The State-of-the-Art in Building Residential Location Models

Francesca Pagliara and Alan Wilson

Abstract This chapter provides an overview of the history of modelling residential location choice. Models of residential mobility typically have developed for illuminating the nature of location choice at different territorial scales or as part of an integrated model of land-use and transport. The latter tend to be more comprehensive in nature, though certain other investigations do consider interactions of location choice with other key decisions, such as work location.

Models presented in this book are described here briefly and are presented here according to three dimensions: theory and method, i.e. the modelling approach at the root of the model; categorisation of residential decision makers; and treatment of space, i.e. continuous, zoning or cells.

1 Introduction

Residential location modelling lies at the heart of one of the grand challenges of contemporary social science. More than 50% of the world's population now live in cities and, in different parts of the world. Effective planning demands a "What if?" forecasting capability and this can be achieved through the development of computer models. Since the elements of a city are highly interdependent, this in turn demands a comprehensive model of a city. Housing, where people live, how they choose their location – the elements of residential location modelling – is a critical element of this modelling task. Urban modelling represents a grand challenge because it can now be recognised as a generic task within the broader field that is now called *complexity science* – the science of understanding and modelling

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F. Pagliara (✉)
Department of Transportation Engineering, University of Naples Federico II, Naples, Italy
e-mail: fpagliar@unina.it

A. Wilson
Centre for Advanced Spatial Analysis, University College London, London, UK

F. Pagliara et al. (eds.), *Residential Location Choice*, Advances in Spatial Science,
DOI 10.1007/978-3-642-12788-5_1,

nonlinear systems. The models presented in this book, therefore, are important for two reasons: first, they are key building blocks for urban models – and, indeed, in many instances, they are presented as components of general models; and secondly, they are exemplars of complexity science.

The models presented here represent the state-of-the-art. However, the ideas behind them have a long history. There are two main strands in this with a number of subsidiary elements, both with origins in the Nineteenth Century. There is a third early Twentieth Century strand which is essentially descriptive geography that we will note below but then not take further in relation to modelling. The first main strand is a focus on economics beginning with von Thunen's famous 1826 model of agricultural land use – "rings" of different kinds of crops around a market – and an associated theory of rent. The second is rooted in spatial interaction – mainly applied to migration or retailing and market areas – by analogy with gravity and hence the notion of "gravity models" – for example, see Carey (1858), Ravenstein (1885), Lill (1891) and in the Twentieth Century, Young (1924), Reilly (1929, 1931), Bossard (1932), Stewart (1942), Zipf (1946) and Iklé (1954). These models were all reviewed by Erlander and Stewart (1990). Neither of these strands, in the first instance, therefore, focused on residential location and structures. The subsidiary strand was contributed by geographers and sociologists: Burgess (1927) had a theory of rings but not based on bid rent – rather ecological notions of invasion and succession. Hoyt (1939) added sectoral differentiation while Harris and Ullman (1945) noted that expanding towns absorbed smaller towns and villages and that this added further polycentric structures. This in turn connects urban structure to the central place theories of Christaller (1933) and Losch (1940) but only indirectly to the theory of residential location.

Residential location modelling as we now know it dates back to the work of Alonso (1960, 1964) who laid the foundations for the economic analysis by applying von Thunen's key "bid rent" idea to residential location; and to Lowry (1964) who used spatial interaction principles in his *Model of metropolis*. Lowry used a very simple interaction model and earlier, Hansen (1959) had based a concept of "accessibility" on spatial interaction which was to play a role in many later models. Authors such as Carrothers (1956), Huff (1964) and Lakshmanan and Hansen (1965) had developed retail models which, again later, could be converted into improved residential location models. A variant on the interaction theme involved casting it in probabilistic form as in the work of Chapin and Weiss (1968). Alonso's model underpinned many future economic models while Lowry's initiated a host of comprehensive interaction-based models each of which had to have a residential location models. There were notable pioneering approaches, initially rooted in the big American transportation studies (e.g. Carroll 1955) which led to land-use transport models such as Penn-Jersey (Harris 1962). Many of the earliest of these are excerpted and described in Putman (1979). The models in this volume have their roots in one of these two strands. There are many histories of these developments: see for example, Batty (1976, 1994), de la Barra (1989), Wegener (1994) and Wilson (1998); Bertuglia et al. (1987) is particularly detailed. Eliasson and Mattson (2000), Iacono et al. (2008), Timmermans (2006) and

Wegener (2004) are more recent examples, with Hunt et al. (2005) providing a detailed review of the most recent large-scale operational modelling systems. Each of these provide routes to many more reviews.

