CALIBRATION AND IMPLEMENTATION OF RESIDENTIAL LOCATION IN LAND-USE/TRANSPORT INTERACTION MODELS

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1. INTRODUCTION

It is widely accepted that there is a two-way relationship between land-use and transport. The effects of a change in the level of activity, for example, the number of residents living in an area on the number of trips made, and the impact of a significant new transport link on the level of activity are both observable phenomena (Mackett, 1992). The former tends to be more rapid and easier to observe, and so there is a common view on the processes involved in the relationship, in terms of the trip generation, trip distribution, modal split and assignment, with a variety of approaches to modelling the processes. However, there is not common view on how to model the converse relationship.

The term land-use covers a variety of topics, including activities such residing, working and shopping; physical infrastructure such as homes and workplaces; and the outcomes of market processes, such as property of land uses. All this topics can be influenced by changes in transport, which will have a consequential effect on travel.

There has been a major revival of interest in land-use/transport interaction modelling over recent years. A number of major reviews of available models have been published, generally concentrating on the designs of the commercially available model packages and of some of the academic model software.

The objective of this paper is on the review process one stage further, looking more closely at a sub-model common to all land-use/transport models, that for residential location. It reviews the residential location sub-model used in a number of land-use/transport interaction models of widely differing complexity. The way in which the various models locate population and housing, the variables used to represent these quantities and the linkages between them are represented. In particular, the focus will be on the different approaches to calibration and implementation that have been adopted in a range of model packages.

Comparison of the different approaches emphases the way in which data availability limitation constrain model development, but also highlights some differences in approach, particularly between the developers of relatively simple models and the developers of more complex software in which the residential location sub-model is only one of several inter-related sub-systems to be calibrated. Hence, in order to follow this framework, the description of the models will be presented considering first the simple residential location model passing through a series of more sophisticated models embedded in more complex software.

The selection proposed does not pretend to cover all possible approaches, but gives a panorama of both models, which are part of a major land-use/transport interaction packages and free-standing models.
The models which have been considered in this process of comparison are starting from the simpler model of residential location choice that for New York city, then two examples of models, calibrated on the same city, coming from academic contributions of the school of transport of Naples (Italy) are described. DRAM developed by Putman as part of the package ITLUP is reported; then the residential component of the MEPLAN package, as applied to Naples, is described. The last two models are the residential location elements of the IRPUD model of Dortmund, and DELTA application to the Trans-Pennine regions of Northern England.

2. THE NEW YORK CITY MODEL

The residential model was developed for the New York City metropolitan region as part of the travel demand modelling efforts of COMSIS Corporation for New Jersey Transit under the New Jersey Hudson River Waterfront Study (Clarke et al., 1991). The model could be integrated into a disaggregate modelling framework.
The main assumption is that the model estimates residential location given the location of employment. Households have been grouped into four income classes.
The variables present in the model are:

3. Travel time
4. Housing price/Income
5. ln(Number of Residential Units)
6. Percent Multi-Family units
7. Large Family/Percent Single-Family units
8. Small Family/Percent Multi-Family units
9. Logsum for Single-Family household
10. Logsum for Multi-Family household
11. Multi-Family Constant
12. Violent Crime rate
13. Worker income 1/HH income 2 and all the other combinations

Each data sources had grouped their data into different geographic aggregations. Data describing the characteristics of the zones were at the Minor Civil Division. Travel time data were based on a transportation network system, which used a combination of municipal boundaries outside of the study corridor and sub-sections of municipal boundaries within municipal borders, which fell within the study corridor itself. Data describing the choice-maker was coded at the census tract.
The calibration was done by using the ALOGIT software package applied to 190 municipalities (zones) comprising Northern New Jersey. All the parameters were significant and of the expected sign.

14. THE MODELS FOR THE CITY OF NAPLES

Calibrating the Naples land-use and transport model has been the objective of many studies (Hunt 1994 see section 5), (Bifulco 1999) and (Cascetta et al., 2000A).

