them in a context of competition for resources and of class conflict. And those of particular, usually governmental, organisations who ask: given our specific brief, how can we improve and implement our policies? There is also a third, super-policy question: are the present institutions adequate for handling current and future problems?

When this background is related to housing, and more specifically to residential mobility, some uncomfortable observations can immediately be made. First, it is clear that in all large cities, for example, and in most other situations as well, many people have housing problems perhaps associated with jobs, services and access to opportunities generally. One of the reasons why policy is not well articulated is that this would involve the admission that the resources are not available to tackle most of these problems in the foreseeable future. So the first step, it can be argued, is to recognise this and to concentrate some effort in spelling out the boundaries of what is achievable.

The interdependence of people's problems is also a difficulty. Many mistakes have been made in housing policy because housing problems have been treated in isolation. This is something else which must not be forgotten in deciding what kinds of models offer the best contributions to policy.

The variety of agencies involved causes difficulties. Any one agency usually offers only a particular contribution to the resolution of housing problems. It would be a good guess to assert that if these efforts could be coordinated, and the systemic consequences of particular actions recognised, then better use could be made of the resources which are available.

It is beyond the scope of this essay to consider any particular policy agencies. The next step in the argument therefore is to discuss in principle what the instruments of policy are so that this provides a background for the discussion of modelling and information needs and, because of the level of generality adopted, it is hoped that any conclusions can be translated easily into the context of a particular organisation.

There are, broadly, four kinds of policy instrument: (i) expenditure; (ii) regulation; (iii) fiscal policy and (iv) form of organisation. All are relevant to the housing and residential mobility field. The difficulties to be borne in mind at present include the current aversion to increased levels of public expenditure, especially at times of economic recession, and the vested interests which have accumulated for the beneficiaries in relation to past policies on regulation, taxation and forms of organisation. A few examples will suffice to sustain the argument:

land-use controls, or the lack of them, favour land-owners in a particular way; tax policies, for example in Britain tax relief on interest on mortgages, generate enormous benefits, especially in inflationary times, for the owner-occupying class; and many people in particular agencies have an interest in the survival of these agencies in terms of their own jobs and careers.

Nonetheless, the policy variables fall under one or more of these four headings and these are the variables which, once explicitly presented, we should seek to represent in our models. We review the adequacy of this, sometimes directly and sometimes by implication, in the outline of models in section 4 below. And we return to this issue in the concluding section.

3. General characteristics of models of residential location and change

The first general point to note and recall is that any residential model is part of a broader model system. This is important in at least two respects. First, people's choice of residence will be partly determined by variables from other sub-models - such as those representing the supply of services, or by income. Such variables will either have to be modelled themselves or treated exogenously. Secondly, the same point becomes particularly significant in another sense if the residential model is to be used in a policy context. This will involve at least the measurement of short-run response to policy and possibly longer-term projections. In such a case, it is more difficult simply to deem other variables to be exogenous.

A residential model has a number of main components: people and household by type, houses by type, an allocation of households to houses and perhaps some related determinants of behaviour such as a representation of the residential environment. This provides a static picture of residential location and obviously, too, the basis of a sequence of comparative static pictures. The next step is to add dynamics and process and this involves the organisations responsible for all aspects of housing supply and related features of residential choice. The "types" adopted in the system description should reflect the different kinds of behaviour thought to represent change. The enormous number of categories apparently necessary for this forms one of the main problems of model construction.

The various entities can be defined at different scales: this is partly a matter of choosing the breadth of classes which make up types; partly a matter of the phenomena involved - decisions by individuals may be influenced by macro variables like quality of the environment which may in turn be seen as an aggregate of many individual decisions; and partly a matter of model design and data availability.

Typically, we would then seek an accounting framework: the basic demographic processes and housing supply processes form a basis for the study of change and a framework for keeping track of all possible and actual transitions.

Finally, we would seek a theoretical base for any model: an understanding of the processes of change and the way in which these hypotheses can be built into a model.