These different perspectives have each been much developed and have to a large extent been integrated. An impetus for this integration came from Wilson's (1967, 1970) development of spatial interaction models on an entropy-maximising basis see also Senior and Wilson (1974). This facilitated the development of more complex models in which the hypotheses could be represented as constraints. There are detailed specifications of residential location models in Wilson (1970, 1974) and these models were tested by Clarke and Wilson (1985). Significant contributions came from Boyce (1978) and Kain (1987). However, the ongoing modelling task remains a formidable one! The system being modelled is immensely complicated and this means that researchers building empirical models have to compromise in various ways. This book offers an extensive range of empirical models and the various examples illustrate the range of choices that modellers have made to make their task feasible. It is interesting to summarise the dimensions of this complexity, how these relate to the roots we have identified and to note how the authors in this volume have responded to the challenges. We consider three main dimensions in turn: (1) theory and method; (2) the categorisation of residential decision makers; and (3) the treatment of space.

1.1 Theory and Method

Many factors can in principle influence residential choice. Lowry rooted his very simple model in the journey to work and the availability of employment. Access to services – such as "good" schools – is another interaction based element. Ways have to be found of characterising the type, quality and price of housing and this again can generate substantial arrays. Ideally, we need to capture the quality of different kinds of environment. Hypotheses on all these factors – and more – have to be incorporated in an underpinning the theory for the model. We have argued that the two starting points are the economic on the one hand – which has the advantage of generating surplus measures – spatial interaction modelling on the other. However, it can be argued, as noted earlier, that the two approaches can be integrated: the logit model and the entropy-maximising model are very closely related – see Wilson (2010) for a recent account of this relationship. One way or another, either the elements of a utility function have to be assembled and combined; or, equivalently, the components of the attractiveness functions in spatial interaction models. The spatial interaction formulation handles constraints very well and it is interesting in a number of these chapters that the importance of constraints has been recognised in other modelling approaches – for example with the development of constrained multinomial logit.

There is a particular theoretical issue associated with change – the dynamics. At any one time, the system of interest is almost certainly not in equilibrium and yet it is necessary at times to calibrate models assuming that it is. The representation of dynamics explicitly is made very complicated by the different "speeds" of the processes involved. There are elements of the population – ready to move – for whom the dynamics are "fast"; the developers are operating at the margin and so also can be considered to be part of a fast dynamics' process. But the whole system changes relatively slowly, though at times there will be phase transitions as whole neighbourhoods change character. It is particularly difficult to model changing land use. In terms of the spatial interaction formalism a method that can encompass phase changes and path dependence – cf. Arthur (1989) – was offered in a retail context by Harris and Wilson (1978) and articulated in a residential location context in Wilson (2000).

A final complication is that the effects of planning and zoning have to be allowed for.

1.2 Categorisation of Residential Decision Makers

The system is complicated by the variety of players. On the demand side, households can be characterised on a great variety of dimensions and this can create unmanageable arrays or model specifications for which there is no hope of assembling the data for effective calibration. On the supply side, the housing stock evolves slowly: developers can create new estates, householders can modify or extend their own properties. Housing is the great consumer of urban land and is in competition with other land uses and so "land" is a third major component of the system description. The finest level of detail which may be desirable produces unmanageable arrays and this leads to the possibility of using microsimulation as a method. This was pioneered by Orcutt (1957) and introduced in a spatial interaction context by Wilson and Pownall (1976). It is now in common use – see, for example, Clarke (1996) – and is used in the models in the Chapters on "Household Behaviour in the Oregon2 Model" by Hunt et al. and "A Microsimulation Model of Household Location" by Feldman et al.

1.3 Treatment of Space

Space can be treated as continuous or discrete – the latter case involving the creation of a zone system. In the limit, of course, a system described through a large number of very small zones mimics continuous space. Economic models, such as Alonso's, have tended to use the continuous representation. It is significant, however, that the translation of Alonso's work into discrete space by Herbert and Stevens (1960) was a significant precursor for the ongoing development of economic models. Interaction-based models nearly always use zone systems notwithstanding the work of Angel and Hyman (1976) in developing continuous space models. In practice, zone systems connect with available data more easily and the models are mathematically more tractable.

Cellular systems are a particular form of zone system and can then be connected to the literature on cellular automata.

When the elements of a residential location model are assembled, many of the components, more probably than for any other urban submodel, are themselves variables in other submodels: employment by location, services by location and transport costs for example. Such problems of interdependence are very difficult to handle outside the framework of a comprehensive model, and it is not surprising that most of the models presented here are developed within such a context.

All the models in this book use discrete zone systems, except for the Oregon model of the Chapter on “Household Behaviour in the Oregon2 Model” by Hunt et al., which uses a cellular system and the Edmonton model of the Chapter on “Stated Preference Examination of Factors Influencing Residential Attraction” by Hunt, which considers individual housing units but only in terms of demand and not in terms of supply or the UrbanSim model of the Chapter on “Modeling Residential Location in UrbanSim” by Waddell, which runs on dicrete zones, gridcells, or parcels depending on the model configuration.

2 Models Described in This Book

The varieties of residential location models presented in this book can be understood against this framework. The framework itself is summarised in Fig. 1.1 and in Table 1.1, the choices made in relation to the models in this book are indicated. In the rest of this chapter, we show how the contents of each chapter link to this framework. Table 1.2 reports the territorial geography of each model and its area of application.