The first models described come from academic research carried out in the Department of Transportation Engineering of Naples (Italy) and they are the works of Bifulco and Cascetta et al. They are very similar in the formalisation, but not in the calibration procedure. For sake of simplicity, they will be named model 1 and model 2 respectively.

In general, both models are based on an explicit simulation of the whole multimodal transportation system, which integrates road, pedestrians and transit networks. In particular, simulated land-use interactions are relative to residential and economic activitiy location, based on behaviourally consistent accessibility measures (logsum variables) as well as potential demand for economic activities and available floorspace. Active and passive accessibility have been both defined and considered.

<u>The Residential location sub-model.</u>

Following a behavioural approach, in both models the problem of simulating the clearing of the urban residential market can be described as that of allocating *h* types of residents in *i* sub-areas or zones of the city from *j* places of employment. In this case *h* refers to the income level.

The basic difference between the two models is the residential disaggregation. In model 1 the households are disaggregated in high, medium and low income levels; in model 2 are the residents who make the location choice and they are disaggregated in high/medium and low income groups respectively.

In table 1 the attributes of the systematic utility influencing the residential location choice are reported for the two models described.

MODEL 1	**MODEL 2**
available floorspace in zone *i*	ln of the housing stock in zone *i*
average housing prices in zone *i*	average housing prices in zone *i*
active accessibility to retail in zone *i* for residents of type *h*	active accessibility to services in zone *i* for residents of type *h*
work-trip costs	active accessibility to work in zone *i* for residents of type *h*
environment quality (dummy variable)	prestige of zone *i* (dummy variable)
housing saturation rate	council houses ratio in zone *i*

Table 1 – Attributes influencing residential location choice in the two models

In model 2 the inputs to the calibration of the residents location choice sub-model include direct observations data. These inputs are of two different types and they are the Census of Population 1991 (ISTAT, 1991) and an RP mobility survey employed by the company ITER in 1998. The data obtained by the latter

are mainly related to transport rather than to land-use. However, they have been useful in order to identify residents of a particular income, living in a given zone of the study area. The information given by the Census have been updated and supplemented by data obtained by the municipality and estate agencies (especially for the average housing prices). The utility function parameters have been estimated with the Alogit software package.
The study area is the urban area of the city of Naples, which has been divided in 145 zones. The results obtained are significant; all the parameters are statistically significant and are all of the expected sign.
The procedure adopted in model 1 for the calibration of the parameters of residential location choice is different in that it compares model results with the observed urban system pattern. The basic idea is that the model should predict the observed distribution of endogenous activity locations. Parameters are turned until a satisfying reproduction is obtained. The sum of squared errors between predicted and observed data has been minimised. The land-use attributes have been obtained by estate agencies, while the transport data are given by assignment on the network. The study area, in this case, has fewer zones 27 for the urban area (145 in the first case) and 12 for the neighbouring. Also in this case all the parameters are significant and of the expected sign.

1. DRAM – DISAGGREGATE RESIDENTIAL ALLOCATION MODEL

The residential location model described below is part of a wider package called ITLUP. The latter is made up of four principal models plus a number of minor sub-models. The four principal models are: 1) EMPAL, for employment location, 2) DRAM, for simultaneous household location and trip distribution, 3) MSPLIT for modal split calculation and 4) NETWK, for trip assignment (Webster et al., 1988). DRAM allocates population according to zone attractiveness calculated according to period t values, but based on zone-to-zone travel costs and the distribution of employment for period t+1. In addition to the origin-destination work trip matrix, DRAM also produces matrices of work-to-shop and home-to-shop trips.
The household (residence) location model DRAM allocates households to the zones using a modified version of the standard singly-constrained spatial interaction model (Wilson, 1974). The modifications are embodied in a multivariate, multiparametric attractiveness function, and in a consistent, balanced constraint procedure which allows zone and/or sector-specific constraints, corresponding to zoning and planning regulations or particular land-use policies. The attractiveness function makes a zone attractive for new residential development if there is plenty of vacant developable land, but only if substantial residential development is already present to provide the necessary infrastructure. Households are normally categorised into income quartiles, and the attractiveness function also depends upon the proportions of households in different income categories already resident in the zone. Allocation of households of different types then depends upon this attractiveness and the access cost to employment of different types.
If a complete data set is available for a given urban area, and considering four types of residents, then a calibration is done for each type. Each of these