Given this background, what kinds of models would we expect to find? It has often been useful to use Weaver's (1958) classification of system and problem types as an aid to exploring what kinds of models are likely to be appropriate to particular situations (cf. Wilson, 1977). He identified three types: simple systems, described by only three or four variables; systems of disorganised complexity, described by thousands or millions of variables, but with only weak interactions between the entities of the system; and systems of organised complexity, which also involves large numbers of variables, but with some strong interactions between them. The first type are of no relevance here, except possibly at a very aggregate scale, say for housing supply as part of an econometric model. We might expect the allocation of households to houses to be represented by a Weaver-II model since the number of cooperative effects is small and these can in any case be explicitly built into the models. This suggests that statistical averaging models will be appropriate, and these could be either of the average-rate accounting type (say in the Markov family) or of the entropy-maximising kind. It can also be argued that various methods used for building economic models involve the same broad kind of averaging to solve the aggregation problem - whether these be the probabilistic methods of random utility theory or the methods of mathematical programming. It is not surprising, therefore, that we find all these methods represented in our survey of models in the next section. When the supply side is added, the system probably becomes Weaver-III. This is for two reasons. First, there are strong interactions between many of the agencies involved; and secondly, in many cases the numbers of agencies, for example involved in house building, will not be sufficiently large to make any sort of averaging feasible. There are no general methods available for building models of such systems but one interesting method for dynamic model building which seems relevant to this context, but which has not yet been applied, will be described in the next section.

One final general observation is appropriate. It is possible to decide on many features of a model and only then to think of the particular mathematical representation to be used. A simple example is the decision as to whether to treat space continuously or as a set of discrete zones. Another is whether to use large arrays with many subscripts on many variables or whether to use lists of entities with lists of characteristics in a simulation model. These issues mean that there are many models which look very different which have underlying similarities and sometimes even equivalences (cf. Wilson and Macgill, 1979, Macgill and Wilson, 1979). This has been referred to as model equifinality. This is an important point to bear in mind when models are being compared.

This brief general section provides an overall background for a wide range of models which will be surveyed in the next section. We will then be in a position to review together both their data needs and their contributions to policy and to make some assessment of research priorities.

4. Models

4.1 Factor identification

It is not surprising, given the enormous amount of literature on residential mobility, that a long list of factors have been identified which have been argued to be relevant. There is some disagreement about the role and significance of particular factors, but on the whole, there is a reasonable concensus. The foundations of the field were laid in Rossi's (1955) work. A more recent example of similar British work is that of Murie (1974). Here, we follow Quigley and Weinberg (1977) and list the kinds of factors involved. Since discussions of these are widespread in the literature, and they have been assessed in a number of review articles, we simply list the factors as a basis for further discussion of models below. Quigley and Weinberg group their factors under three main headings as follows:

(1) The family life cycle:
- stages of life cycle
- marital status
- age
- sex
- household size
- household composition

(2) Other household characteristics:
- tenure
- prior mobility
- race
- income
- education
- occupation
- workplace location (access to jobs)

(3) Environmental characteristics
- racial neighbourhood mix
- neighbourhood quality
- crime and violence
- perception of deterioration
- overcrowding
- price and availability of alternative dwellings

(3) Environmental characteristics (continued)

- mortgage availability
- distribution of public services and taxes (accessibility to services by quality)

There also seems to be an argument, at least intuitively, for a fourth heading, which is only mentioned in passing by Quigley and Weinberg:

(4) Housing characteristics

- housing quality
- house size, etc.

These factors arise from a great deal of empirical work and are the basis of much verbal theorising. A conceptual framework can be established which provides a basis for the explanation of mobility in relation to these characteristics. This usually involves a break-down into at least two stages: (i) the decision to move and (ii) the search and choice process for the new location. Some index of satisfaction (or utility or stress) is usually suggested as the basis of the decision to move (cf. for example, Wolpert, 1965; Brown and Moore, 1970; Brown and Holmes, 1971).

4.2 <u>Linear models</u>

Given the kinds of results sketched in the preceding subsection, the first step in analysis is the more formal investigation of correlations between these variables and mobility rates. Indeed, of course, much if the "factor identification" work has been carried out in this way and the two modes of analysis are artificially separated here for convenience.

The methods used range from standard investigations of correlation or factor analysis. More sophisticated methods can be used which investigate the influence of certain variables while controlling for others, or for the influence of variables acting simultaneously. These usually involve the methods of Blalock (1964), for example by Moore (1969), and for a more recent British example, see Permanand and Moore (1978). The methods of path analysis have also been used (Pickvance, 1974).

The final step in the use of linear methods is the use of some form of regression analysis to estimate mobility rates in terms of independent variables selected from the list in section 6.1 below. These can take simple and straightforward forms or could involve simultaneous multiple regression.