The authors in this book represent a substantial proportion of the community that has the capability to build large urban models and to calibrate them empirically. It is fascinating to see the range of choices that have been made in the interests of feasibility. The reader will be able to tease out very easily the different ways in which the authors have characterised systems of interest and many have systematically reviewed the range of factors which could be incorporated in their models before almost inevitably, paring down their ideal lists.

There is a spin-off benefit from collecting these chapters together: to be able to see residential models developed for such a variety of national environments – covering virtually every continent. Table 1.2 reports the areas of application of the different models.

Table 1.1 summarises the different models reported into the classification shown in Fig. 1.1. The discrete choice/(possibly nested) logit model is much the most popular methodological base – used in the Chapters on “Stated Preference Examination of Factors Influencing Residential Attraction” by Hunt, “DRAM Residential Location and Land Use Model: Forty Years of Development and Application” by

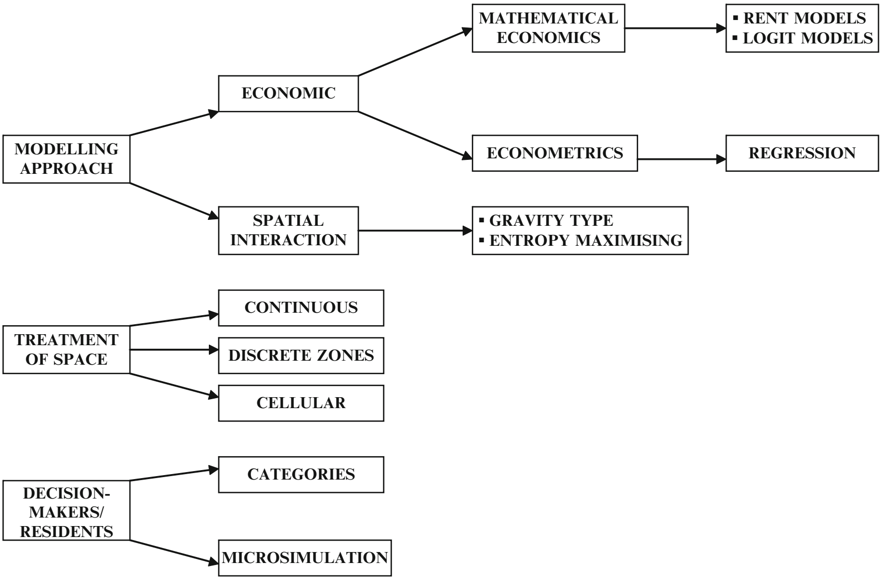

Fig. 1 Framework

Putman, “The Influence of Accessibility on Residential Location” by Eliasson, “Modeling Residential Location in UrbanSim” by Waddell and “The Residential Choice Module in the Albatross and Ramblas Model Systems” by Arentze et al. There are overlaps in these lists as models that start as spatial interaction models are converted into logit models for calibration purposes with a range of econometric methods deployed. The economic basis of the models figures strongly – consider for example the analysis of surplus in the Chapter on “DRAM Residential Location and Land Use Model: Forty Years of Development and Application” by Putman. The notion of bid rents still rates highly showing how Alonso’s wonderful insights still play a major role (Chapters on “The MUSSA II Land Use Auction Equilibrium Model” by Martínez and Donoso, “The Impact of Transport Policy on Residential Location” by Pagliara et al. (2002), and “The Influence of Accessibility on Residential Location” by Eliasson). In Chapter “The Influence of Accessibility on Residential Location” by Eliasson and “The Residential Choice Module in the Albatross and Ramblas Model Systems” by Arentze et al., the economic analysis is explicitly linked to activity patterns. Many of the models emphasise their treatment of constraints in interesting ways (Chapters on “DRAM Residential Location and Land Use Model: Forty Years of Development and Application” by Putman, “The MUSSA II Land Use Auction Equilibrium Model” by Martínez and Donoso, “Modeling Residential Location in UrbanSim” by Waddell, and “The Residential Choice Module in the Albatross and Ramblas Model Systems” by Arentze et al.), including the introduction of constrained multinomial logit models. At this stage, the modelling of dynamics is typically on an incremental basis – essentially from one equilibrium to the next, period by period. In the Chapter on