calibrations involves estimating nine parameters, using the techniques described in Putman and Ducca (1978A) and the gradient search.
The procedure is to select a criterion, which one may measure the “goodness of fit” of the model formulation to the data set being used for calibration. This criterion will be a function of an observed variable and of a set of estimates of the variable.
Calibration results were presented in Putman and Ducca (1978B) for twelve US cities plus Vancouver BC. The case it is described here deals with the city of Hong Kong. The area includes the island of Hong Kong, plus Kowloon and New Kowloon on the mainland. They have been divided into 111 zones. The zone-to-zone impedance matrix was based on distances in km adjusted for the fact that Hong Kong connects to Kowloon principally via a tunnel and causeway. The Hong Kong data set was, with the exception of the impedance data, the most complete data set of all those available for non-US cities. Thus it was possible to estimate the full nine-parameter version of DRAM. Results obtained testify that the upper-income households in the Hong Kong metropolitan area may well live rather close to their workplaces. Low-income households are almost equally likely to be found located in zones with high proportions of low-middle-income households. However, low-middle-income households are also rather likely to be found in zones with high proportions of low-income or upper-middle-income households. Upper-middle-income households are most likely to be found in zones with high proportions of upper-middle-income households, but are also likely to be found located with lower-middle-income households as well.

2. MEPLAN

MEPLAN (Echenique, 1994) is a multi-purpose software package developed by M&P in 1984. The example reported here deals with the Naples metropolitan area. The project, commissioned by Ansaldo of Italy on behalf of the Municipality of Naples, included some survey work to collect data specifically for the model calibration. One of the main objectives was to synthesise origin-destination matrices for use in various planning exercises.
Cluster analysis was used with various household characteristics to define five categories of household based on occupation of the head of the household: agricolture (1), white collar or self-employed (2), owners of firms or managers (3), blue collar (4) and “others” (5). Recognition of the potential influences related to the relatively large public housing sector in Naples led to the definition of two types of residential floorspace – public (PUB) and private (PRV) – and to the splitting of the categories of households eligible for public housing into public and private components. This resulted in a total of eight different categories of household. Concerns about the effect of (and the potential impacts of planning policies on) these characteristics also influenced the structure of the model with regard to household category 5: some households in category 5 are “consumed directly” by households in categories 2 and 3 and those households in category 5 that do not contribute any production to the Naples economy are specified exogenously (as exogenous production). Concerns about regional development issues led to representation of the level of imports demanded by each factor.

The general framework of the model uses an input-output type format to establish the demand for further production to satisfy consumption arising as part of the production activity in a given zone.

The Residential location sub-model

The number of households of a particular category are allocated to a residence zone according to the following factors:

- the cost of living for a household locating in that zone (floorspace rent plus costs of services)
- the amount of floorspace the household will consume (a function of the rent and of the income of the household)
- the amount of residential floorspace in the zone
- the accessibility to suitable employment opportunities for the employed members of the household (transport costs and times for work trips)
- the accessibility to shopping and services (transport costs and times for non-work trips)
- the intrinsic attractiveness of the zone to that SEG.

The calibration of the model was complicated by the fact that the land-use data and the transport data were available for different years: 1981 for the land-use data and 1989 for the transport data. (A four-year step size was chosen in part because two steps would then fit neatly within the eight-year gap between data). This disparity regarding points in time meant that a circle for a single given point in time could not be considered directly.

The approach in this case was first to use the 1981 and 1989 data as if they were all 1985 data, get the circle started, and arrive at some initial parameters.

When these initial parameters had been identified and the circle was stable, then the full set of incremental allocation models was developed with data for the period from 1985 to 1989, with the parameters for these models estimated by applying generalised least squares on linearised versions of the model equations developed by taking algorithms. The 1985 pseudo-circle was then pulled out to a helix operating from 1977 to 1989.