Work using this family of methods is useful in establishing the relevance of various possible independent variables in the study of mobility but less useful as the basis of predictive models. The situation is rather analogous to the development of transport models in very early days, when regression methods were also used: there are parts of the model, involving the rates themselves, where the methods may be useful but not necessarily the best (why not consider category analysis - cf. Wootton and Pick, 1967 - for example, in the estimation of rates?) while there are other parts - on search and destination choice, where there are better techniques available. These will be discussed in later sections.

4.3 Markov and other 'rate' models

We noted in section 3 that it is important in principle to establish an accounting base for the analysis of mobility (and indeed it is one of the weaknesses of linear models that they are inadequate in this respect). Such a framework then lends itself to the building of average rate models. Mobility involves a transition from one state to another and a matrix of all possible transitions from one time to another, that is during a time period, is a set of accounts. If the elements of such accounts are divided by the corresponding row sums, this leads to the formation of a matrix of rates which can also be interpreted as a matrix of probabilities. If the process is stationary, then Markovian assumptions apply and the whole range of corresponding modelling techniques can be applied. These methods, and developments of them, have a long and distinguished history - see, for example, MacGinnis (1968), Ginsberg (1973, 1978).

The difficulty (see, for example, Huff and Clark, 1978) is that the process is not, typically, stationary. Various methods have been used (semi-Markov models, transformations to make the process stationary, and so on) to get over this problem but Huff and Clark argue that they have not proved satisfactory and they themselves have proposed a new method using biproportional matrix techniques. This is important in two respects: first, it connects this field of work to others, for it is essentially an entropy-maximising method. And secondly, it offers an important clue on the development of account-based methods: that is, the accounts *are* important, but not simply for the construction of average rate models. The use of the biproportional matrix method in effect allows non-linearities to be built into the model *and makes the best use of available information.* This will be an important principle to consider in a broader context later (cf. Rees and Wilson, 1977, for the use of similar methods more widely in the spatial population field).

The other problem with average rate models - and this is one which is shared with a number of other methods - arises from the large number of factors which have to be handled. Moore (1978), for example, defines an occupancy class based on household type, say w, and dwelling type, say k, simultaneously. Transitions are then from one (k,w) state to another, say (k',w'). k and w may themselves be lists of variables and it is not difficult to see that the transition matrix can quickly become inordinately large. Theory demands that this should be the case; the result is difficult to handle and there is almost never the data available to calibrate the model. This is another general issue to which we will return below. See also Byler and Gale (1978) for an interesting discussion of accounts in this context which involves some large arrays.

4.4 Search behaviour

The residential relocation process is usually broken down into two main stages: the decision to move and the decision on where to relocate. An important intermediate step is often [illegible]ted, however, and we discuss this briefly here: the nature of the process of search for alternatives. A typical paper is that by Brown and Holmes (1971) which builds on the conceptual model of Brown and Moore (1970). The migrant is supposed to have an 'awareness space' and to acquire information about this through his 'activity space' and his 'indirect contact space'. These concepts combine to produce the 'search space' of the migrant. There has been a certain amount of empirical research based on conceptual frameworks of this kind, but until recently, no attempt to develop a formal model of the search process. There has been a recent contribution to this end by Smith, Clark, Huff and Shapiro (1979) and they are currently involved in an empirical test of their model. Its basis is the specification of the household utility function and its expected value in other locations. We should also note that this kind of work has an affinity to the geographer's concern with mental maps (Gould and White, 1974). We reserve until the final subsection of the current section our own comments on likely future developmentsin this area.

6.5 Economic models

The development of economic models of residential location has a long history, going back for example at least to von Thunen. This history is effectively charted in a review article by Senior (1974). Here, we concentrate on identifying some of the main features which form the basis of our discussion in subsequent sections on modelling strategy.

Economic models are based on the theory of consumers behaviour (on the demand side) and the theory of the firm (on the supply side) involving the maximisation of utility and profits respectively. Most recent work is based on the seminal studies of such authors as Alonso (1964), Muth (1969), Mills (1972) and Evans (1974). The most developed side, and on the whole the most relevant for studies of residential mobility, relates to demand. The utility function contains a representation of housing preferences, usually in the form of bid rents. There is usually a difficulty in that two kinds of consumption are involved: of land and of buildings. And this if further complicated by some of the other variables noted in section 6.1, such as environmental quality. The main emphasis has been on space consumption relative to accessibility to workplaces and a composite bundle of other goods. It could then be argued that in many of these models, a number of variables shown to be important in empirical studies are neglected. However, the important point to note here is the kind of frameworks which have been developed, and we reserve for later discussion the task of incorporating new variables into these models - which is often, at least in principle, a straightforward task.