Table 1.1 Models presented in the book set within the classification

Model – short name	Chapter	Author(s)	Modelling approach	Treatment of space	Decision-makers/residents
Edmonton	Stated Preference Examination of Factors Influencing Residential Attraction	Hunt	Mathematical economics – Logit models	Hypothetical individual residential units regarding demand only	Categories – Households divided into groups
DRAM	DRAM Residential Location and Land Use Model: 40 Years of Development and Application	Putman	Spatial interaction – Gravity type and Mathematical economics – Logit models	Discrete zones	Categories – Households divided into groups
DELTA	The DELTA Residential Location Model	Simmonds	Mathematical economics – Logit models	Discrete zones	Categories – Households disaggregated by composition, age, working status of working-age adults in the household, and the socio-economic group
MUSSA	The MUSSA II Land Use Auction Equilibrium Model	Martínez and Donoso	Mathematical economics – Constrained Logit and Rent models	Discrete zones	Categories – Households divided into groups by in-come, size and car ownership
Oxford	The Impact of Transport Policy on Residential Location	Pagliara et al.	Econometrics – Regression	Discrete zones	Categories – Households divided into income groups
TILT	The Influence of Accessibility on Residential Location	Eliasson	Mathematical economics – Logit models	Discrete zones	Categories – Households disaggregated into income groups
UrbanSim	Modeling Residential Location in UrbanSim	Waddell	Mathematical economics – Logit models	Dicrete zones, cells, or parcels	Categories – Households disaggregated into income, and size
Oregon2	Household Behaviour in the Oregon2 Model	Hunt et al.	Mathematical economics – Logit models	Cellular	Microsimulation
ALBATROSS RAMBLAS	The Residential Choice Module in the Albatross and Ramblas Model Systems	Arentze et al.	Mathematical economics – Logit models	Discrete zones	Microsimulation
SimDELTA	A Microsimulation Model of Household Location	Feldman et al.	Mathematical economics – Logit models	Discrete zones – ward level	Microsimulation

Table 1.2 Models areas of application

Model – short name	Geographical territory scale	Areas of application
Edmonton	Urban scale	Edmonton, Alberta
DRAM	Urban and metropolitan scale	Cities and metropolitan areas in USA
DELTA	Urban and regional scale	Cities and city regions in England, Scotland and New Zealand; national model of Scotland
MUSSA	Urban scale	Santiago, Chile
Oxford	Urban and regional scale	Oxfordshire
TILT	Regional scale	Stockholm region
UrbanSim	Metropolitan scale	Cities and metropolitan areas in USA and Western Europe
Oregon2	U.S.A. state scale	State of Oregon
ALBATROSS RAMBLAS	National scale	The Netherlands
SimDELTA	Urban and regional scale	South/West Yorkshire, England

"The DELTA Residential Location Model" by Simmonds, the notions of "mover pool" and "mobile population" are introduced in an interesting way. And as we noted earlier, a number of the models are rooted in a comprehensive framework and so represent interdependence. Logit models dominate model operationalisation – but it is interesting to see microsimulation beginning to appear significantly (the Chapters on "Modeling Residential Location in UrbanSim" by Waddell, "Household Behaviour in the Oregon2 Model" by Hunt et al., and "A Microsimulation Model of Household Location" by Feldman et al. – the later being a microsimulation version of the Chapter on "The DELTA Residential Location Model" by Simmonds model). Three of the chapters ("Stated Preference Examination of Factors Influencing Residential Attraction" by Hunt, "The Impact of Transport Policy on Residential Location" by Pagliara, and "The Residential Choice Module in the Albatross and Ramblas Model Systems" by Arentze et al.) use versions of stated preference methods to obtain their samples for model calibration. Finally, it will be noted that most of the models have been designed to contribute to the planning process and some engage explicitly with the zoning issue.

While the models reported here cover the main variety of residential location models, usually within a comprehensive framework, there are, of course, others that it has not been possible to include here. These are noted in the various reviews cited earlier. We note several of these approaches here to help complete the picture.

The MEPLAN model system (Echenique 2004), and the closely related TRANUS model system (de la Barra 2001) for developing integrated land use transport models include explicit representation of residential location. Work on these model systems, seeking a generalized representation for application in a range of different contexts, started in the 1980s, drawing on earlier models (Hunt and Simmonds 1993). These systems use a spatially disaggregated input–output structure to represent the behaviour of industry sectors and household categories and their interactions to simulate the spatial distributions of incremental production and floorspace rents arising from an initial allocation of exogenously generated "basic" components. The quantities of floorspace supply by type by geographic zone are adjusted in response to floorspace rents. The model system moves through time from one period to the next. In each period the distributions of incremental production are re-determined in response to changes in exogenous demand and floorspace. From one period to the next, the quantities of floorspace are adjusted in response to the changes in rents.

Households provide labor in response to industry demands at locations selected in response to wage rates, travel costs and the prices of key inputs, including residential space. In many specific applications, household expenditures are allocated among residential space, travel and other goods and services using a Cobb–Douglas function based on utility-maximizing assumptions. Travel costs are represented using a composite utility for the range of available mode alternatives between zones, these developed from a nodes-and-links representation of the available transportation supply. The list of practical applications of MEPLAN and TRANUS is extensive, including London, Napoli (Hunt 1994), Bilbao (Geraldes et al. 1978), Sacramento (Abraham and Hunt 1999), Sweden, Caracas and Mexico City and many others.