Further trial-and-retrial efforts were then used to adjust the land-use sub-model parameters according to 1981 conditions and carry them forward in the model; to adjust the transport sub-model parameters according to 1989 conditions and carry them back in the model; and to adjust the parameters in the incremental allocation models in response to the changes in the synthesised 1985 values.

3. IRPUD

The IRPUD model of Dortmund (Wegener, 1985) contrasts markedly with many aspects of the preceding models. It provided much of the inspiration for the overall approach taken in the DELTA package (see below).

Key features of IRPUD's treatment of the housing market are that

- it does not assume that supply and demand arrive at equilibrium;
- it takes account of the limited information and high uncertainty surrounding housing market decisions, by modelling search behaviour both of households seeking dwellers and of landlords seeking tenants
- it does this by using micro-simulation.

The housing market model starts from the situation in which

- all households and dwellings have been aged by one simulation period
- life cycle changes in households have been processed (these may, inter alia, create new households, and affect the satisfaction of households with their present dwelling)
- in-migrant households have been calculated

The decision behaviour of households is controlled by measures of housing satisfaction, represented by a utility function including housing size and quality, neighbourhood quality, location and housing cost. (taking account of the preferences and requirements of each household type). The neighbourhood quality can include a wide variety of factors such as

- population density
- percentage residents in the same income group
- floorspace per dwelling
- rooms per person
- % low quality housing
- % land in industrial use
- etc

The location element is introduced by accessibility measures based on the mean trip utility either to different sets of opportunities (potential destinations) or to actual destinations for different trip purposes. In addition, for households with existing locations, a measure of “migration utility” is calculated to describe the locational attractiveness of alternative zones relative to their present zone.

The model operates by a Monte Carlo simulation in four phases

- sampling, ie identification (from the aggregate starting data) of a household which is going to look for a new dwelling, or a dwelling that a landlord wishes to let;
- searching, ie looking for a dwelling, or a potential tenant;
- choice, ie acceptance or rejection of the dwelling or the potential tenant identified; and
- aggregation, ie adding the resulting change (if any), scaled up by the sampling factor, to the aggregate end data, both in terms of household location and in terms of dwelling vacant and occupied.

The search process takes explicit account of distance from the previous location: households are less likely to search far away. The choice process assumes satisfying behaviour, ie households accept a dwelling if it offers a significant improvement in housing satisfaction relative to their present dwelling. If the first dwelling is rejected, the search and choice processes are repeated a number of times; if, after a number of unsuccessful searches, it has still not found a worthwhile move, the household is forecast not to move in this period. A similar process is applied to represent landlord’s attempts at letting their dwellings. The proportion of simulations starting with a household-seeking-housing or with a dwelling-to-let depends on market conditions and is intended to make the simulation more efficient rather than to modify the results. The simulation ends when no more households are considering a move. Note that housing rents are kept constant within each simulation period; they are updated between periods to reflect regional rent inflation, quality changes and a response to change in demand as indicated by the vacancy rate.

The IRPUD model was calibrated not by statistical estimation but by “judgement, inferences, analogies and careful checking of plausibility” (Wegener, op cit, p 182), including some formal analysis of data for the base situation. Considerable emphasis has been placed on validating the model’s performance against observed change over time.

4. DELTA

DELTA (Simmonds 1999, 2001) is intended as the “land-use” component of a land-use/transport interaction model, with the transport component being provided by other software. In the Trans-Pennine application, the transport model was implemented using MVA’s START package, as described by Simmonds and Skinner (2001). DELTA consists of a database structure and a number of sub-models each representing one or more recognisable process of urban change; some though not all of these respond, usually with time lags, to the results of other processes.

<u>DELTA households’ location sub-model</u>

The main attributes influencing the location choice respond to changes in four variables:

- Accessibility;
- Quality of the local environment;
- Quality of the area (particularly of housing);
- The cost or utility of consumption, i.e. of spending income on housing, travel, and other goods and services.