The main achievement of the early urban economists was perhaps to show that a comprehensive model could be built which included a market-clearing mechanism and that an equilibrium solution existed. The rent surface could also be predicted: the maximisation of utility corresponded to the minimisation of actual rents paid. The models of Alonso and Muth were cast in a continuous space representation of cities and this usually forced the restrictive assumption that all jobs were located in the centre of the city. The next major breakthrough was the discovery by Herbert and Stevens (1960) that a way could be found of building operational models based on these principles. This involved a change to a discrete representation of space, using a zoning system, and a linear programming mechanism to represent market clearing. An important empirical task was the estimation of bid rents to be incorporated in such a framework, and the early work on this was carried out by Harris (1962) in the context of the Penn-Jersey Transportation Study using regression methods. It is at this point that such models can easily be extended to include new variables: they can be incorporated into the utility function to be estimated empirically. A more recent development can also usefully be noted at this point: Goodman (1976) and Hanushek and Quigley (1978) each criticised the equilibrium assumptions of this kind of model and showed how to compute the divergence from equilibrium of particular households - the 'drift' from equilibrium over time. They relate this to the costs of moving, which are neglected in many models of residential mobility, and show how the two concepts can be used as the basis of a probabilistic model of residential relocation. There are also a number of studies concerned with specific aspects like tenure choice (for example, Stryuk and Marshall, 1974; Walker, 1976; and Jones, Gudjonsson and Parry Lewis, 1978).

These ideas lead to a number of major efforts in the development of comprehensive operational models. Many of the features noted in section 3 above had to be added to the basic economic mechanism: such as a demographic model, an economic model and a housing supply model. One of these, the Penn-Jersey Study, has already been mentioned. Two other notable examples were the San Francisco Study (Robinson, et al., 1965) which focussed, interestingly, on modelling housing supply within such a framework and the NBER model (Ingram, et al. 1972). The latter was a particularly ambitious project which has now had a long history. We will return to this in another context - simulation methods - below.

Many detailed criticisms can be made of these models. However, this is not very productive: the researchers in each case had to make decisions in relations to data availability and model feasibility, and in other circumstances, it would be possible to rectify the models in a straightforward way. However, there are more fundamental criticisms which lead into the next subsection. The most important of these is the assumption of relatively perfect behaviour on the part of consumers and the associated equilibrium assumptions. The core of the allocation mechanism is usually some kind of programming model which allocates consumers in an optimum way. The problem is that when the results of such an allocation are compared with data, the world does not seem to be so perfect. The problem is generated by a theorem of linear programming which guarantees that many of the assignments to an allocation array are zero - much more so than is evident in any data. There are many reasons for this dispersion from the optimum. A variety of taste on the part of the consumers which is not built into the model (cf. Wheaton, 1972), lack of perfect information, market imperfections, aggregation in the model, and so on. A way of dealing with this problem - in fact more than one way - has emerged by combining this style of work with others and this will be discussed in the next section.

4.6 Dispersion: entropy maximising and random utility theory

Quigley and Weinberg (1977) exclude the contribution of 'gravity models' from their review on the grounds that they are more concerned with 'parsimonious description' of an aspect of the residential mobility process rather than with explanation. They specifically note entropy maximising methods in this respect, but in this section, we show that the contribution of such methods can be integrated with economic approaches and that they contribute in a fundamental way to handling the problem of dispersion.

Spatial interaction models, whether based on entropy maximising principles or many of the other alternative theories now available, have their origins in the study of transport flows. They were involved in many early residential location models in which residential choice was assumed to be based on distance from workplaces (see Wilson, 1970, for an account of such models, and Senior, 1973 for a useful detailed review which parallels his work on economic models). Such models were then disaggregated to include a representation of houses by type, although house prices were included exogenously. The significance of this approach for economic models was changed, however, with the work of Evans (1973) which showed a close relationship between the doubly constrained gravity model and the transportation problem of linear programming. This work was developed in a residential location context by Senior and Wilson (1974) and some general results deduced on the relationships of the duals of the two classes of problem (Wilson and Senior, 1974).