The PECAS model system for developing and applying spatial economic models also includes representation of elements of residential behaviour (Hunt and Abraham 2003). PECAS stands for “Production, Exchange, Consumption Allocation System”. It is the name of a generalised framework and associated software system emerging since the year 2000.and now being used in a range of practical applications, including San Diego, Sacramento, Los Angeles, Atlanta, Baltimore and the State of California. (Hunt and Abraham 2005)

PECAS includes a computable general equilibrium structure for representing how “activities” (including industrial sectors, government and household categories) locate within the building space provided by developers and how these activities interact with each other at a given point in time. Flows of “commodities” (including goods, services, labour and space) going from production activity to consumption activity are determined according to technology options available to the activities and allocated from production location to exchange zone and from exchange zone to consumption location using an extended form of nested and additive logit model based on random utility theory (Abraham and Hunt 2007). Prices are determined for each commodity in each exchange zone in order to clear all markets. The actions of developers in the provision of the space (land and floorspace) consumed by activities in each zone – including the new development, demolition and re-development that occurs from one point in time to the next – are determined using a set of joint nested and continuous logit allocation models in response to relative prices, construction-related costs and zoning rules that specify allowable uses and intensities (Abraham and Hunt 2007). The resulting new quantities of space are used in the representation of the interactions among activities for the next point in time.

Households, as particular categories of activities, select residential locations, life-styles (as alternative technology options involving varying quantities of commodity production and consumption, including residential size and type), workplaces (as exchange locations for selling the labor “commodity”), the locations for other actions (as exchange locations for consuming other commodities) – all according to an extended form of nested and additive logit model whose parameters are calibrated for each household type as part of the development of a specific model. Households, as de facto developers when home owners, also determine whether or not to change the type and/or quantity of residential space from one point in time to the next.

Anas and Liu (2007) report the RELU-TRAN model. This is interesting as an economic model that is computationally challenging, interesting, and important but does not conform to linear, quadratic, or other standard nonlinear programming formulations. Rather, such models require the solution of highly nonlinear equations systems using non standard and innovative, iterative algorithms that exploit the special features of those equations. This is the approach that is used to design the RELU-TRAN algorithm. Numerical solution of models using iterative techniques has been a goal, though poorly practiced within the field of transportation and land-use modeling. Meanwhile, iterative numerical methods are gaining broader applicability within economics to solve a variety of problems.

RELU is a dynamic general equilibrium model of a metropolitan economy and its land use. It equilibrates floor space, land and labor markets, and the market for the products of industries, treating development (construction and demolition), spatial interindustry linkages, commuting, and discretionary travel. Mode choices and equilibrium congestion on the highway network are treated by unifying RELU with the TRAN algorithm of stochastic user equilibrium. The RELU-TRAN algorithm's performance for a stationary state is demonstrated for a prototype consisting of 4-building, 4-industry, 4-labor-type, 15-land-use-zone, 68-link-highway-network version of the Chicago MSA. The algorithm solves 656 equations in a special block-recursive convergent procedure by iterations nested within loops and loops within cycles. Runs show excellent and smooth convergence from different starting points, so that the number of loops within successive cycles continually decreases. The tests also imply a numerically ascertained unique stationary equilibrium solution of the unified model for the calibrated parameters.

RELU-TRAN is a spatially disaggregated, computable general equilibrium model based on microeconomic theory and in which economic activity is modeled at the level of fully interdependent model zones with a link-node transport network. It treats the stock of buildings in each model zone as changing slowly while other markets clear instantaneously. The metropolitan economy is treated as open in a number of ways. Consumers can locate their residences or jobs outside the metropolitan area, income can originate from outside and a part of assets within the area can be owned by outsiders, while firms can produce, in part, by paying for inputs located elsewhere. The model treats interactions between firms and consumers and among firms as purely pecuniary, which are sufficient to generate a pattern of spatial agglomerations.

Another example model is described in the work of Deal et al. (2005). They describe the Land-Use Evolution and impact Assessment Model (LEAM) which uses the STELLA/SME/GIS collaborative environment for the purpose of developing a Planning Support System (PSS) to generate and evaluate development patterns. It describes land-use changes across a landscape that result from the spatial and dynamic interaction among economic, ecological, and social systems in the region.

In the LEAM approach, groups or individuals who have substantive knowledge relating to a particular system develop and test separate models of that system. These contextual sub-models are linked and run simultaneously in each grid cell of a set of raster-based GIS map(s) to form the main framework of the dynamic spatial model (LEAM).

Inputs to the model use national land-use data sets (at 30 × 30 m resolution), census and economic data (readily available and transportable for application to multiple sites) along with variables relating to impact assessment sub-models (e.g. habitat, ecoregional inputs, water and energy inputs) to set model parameters. The products of LEAM model runs are analyses of a series of policy scenarios, presented as GIS maps or movies that show the transformation of the subject landscape as a product of policy related inputs. These dynamic visual outputs are beneficial for testing policy scenarios and raising concerns regarding the impacts of development, environmental degradation, or conflicting land-use policies. The final PSS tool will include a simple user interface and transportable data sets for application to multiple sites.

The economic model in LEAM (LEAMecon) forecasts changes in output, employment and income over time based on changes in the market, technology, productivity and other exogenous factors. The resulting economic trend is used as an input to a dynamic housing market simulation that then feeds into LEAM as residential land-use change. The agent-based housing model predicts actual houses built in a given year based on trends in the economy and anticipated demand by specific population cohorts. The combined economic and housing model serves as a prime driver of land-use change. Through LEAM, this work connects knowledge in regional science, housing markets, and spatial land-use analysis.