The model program is the following:

- Find densities for floorspace-using activities, at the current rents (from the last iteration, or - in the first iteration - from the last database)
- Find the utility of consumption or cost of location at that density and rent, for floorspace-using activities;
- Calculate the location of all activities, given the current utility of consumption or cost of location and all the other location-influencing variables;
- Find the total amount of each type of floorspace "occupied", given the location of each type of activity (from step 3) and the density (from step 1); if this is not equal to the amount of floorspace currently available, adjust the rents and repeat the calculations;
- Adjust supply of floorspace on the basis of the rent change since the last period; if no further adjustment needed, finish, else go back and repeat steps 1 to 4 until converged again.

Each activity can use only one type of floorspace, but there may be many activities competing for each type of floorspace. The program deals with each type of floorspace in turn. It carries out steps 1 to 3 for all the activities which use that type of floorspace, then applies step 4. That sequence is repeated until the amount of floorspace used by the activities equals that available, i.e. until the model has "converged" for that floorspace type at this level of supply. The supply is then adjusted (if elastic) in accordance with change in rent since the last period, and the calculations are repeated. When no further change occurs, the program continues with the next floorspace type.

This process is shown diagrammatically in Fig. 1.

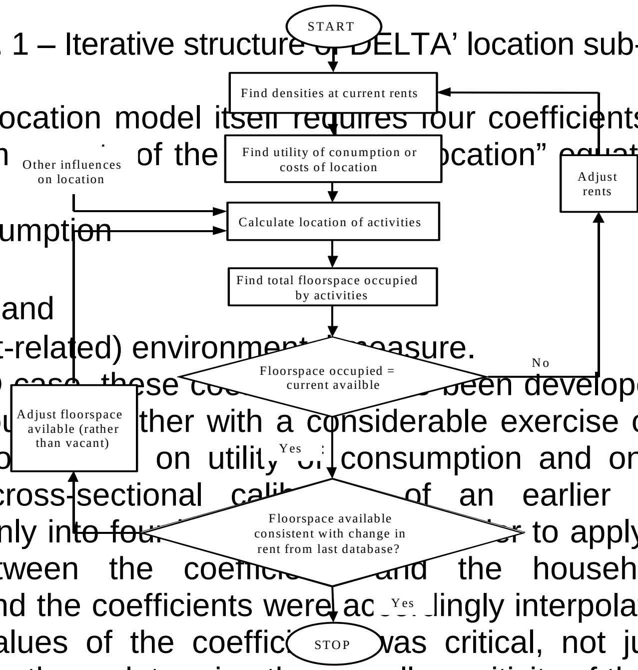

Fig. 1 – Iterative structure of DELTA' location sub-model

The residential location model itself requires four coefficients in order to weight the different com[illegible] of the [illegible]ocation" equation. These apply to changes in:

- utility of consumption
- area quality
- accessibility, and
- the (transport-related) environment[illegible]easure.

As in the IRPUD case, these coe[illegible] been developed from a variety of sources and brou[illegible]ther with a considerable exercise of judgement. Initial values of the co[illegible] on utility of consumption and on accessibility were derived from cross-sectional cali[illegible] of an earlier model for Bristol, disaggregated only into fou[illegible] to apply them in DELTA, a relationship between the coeffici[illegible] and the household incomes was hypothesised, and the coefficients were ac[illegible]ingly interpolated or extrapolated. The absolute values of the coeffic[illegible] was critical, not just the relationship between them, as these determine the overall sensitivity of the model.

Note that the two coefficients derived from the Bristol work deal with the effect of the variables that must change for the model to work at all, i.e. accessibility and housing rent. The coefficient on utility of consumption was particularly important, because given this, it is possible to derive the coefficient for any of the other variables that will reproduce an exogenously researched willingness-to-pay. This has been the main basis for the other coefficients, drawing on a variety of literature and on research carried out for enhancement of the DELTA calibration by the University of Leeds Institute of Transport Studies (Wardman et al, 1997).

8. COMPARISON OF RESIDENTIAL LOCATION MODELS

In this section, we attempt to draw out some of the interesting points of comparison between the models outlined above.