The relationship between the two classes of model can be shown in very general terms as follows. Suppose Z is a utility function and that the equilibrium values of some variables, $\underline{x}$, are to be determined by maximising this subject to some constraints. Say,

$$\max_{\underline{x}} \; Z(\underline{x}) \tag{1}$$

such that

$$\underline{f}(\underline{x}) = 0 \tag{2}$$

Consider the following entropy maximisation problem:

$$\max_{\underline{x}} \; S(\underline{x}) \tag{3}$$

such that

$$\underline{f}(\underline{x}) = 0 \tag{4}$$

and

$$Z(\underline{x}) = Z_s \tag{5}$$

where S is entropy. The utility function is now incorporated as a constraint and it is given a suboptimal value Z_s. If the optimum value is Z_{opt}, then it turns out that, as $Z_s \rightarrow Z_{opt}$, then the solution of the entropy maximising problem tends to the solution of the mathematical programming problem. This is equivalent to saying that the parameter which is the Lagrangian multiplier associated with (5) tends to infinity and it is in this sense that the mathematical programming problem is a special case of the entropy maximising problem. The EM problem can then be interpreted as a representation of the perfect market model given by (1) and (2) modified to include any imperfections in a 'most probable' way. In the 'imperfect' model, the dual variables still represent rents paid, and these can be shown to be higher than in the 'perfect' model by an amount which reflects the degree of imperfection.

The consequence of this idea is that it is possible to build a model based on economic principles, by incorporating a utility function directly, but still have the advantages of also building in dispersion and hence deriving a model which usually fits much better against data. It could then be argued that the degree of explanation offered by such a model is better than the original, rather than that it simply offers 'description'.

Both the incorporation of linear programming mechanisms into 'pure' economic models, and the entropy maximising method, can be seen as ways of solving the aggregation problem in model building. As we have seen, the second has the advantage of building in dispersion which can be considered to arise for many reasons ranging from variation in tastes to the model builder's ignorance of certain features of the system. It is now also possible to build dispersion into models based on economic theory directly using the methods of random utility theory. There is a thorough review of these techniques offered by Williams (1977), building on and extending the work of such authors as McFadden (1974) and Cochrane (1975). These methods have been applied explicitly in a residential location context by Lerman (1977) and, more broadly, by Coelho and Williams (1977). The essence of the idea turns on the addition of a random term to the utility function. If $\bar{u}_j$ is the mean utility derived from being in state j, then the utility of an individual in the population is taken as

$$u_j = \bar{u}_j + e_j \tag{6}$$

where e_j is a random variable. If this is assumed to have a Weibull distribution, then it can be shown that the probability of an individual choosing the state j is given by

$$p_j = \frac{e^{\beta \bar{u}_j}}{\sum_k e^{\beta \bar{u}_k}} \tag{7}$$

where β is a parameter. For various forms of $\bar{u}_j$, this model can be used to generate a wide variety of models, some familiar, some less so. In many cases, the models derived are identical in form to those generated by entropy maximising methods, though there are important differences particularly in the interpretation of parameters (see Clarke, Keys and Williams, 1979) and also in the form of the models in more disaggregated cases. The model is also similar in form to those derived from Luce's (1959) theory of choice, as in Huff (1979) for example. As presented, the model is used to derive a cross-section but can be used as the allocation procedure at the heart of a dynamical model.

4.7 Optimisation models

In this section, we note briefly a general point and a particular technical advance. First, if we are seeking to employ residential models in a public policy context, then it is important to isolate the variables which can be controlled by planners and policy implementers. An obvious use of models is then to input settings of such policy variables and to run the model to help in the assessment of impact. Various evaluation measures can be computed as an aid to this. The task involved at the outset is what was referred to in section 2 as 'policy articulation' - which demands both the identification of policy variables and the 'design' process of inventing alternative settings of them for testing.

The advance in technique is, having identified the variables, to seek optimal values of them. It has been shown that (Coelho, Williams and Wilson, 1978) the behavioural models described above can be embedded in a broader mathematical programme which achieves this optimisation. Suppose we have behavioural variables $\underline{x}$ generated by a model of the form of equations (1) and (2) or (3)-(5). Suppose there are also variables $\underline{y}$, the planning variables. Then, if an objective function $E(\underline{y})$ can be identified, possibly together with additional constraints, say $\underline{g}(\underline{y}) = 0$ (which may include budget constraints for example), then it can be shown that a programming of the form,

$$\max_{\underline{x},\underline{y}} \; S(\underline{x})+E(\underline{y}) \tag{8}$$

such that

$$\underline{f}(\underline{x}) = 0 \tag{9}$$

$$Z(\underline{x}) = Z_s \tag{10}$$

together with the new constraints

$$\underline{g}(\underline{y}) = 0 \tag{11}$$

provides an optimal solution and a set of behavioural variables, $\underline{x}$, which satisfy the original model (where we have used the entropy maximising formulation). This has been applied in retailing by Coelho and Wilson (1976) and in a residential location context by Coelho (1977).