In the first substantive chapter “Stated Preference Examination of Factors Influencing Residential Attraction” by Hunt, a Stated Preference (SP) approach is used to develop a representation of household sensitivities to a range of both local and urban-level elements of residential locations. Each of a sample of respondents/residents in the population in Edmonton in Canada was asked to imagine moving the household to a new home location and to indicate preferences among hypothetical alternatives for this new location, with these alternatives described in terms of attributes related to the elements of interest, including housing type, mode specific travel times and costs for work and shopping, air quality, traffic noise, local street treatments, walking connectivity to local schools, and rent or taxes. The observations of choice behaviour thus obtained were then used to estimate logit choice models with utility function parameters indicating the sensitivities to these attributes. The results are indications about the influences on residential location and models incorporating representations of these influences.

In the Chapter on “DRAM Residential Location and Land Use Model: Forty Years of Development and Application”, the Putman DRAM model is presented as a component of the wider package ITLUP (Integrated Transportation and Land Use Package), which is arguably the first fully operational transportation-land use modelling software package. This has its origins in Putman (1983, 1991). It has now been applied in nearly 30 different metropolitan regions for public agency forecasting and policy analysis purposes. Designed on the Lowry framework, ITLUP offers a network representation that allowed for the incorporation of congested travel times in the distribution of activities. At the core of ITLUP are two allocation submodels: a household allocation submodel, which is DRAM, and an employment allocation submodel, EMPAL. Trip generation and distribution functions for the travel forecasting model are developed within DRAM, simultaneously with household location. Travel times from runs of the travel mode are fed forward to compute new activity distributions.

An interesting feature of DRAM is the location surplus measure, which defines the aggregate benefit households receive from the attributes of their chosen residential zone. The larger the value of location surplus, the more utility households receive from their choices of residential location. The surplus measures used in DRAM can be derived by using either of two different methods. Both methods produce the same location surplus measures and are based on the assumption that households attempt to maximize utility when choosing residential locations. For the first method, the DRAM model is interpreted as a multinomial logit model and the location surplus measure is found by calculating aggregate indirect utility. In the second approach, the location surplus measure is found by directly integrating the DRAM travel demand function.

The Chapter on “The DELTA Residential Location Model” by Simmonds describes the residential component of the DELTA land-use/economic modelling package. In its core, markets for residential and commercial real estate are represented, with transportation models linked into the overall model structure. The model system is divided into processes that represent spaces and those that represent activities. Processes dealing with activities include household formation and dissolution, employment growth or decline, location and property markets, and the employment status of individuals. The model system is designed to be run over a series of short steps of no more than 1 or 2 years. The main objective in creating this package has been that of creating a practical tool to forecast urban and regional change, and in particular to examine the expected impact of transport change; to provide a land-use/economic model which works in interaction with any appropriate transport model, and can therefore be used to extend relatively conventional transport models into land-use/transport interaction.

The location sub-model is both the “location and relocation sub-model”, and the “property market sub-model”. Mobile activities respond to changes in five variables: accessibility; quality of the local environment in general; quantity of housing; quality of housing; and the cost or utility of consumption, i.e. of spending income on housing, travel, and other goods and services.

DELTA is intended to be applied with a detailed classification of households reflecting household composition, age of household members, working status of working-age adults in the household, and the socio-economic group to which the household belongs. An important characteristic of the model is that only a proportion of households make residential choices in any one period. It is assumed that the main reasons for making a new residential choice are linked to change in one of the household classification variables, e.g. a change in the household’s composition or in its work status. The households in the location model fall into two groups: “pool” households, which have no previous location within the area, and “mobile” households, which do have a previous location within the area modelled. Newly formed households and households resulting from existing households merging (e.g. singles forming couples) are assumed to make new location decisions and are counted as “pool” households. “Mobile” households are those which are undergoing other changes (mainly from couple with children onwards). In addition, a proportion of non-changing households is assumed to be “mobile” in each period. The numbers of “mobile” and “pool” households are initially calculated in the household transition model (which also finds and subtracts the numbers of households which have dissolved or migrated out of the modelled area altogether). The inter-area migration model is then applied, before the location model. The migration model predicts moves of households between areas within the modelled system: these households are subtracted from the “mobile” and “pool” numbers for the areas they leave, and added to the “pool” numbers for the areas into which they migrate. Households migrating from the rest of the world are also added to the “pool” numbers. The main location equations are weighted incremental logit functions, with slightly different forms for “pool” and for “mobile” households.

In the Chapter on “The MUSSA II Land Use Auction Equilibrium Model”, the MUSSA model is described by Martinez and Donoso. It is designed to forecast the expected location of agents, residents and firms, in an urban area. It presents an alternative framework for modelling land markets in transportation and land use models by adopting a modified version of the bid choice framework as it combines bid rent and discrete choice approaches to land markets by dealing simultaneously with both sides of an auction in an integrated framework. Real estate is allocated to the highest bidder by auction and market equilibrium is attained by the condition that all agents are located somewhere, and therefore supply satisfies demand. This auctioning process produces rents for each real estate in the market and simultaneously defines levels of satisfaction (benefits) to located agents at equilibrium. A discrete approach is followed for all units of demand and supply: households and firms are clustered into categories, while land is divided into zones and dwellings into types; the number of discrete units is defined by the modeller. Consumers’ agents, households and firms, are assumed rational and their idiosyncratic differences are modelled by a stochastic behaviour.