Unit of decision. All of the models considered work in terms of households, with the exception of the model for the city of Naples (2), whose decision units is represented by residents. All are aggregate and operate by allocating total numbers of households (see below) between sets of zones. Except for IRPUD, they all work in terms of real numbers and therefore tend to allocate fractions of households rather than being constrained to integers.

Total households to allocate. The total numbers of households (or residents) are in some cases exogenously prepared and specified as inputs (N.Y. model, models for Naples, DRAM). In others they are endogenous to the wider model system and are calculated either as functions of the economy (MEPLAN) or as functions of demographics modified by economy-influenced migration (IRPUD, DELTA).

Disaggregation of households. The number of household categories distinguished in the residential location process ranges from just two socio-economic groups in the simplest models to over a hundred socio-economic/composition/employment-status combinations in some of the DELTA applications.

Pre-conditions. Most of the models calculate the probabilities that households will locate in each zone conditional on the household worker or workers is employed in a particular zone; there is therefore a residential location process for each household type and for each work zone. In these cases, the implications for residential location of households having more than worker are unclear. In the case of DRAM, MEPLAN and the Naples models, the location of jobs is itself endogenous to the model. The exceptions to the general pattern are

- DELTA, which at the local level works on the basis that accessibility to work is just one of the characteristics influencing household location, and
- IRPUD, where the workplace is an influence on the search for a new dwelling but not directly upon the choice.

In both of these models the number of jobs available influences migration at the wider, regional level.

Incremental or total allocation. All but three of the models considered are total models in the sense that they allocate all households in each period. DELTA and IRPUD are the opposite of this, in that only a minority of households is located in each period. In DELTA, the size of this minority is determined largely by the numbers of households which experience change in composition and/or economic status during each period, which in turn are determined by the rates of demographic and economic change and by changing access to work. In IRPUD, the number of households located is limited by the number sufficiently dissatisfied with their present dwelling to search for an alternative; this dissatisfaction is influenced by factors similar to those at work in DELTA. MEPLAN is pre-dominantly total in that all households whose income derived from work are allocated in each period; however, there is a minority of "exogenous" households, eg the wholly retired or wholly unemployed households, which is separately allocated *before* the main location process.

Moving house or moving zone? The IRPUD model is the only one, which can positively distinguish households moving between dwellings within one zone; the others can only identify the net changes in numbers of households located in each zone.

Dynamic and timelags. In the cases of the models of N.Y. and those of Naples, they represent a state at a base year and therefore they are cross-sectional. All of the other models involve some time-lagged terms. DRAM allocates population according to zone attractiveness calculated through period t values and based on zone-to-zone travel costs and the distribution of employment for period t+1. In the case of MEPLAN and DELTA, the time-lagged terms are combined with indirect use of an “instantaneous” rent term, which takes account of the changing demand for the stock of housing.

Influence of transport. In all cases except DELTA and IRPUD, the main influence of transport is a variable describing the journey from each possible residence zone to the pre-determined workplace zone. In MEPLAN, the cost of transport incurred by households of each type in obtaining services from each possible residence zone is also an influence. In DELTA, the generalised cost of travel from each possible residence zone to the range of destinations which each kind of household may need to visit (work, shops, education, etc) is used in calculating accessibility measures, and changes in these are included in the variables influencing the changing pattern of household location. IRPUD is similar, but uses both accessibility to potential destinations and average travel utility to actual destinations, plus an influence of present workplace (if any) on the residential search process. The influences of transport in residential location are summarised in table 2:

Model	**Travel to work**	**Other travel**
New York	Travel time to predetermined workplace	(none)
Naples (1)	Generalised cost of travel to predetermined workplace	Accessibility to retailing
Naples (2)	Accessibility to workplaces in general	Accessibility to services
DRAM	Generalised cost of travel to predetermined workplace	(none)
MEPLAN (Naples)	Generalised cost of travel to predetermined workplace	Cost of travel to obtain goods and services
IRPUD	Accessibility to potential and actual destinations for different purposes. Workplace location influences the area of search for possible dwellings.	
DELTA (Trans-Pennine)	Accessibility to different kinds of destinations, including workplaces of appropriate socio-economic group for households with working members	