4.8 Simulation models

One of the main problems with most of the models discussed so far is that they involve arrays of high dimension - especially when they are disaggregated in the direction of greater realism and policy usefulness. A simulation technique, apparently originally due to Orcutt et al. (1961), can be used to overcome this problem, and it also turns out to have a number of positive advantages. The problem with high dimensional arrays is that they include many elements which are zero. It is therefore very wasteful of computer storage to handle them, and also it is usually impossible to obtain corresponding data. The essence of Orcutt's method is to generate lists of entities and to list their characteristics for each. Although this generates a large amount of information, it is considerably less than that demanded by high dimensional arrays. How can such information be obtained? Typically, of course, it cannot. The essence of the simulation method is to reconstruct it within the model using Monte Carlo techniques while ensuring that the resulting population satisfy all known probability distributions. There is considerable scope within this method for building in a substantial amount of theory also since model building decisions have to be taken as to which probabilities are prior to other and which are conditional on others. It is also possible, within the simulation model, to impose constraints which would be more difficult to handle within some analytical models. Finally, the greatest advantage, especially in cases where a considerable amount of interdependence of characteristics has been built into the model via constraints, is that information is not lost. Using arrays, the only practical method of proceeding is to have several sets of arrays of reduced dimension. For example, arrays will record residence and workplace, residence and shopping location, residence and school and so on. What is not then available is residence, workplace, shop and school simultaneously for typical individuals. In the simulation model, this information is always available and can be re-aggreated in any way which is then desired. This is particularly important from a policy point of view. In the evaluation of housing policy, for example, it is important to know the other effects on each household's 'lifestyle-package' as well as on housing directly. This method facilitates such investigations. Further, the advantages of other modelling methods can be incorporated. For example, entropy maximising methods could be used to compute some of the probability distributions to be used in the simulation process, or a mathematical programming method could be used to represent the allocation of movers to houses.

This representation has been used extensively in the NBER model (Kain, Apgar and Ginn, 1976) and by Wilson and Pownall (1975) in Leeds. At present, a major model is being developed using these methods by the Leeds team (see Clarke, Keys and Williams, 1979).

4.9 Aspects of dynamical modelling

The treatment of time in most of the models discussed so far is of a comparative static nature or involves the use of data to patch up the non-stationarity of average-rate models. The purpose of this section is to draw attention to some newly developing techniques, and some potentially surprising results which are associated with them. They have as yet not been applied, beyond some theoretical speculations, in the residential modelling field.

The main applications of this method to date have been in the analysis of retail centre development, though it is clear that this model acts as a paradigm for others (Harris and Wilson, 1978, Wilson and Clarke, 1979, Wilson, 1979). Essentially, the technique is to identify an appropriate state variable, such as the provision of shopping floor space at a location, and to construct a set of differential (or difference) equations to represent the time development of this variable.

This is straightforward enough in principle. The new interest arises from the bifurcation properties of the solutions of these equations. It can be shown that there are critical values of parameters in the equations at which non-zero equilibrium solutions vanish or vice versa. Such bifurcation arises from two features of the system: first, when there are non-linearities, and secondly when there are strong interdependencies between elements of the system - in this case because the shopping centres at different locations are competing for a fixed number of customers.

It is clear that there will be analogues in the residential modelling field, and indeed that in this case the situation is more complicated. We can work from the supply and demand sides separately in the first instance. On the supply side, there is a direct analogy with the shopping case: we are modelling the supply of structure in response to demand by the population. The analogy is very close if it assumed that this demand arises in relation to workplace location, but other assumptions could easily be substituted. On the demand side, in the shopping case, it is usually assumed that the population is differentiated only by income and that it moves rapidly into equilibriumand stays there. The residential case is more complicated because different population groups are competing directly for the same housing stock in some locations. This provides new interdependencies which should lead to new bifurcation behaviour.

Some of the earliest applied work using these methods was in the field of ecological modelling and it is easy to see that there are analogies, fairly directly, with the residential case. If there are N groups which have been identified, competing for K different house types, then this represents a more elaborate version of the biological case of N species competing for K different resources (cf. Rescigno and Richardson, 1967; Hirsch and Smale, 1974).

One consequence of these analyses is to stress the concept of criticality - that fundamental changes in the system can take place at critical parameter values. For example, it may well be possible to explain the phenomenon of 'tipping' in a neighbourhood in these terms. This provides a new focus for policy as well as for analysis. If critical parameter values exist, then it important for the planner to know where they are. It may then be possible either to maintain a neighbourhood in its existing state by manipulation of such a parameter or to modify the parameter in such a way as to encourage change.