The place of MUSSA in the context of other land use models can be defined from a theoretical and historical perspective. A first generation of these models was designed under the assumption that agents locate as to minimize the travel cost to other activities, which may be called the maximum access model, where the transport system has a predominant role. Several models of this class were developed following either Alonso’s bid-rent approach or Lowry’s gravity – entropy – approach, or even a combination of these two. A second generation introduced market elements into the location problem by including rents and good prices, what we call the linear market model. Rents have been introduced in two ways, using a hedonic rent function based on average zone attraction indices, or by assuming the location options are quasi-unique so rents are the result of simulating an auction process known as the bid-auction approach. In this case, input–output tables have been used to incorporate spatially differentiated prices on goods. The third generation introduces an important amount of complexity into the model by incorporating an explicit representation of the direct interaction between agents decisions, that is the interaction that affect behaviour in addition to the price effects. These interactions describe the fact that location options are valued, by all agents and in a significant degree, by their built environment and the location pattern, usually called zone attributes.

A significant difference with other land use models is that in MUSSA the interaction between consumer agents – households and firms – is explicitly described in agents' behaviour and solved to attain equilibrium. This model was renamed as CUBE LAND with application currently being developed in several cities of USA, Europe and Asia.

The models developed for Oxford (Pagliara et al.) in the Chapter on "The Impact of Transport Policy on Residential Location" are not integrated into a formal package. The aim is that of assessing the extent to which transport impacts on residential location decisions and hence on house prices and that of evaluating the extent to which transport policy decisions (such as road user charging, work place parking levies, changes to fuel duties or the provision of light rapid transit systems) affect housing markets. This was achieved by undertaking two Stated Preference (SP) experiments in the Greater Oxford area divided into discrete zones, each with around 100 respondents corresponding to householders disaggregated into income groups. The aim was to determine the key transport and location factors that householders take into account when determining their residential location. It was intended that the choice models developed from the Stated Preference experiments would be used in conjunction with data on house prices to produce a bid choice model. However, price data was not available at a detailed enough level of spatial aggregation to permit calibration of an appropriate bid choice model. Instead, the SP data was used to develop an Hedonic Pricing (HP) model. Validation tests indicate that the HP model provides more reliable forecasts of house prices than the SP model. The HP model was used to provide preliminary forecasts of the impact of transport improvements on house prices in the Greater Oxford area.

In the Chapter on "The Influence of Accessibility on Residential Location", Eliasson describes the influence of accessibility on the household's location decision has been modeled through the use of the comprehensive TILT (Tool for Integrated analysis of Location and Travel) model. The main theoretical contribution is an elaborate specification of what it is meant meant by "accessibility" in this context. This is done by assuming that households, disaggregated into income groups, make a joint choice of location and activity pattern subject to income and time constraints. This activity pattern implies a stochastic travel pattern, the expected value of which is known at the time of location. The locational utility then consists of four parts: the indirect utility of income and time net of housing cost and expected total travel time and travel cost, the direct utility of the optimal activity pattern, the direct disutility of the expected travel pattern and the direct utility derived from location characteristics. The locational utility is then used in a discrete choice model for the choice of residential location.

In the Chapter on "Modeling Residential Location in UrbanSim" Waddell describes the residential component of UrbanSim, which is a microsimulation model of land markets, noted as the most widely used model today by Metropolitan Planning Organizations in the United States. It uses a flexible, modular structure to implement models that can be adapted to differtent geographic units such as zones, gridcells or parcels. The model system emphasizes clear behavioural realism, and attempts to avoid abstract modelling assumptions that are not reflected in observed behavior.

The UrbanSim model system contains model components representing household and employment relocation and location choices, and real estate development. The function of the household location choice model is straightforward, as is the data structure on which it operates. A list of households, generated using a synthetic population synthesizer, is represented in the base year database as a table with one row per household. Each household has a unique identifier, attributes such as number of persons, income, number of workers, presence of children, and a unique identifier for its location. As the model system proceeds in the first simulation year, the demographic transition model adds new households to the household table, providing their characteristics and a unique identifier, but not a location identifier. Then the household relocation model simulates the choices of certain households to move from their current location, and resets the location identifiers of the moving households to a null value. As a result of these two models, then, the household table contains some households that have moved into the region, and some that have been predicted to move within the region. These locating households are selected by identifying all households in the table that have a null location identifier. This is the set of households that the location choice model is applied to.