Table 2 – Influence of transport

Influence of housing. In all the models allocation of households (residents) depend on the quantity of housing available which acts as a size variable, ie if all other factors were equal, households would locate in proportion to the quantity of housing (usually measured in floorspace) available. In DRAM a zone is attractive for new residential development if there is plenty of vacant developable land, but only if substantial residential development is already present to provide the necessary infrastructure. In MEPLAN, “available” means the total less that occupied by exogenous households; in DELTA, it means housing not occupied by households which are not considering moving in the current period. In addition, as noted above, location in both MEPLAN and DELTA is influenced by a rent measure which is adjusted to equilibrate the current demand for housing with the available stock; in both cases, rent affects both the quantity of space demanded per household and the probability of households locating in each zone. In IRPUD, the size variable affects choice through the prior search process, and rents are updated only between simulation periods, not within them.

Other explicit variables. These are listed in table 3 – those in italics are endogenous to the overall model system (including whatever transport model is attached to DELTA).

Model	**Explicit variables other than housing supply and transport/accessibility terms**
New York	Housing mix (several variables) Household mix (several variables) Violent crime rate Socio-economic characteristics of current residents Composite indicator of income, education, poverty etc
Naples (1)	dummy variable for environmental quality (good/bad)
Naples (2)	dummy variable for prestige (high/low)
DRAM	Socio-economic characteristics of previous residents
MEPLAN (Naples)	(none)
IRPUD	*Population density* *% foreign population* *% own income group* *floorspace per dwelling* *rooms per person* *% low quality housing* *% high quality housing* *% single-family units* *floorspace ratio* % industrial use % roads % green space % forest kindergartens primary schools local shopping local services *traffic noise* *air pollution*

Model	Explicit variables other than housing supply and transport/accessibility terms
DELTA (Trans-Pennine)	*Housing area quality* *Environmental quality (environmental impact of transport)*

Table 3 – Other explicit variables

Implicit effects. Neither the N.Y. model nor the models for Naples have been used in forecasting mode. DRAM the t data and the trips produced are split into trips by mode in MSPLIT. In MEPLAN, alternative-specific constants (i.e. constants for each zone and household type) can be estimated to ensure that the model correctly reproduces the location of households by type in the base year; these are then held constant in future years, representing the constant influence of all unmodelled factors. Similar constants are implicit in the incremental formulation of DELTA.

Calibration procedures. There is a distinction to be made between

- the models in which residential location is predicted by a single equation, and
- those in which residential location involves feedback processes and more than one equation – ie MEPLAN and DELTA.

In the former group, the calibration of the residential location model is a relatively straightforward exercise, which can be carried out using statistical methods and software appropriate to the form of the model – for example, maximum likelihood and ALOGIT for logit models. In the latter group, calibration is necessarily more complex and typically involves a mixture of

- formal statistical analysis where data is available
- reuse of findings from previous analysis and research, possibly in other locations
- modeller judgement, particularly regarding the interaction between different package components (eg residential location vis-à-vis other sub-models).

One development of interest is the development of automated heuristic techniques to assist the calibration of complex model packages such as MEPLAN and DELTA (see Hunt and Abraham, 2000) in situations where a variety of (usually incomplete) data is available for different points in time. The development of the IRPUD model included a major, non-automated exercise of this type.

9. CONCLUSIONS

This paper has attempted to illustrate something of the variety of residential location models, concentrating on those which are used within wider land-use/transport interaction models. Their variety reflects a number of factors, including

- the circumstances for which they have been developed (ranging from limited research exercises to long-term research programmes, and from unique, ad hoc models to packages intended for repeated application)
- the availability of data
- the approach to calibration – particularly the degree of importance attached to calibrating the model on local data.

The authors hope that they have fairly represented the different models discussed, within the limits of the space available, and that the comparisons presented will encourage further debate about the appropriate forms of residential location models for future work, and about the appropriate methods for calibrating such models.

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