4.10 Models: summary.

We can now draw together the conclusions from this survey of the range of models and theories available.

(1) The conceptual framework has now had a pretty thorough going over. Large numbers of factors have been identified, sometimes correlated with each other, which play a role in the residential mobility process and it may now be that these roles should be explored in the context of more formal models.

(2) It may occasionally be useful to use various forms of linear models, especially where it is possible to establish directions of causality, but again it may be more useful to focus on the more formal models. There is one possible important exception to this: the development of models of aspatial mobility rates. The break-down of the relocation decision into 'whether' and 'where' parallels the distinction between trip generation and trip distribution in transport modelling. The more complex aspects of the model, in part, turn on the second question. As a first approximation at least, it would be useful to have readily available models of mobility rates for different categories, and as noted earlier, it is surprising that the technique of category analysis (Wootton and Pick, 1967) which has been extensively used in trip generation modelling has not been used here. It is recognised, of course, that more fundamental questions are involved, but what seems to be missing is at least a short-run robust working tool. If this was coupled with certain kinds of monitoring procedures, then it could be updated when appropriate.

(3) The Markov and related accounting models provide another useful focus on rates. Again, they may contribute to some useful short-run robust models. Two main further points need to be made. First, the accounting framework is always a useful underpinning of other models. Secondly, it has been remarked (for example, by Smith, Clark, Huff and Shapiro, 1979) that most Markov models take little account of space. This in principle is an easily recifiable deficiency: the state definitions would have to be expanded to include spatial labels and submodels added for the probabilities of spatial interaction - and fortunately, there are plenty of these available (cf. Rees and Wilson, 1977, for a discussion of this problem with another kind of account-based model);

(4) It is obviously tempting to seek to build more detailed models of the search process. However, this may not be the most fruitful way of proceeding, especially if not informed by empirical research. There may be an argument for more empirical work which may then lead to model building. However, there are two ways in which search behaviour can be reflected in existing models, one implicit and one explicit. First, we saw in section 4.6 that dispersion could be included in many models, and one feature of this could a representation of the uncertaintities and imperfections of search behaviour. Secondly, if it is thought that search behaviour biases model results which do not incorporate it explicitly, then it could be built into spatial interaction models as some kind of 'search cost' - to be added to the usual cost terms, but including directional biases or whatever empirical research had found to be appropriate.

(5) Further developments of economic models are inevitable! Indeed it may well be that many of the new insights needed for a new generation of operational models will come from this direction. However, their current problem is that they are difficult to make operational and are not realistic. Ways have been suggested above, by incorporating dispersion, which can often rectify this. It is also important to try to develop economic models within a realistic mathematical representation rather than the idealisations of continuous space, all-employment-in-city-centres, and so on.

(6) The next class of models might broadly be called the 'dispersion models'. These have proved robust in a number of fields and are designed to make further developments relatively straightforward. It is easy for example to incorporate new terms into utility functions or their equivalent (which are the 'attractiveness' and transport terms of interaction models) and to calibrate and test such models using either aggregate or individual household data. It can also be argued that they have a better 'behavioural' base than may have been thought. They lend themselves to the inclusion of additional constraints and also to 'information adding' procedures (cf. Batty and March, 1977) which will be discussed again in a broader context below.

This class of models has the advantage that there is a wide variety to choose from to meet many tastes in theory. They can be used in conjunction with other models, such as the Markov models as noted earlier; but it should also be emphasised that they often need inputs from other models, such as a mobility rates model.

(7) We have seen that there is some scope for the development of optimisation models in the policy field, particularly with respect to the location and type of housing. The component submodels would then provide a record of things like filtering effects and a number of evaluation measures (cf. Coelho and Williams, 1978, for applications in a related field).

(8) The growth area of future model building could well lie in the simulation field. This is because such models are the most economical with regard to computer storage requirements and can also make the best use of a lot of partial data. They can be linked with other modelling styles - such as an accounting framework, spatial interaction models to compute certain probability distributions, and so on. It is possible that they need more than the average effort for initial set up and use, but they probably form the most flexible and effective analytical base for a policy agency.

(9) It is clear from experience in other fields that a new class of dynamic models will emerge which will contain representations of new phenomena based on concepts of critical parameter values. This will have an obvious importance in planning. The difficulty is going to lie in the calibration and testing of these models: the data demands - involving time series - are likely to be more stringent than in any models known hitherto. So while the theoretical insights may be important in the short run, this is likely to be a longer-run development for applied work.