The framework for the household location choice model, like most of the models in the UrbanSim model system, is a standard choice model. Although more sophisticated choice model structures can be used, the most common in practice is the Multinomial Logit Model (MNL). The underlying logic of the model is that households that are in the market for a location take into consideration their own characteristics, such as income, and household size, and consider some sampling of available, vacant housing units and consider their price and characteristics such as density, age, and accessibility to employment and other opportunities. The relative attractiveness of these alternatives is measured by their utility. The choice model then proceeds to compute the probabilities of making a location choice from the available alternatives, defined as vacant housing units, given the preferences and budget constraints of locating households. Once location probabilities are computed, the predicted choices are simulated, using one of the available algorithms to reflect different assumptions regarding how the housing market clears. The model proceeds in steps. After loading the model specification and coefficients from input data, the model selects the agents that will be making a choice.

UrbanSim is implemented in the Open Platform for Urban Simulation (OPUS), and runs on multiple operating systems, using standard desktop or laptop computers.

Computational performance is efficient, with run times reported for parcel level model of San Francisco of 2–3 min per simulation year, using a full population for microsimulation.

In the Chapter on "Household Behaviour in the Oregon2 Model" the Oregon2 model is described by Hunt et al. It uses a set of seven connected modules representing different components of the full system, each running in turn for each year of simulation. Two of the modules concern elements of household behaviour. The household allocations module provides an agent-based microsimulation of each household and each person, simulating the transitions and choices made by these agents over 1 year. The Land Development Module provides a representation of space development using 30 m × 30 m grid cells covering the model area, microsimulating development transitions occurring in each cell over 1 year. It determines changes in developed space over time and in response to potential policy actions involving pricing, regulation and infrastructure in both transportation and land use. The Household Allocations (HA) Module provides a fully disaggregate representation using an agent-based microsimulation of each household and each person, simulating the transitions and choices made by these agents over the period of 1 year. The intent is to perform an endogenous determination of changes in social characteristics, so as to provide a more complete and consistent representation of demographic changes over time and in response to a wide range of potential policy actions involving pricing, regulation and infrastructure in both transportation and land use.

An initial population of households and household members for use in the simulation, with all attribute values assigned, is synthesized for the year 1990 using a sampling process that draws on a disaggregate sample of actual households and relevant marginal distributions from the Census.

The state-of-the-art in transportation and land-use modelling is defined by current research efforts aimed at building comprehensive microsimulation systems of urban areas, with representation at the level of individual agents (persons, households, firms, etc.) and simulations of the behaviour of the entire population of interest. The advantages of adopting such modelling approach for urban systems are that urban systems are dynamic, with a significant time element and components changing a different speeds. The behaviours of these systems are complex, with interacting agents, complex decision-making processes, and significant probabilistic elements. Closed-form mathematical and statistical representations of urban systems often induce large amounts of bias and lead to poor forecasts. Chapters on "The Residential Choice Module in the Albatross and Ramblas Model Systems" by Arentze et al. and "A Microsimulation Model of Household Location" by Feldman et al. deal with this issue. MUSSA, UrbanSim and Oregon2 present disaggregated households at a level of detail sufficient to operate them in a static microsimulation format, where a representative sample is used within a microanalytic framework for short run applications. However, for long run forecasts, the population should be synthesized or updated to represent the dynamics of individuals and the environments within which they make choices.

In the Chapter by Arentze et al., they describe the residential choice component in the Albatross and Ramblas model systems. Both models are primarily activity-based models of transport demand. Their prime goal is to predict activity-travel patterns and associated traffic flows. The distribution of residential land use, in terms of households and persons, is exogenously given in the case of Albatross. The spatial distribution of residential land use plays a double role in the simulation of activity-travel patterns in both models. First, both models assume the construction of a synthetic baseline population at the start of the simulation period. To that effect, the number of individuals and their values on a set of sociodemographics in each postal area are predicted, reflecting the spatial distribution of residential land use. This distribution influences the activity agendas and the spatial–temporal constraints underlying the models. This data can be exogenous to the models, implying that the relevant distributions should be based on an external model or data source and the creation of the synthetic population takes places at each simulation run. Secondly, residential land use is an integral part of the dynamics in the model systems. In this case, the aging and redistribution of the population, partly reflecting residential choice behaviour, is internal to the model system. In this case, a special sub-model or module predicts housing choice behaviour as a function of sociodemographics, characteristics of the available dwelling stock, characteristics of the transport network, and possibly activity agendas.

In the Chapter "A Microsimulation Model of Household Location" Feldman et al. describe the development of SimDELTA, which is a new microsimulation model of individual and household changes and choices within a land-use/transport interaction modelling structure as a development of the DELTA model. The microsimulation components explicitly model changes to members of the sample over time (rather than, as in many other microsimulation models, generating a separate sample for each modelled period of the forecast). The microsimulation modelling is carried out at ward level. The major strength of the model is naturally its disaggregate and dynamic nature, which means that the user can aggregate the output at any desired level of household or person characteristics, and that it is possible to trace individuals, households, jobs and dwellings over time so as to observe the modelled processes of change at a level of detail that is simply not possible in other types of model.

These chapters offer a very rich set of models. They are valuable in themselves and provide the foundation for the next generation of researchers working in this field. It is an effective representation of the present state-of-the-art.

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