5. Concluding comments

5.1 Model availability

It is clear from this brief survey that there is a wide range of models available which make contributions to the study of residential mobility and that these form a rich basis for future work. A number of suggestions have been made in the paper about how these can be combined in various ways and also how the field may have much to learn from modelling developments in adjacent fields in urban studies. There are some new problems which are just beginning to be effectively tackled - like the study of the effects of 'chaining', and other fields where it may be quite a long time before effective applied work is possible, like the study of criticality. Nonetheless, the substantive conclusion is that a good range of models is available for both analytical and policy work.

5.2 Models and data availability

There is no doubt that if an ideal model was designed, then it would outstrip data availability. But one of the main arguments of this paper has been that models can be adapted to make the best use of available data. In effect, knowledge can be accumulated in a Bayesian way, though this may demand a particular form of organisation of work which is discussed briefly below. It is probably also true that the British record is better than the American one in this respect. There are a number of examples of the development of large scale models where some of the data is missing, but submodels have been added, or various estimation principles adopted, to fill in the gaps in such a way as to allow model building to go ahead. (See Rees and Wilson, 1977, for examples in the demographic field and Wilson, Rees and Leigh, 1977, for a wide range of examples). In general, much use can be made of standard data, such as that from Censuses, and this can be supplemented by a variety of special surveys in particular cases.

5.3 Policy variables and models

There is not a good record in the field of building variables into models which are sensitive to policy (cf. Gale, 1978). In part, this involves some model development which will be referred to in section 5.4 below. But in general, much progress could be made with available models. What is needed is much more experience of the use of models in a policy context and this is picked up in section 5.5 below. Some additional research may be needed on the formulation of evaluation measures, but this issue is closely connected to the difficult task of policy articulation discussed in section 2 above. When policy objectives can be clearly articulated, there should be no difficulty in principle of constructing appropriate evaluation measures from model outputs.

5.4 Institutions and models

Perhaps the biggest gap in available models relates to the roles of institutions in residential mobility. There are both analytical and policy questions involved here. For example, what are the impacts of mortgage availability, both overall and spatially? It would be useful to develop more research, which would be of a historical nature, of the roles of institutions, over a long period and currently, in residential development. Ultimately, such work could then lead to results which could either be incorporated into models or would clarify the way in which models could be used in a policy context.

5.5 The organisation of future work

If models are to make more contributions to policy, then there is probably no substitute for the relevant agencies to become more directly involved. In this way, knowledge can be accumulated in one place, and this also makes a direct contribution to the data problem. Again, knowledge would be accumulated. Monitoring is also important in this context, both for its direct usefulness and also to help in data accumulation. There are useful lessons to be learned from the transportation studies here. It is probably true to say that the policy and planning agencies which have gained most from these studies are those which have had a considerable in-house effort which could be maintained and continued after the initial study.

The other point to stress in this context is the importance of variety in the work to be carried out. It has been emphasised above that housing is part of a larger system and that interdependencies are important both in understanding and in assessing the impacts of policy. This implies that there should be some large-scale model building efforts on the scale of the NBER work for example. But there are also many possible smaller studies which could be carried out. Models could be designed ad hoc in relation to particular problems. It is in the light of this kind of experience, for which there is no substitute, that the best decisions can be made about the future of this kind of work.

5.6 Prospects

It is worth ending by quoting from Harvey (1973) on the problems of the ghettos in American cities and the kind of work needed to solve them:

> "It does not entail yet another empirical investigation of the social conditions in the ghettos. In fact, mapping even more evidence of man's patent inhumanity to man is counter-revolutionary in the sense that it allows the bleeding-heart liberal in us to pretend we are contributing to a solution when in fact we are not. This kind of empiricism is irrelevant. There is already enough information in congressional reports, newspapers, books, articles and so on to provide us with all the evidence we need."

Part of this argument was implicit in section 2 above. There are many well-known problems and much of our research is making little contribution to their solution. This is the sense in which we have to recognise that there is not an intractable data problem. However, I would not agree with the implication of this particular quotation from Harvey (although in this respect, the quotation is out of context and I am not sure he would agree either) that further analytical work is not relevant. But it is as much responsibility of the policy makers to articulate what it is we seek to achieve before this kind of work is likely to become effective. Good progress is possible in both analysis and policy, but past evidence suggests that it is not very likely.

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