

Sustainable Life Styles? Microsimulation of Household Formation, Housing Choice and Travel Behaviour

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1 Introduction: Life Styles and Sustainability

There is growing awareness that the way of life practised in the most affluent countries of the world is not sustainable. People in the richest countries consume significantly more energy and other resources per capita than people in the poorest regions and by the same margin generate more noxious emissions and waste. And this imbalance is increasing due to the faster growth in income in the already richer regions and the subsequent changes in life styles and consumption and travel patterns. In more general terms, there is a close relationship between income development and fundamental life style decisions which in turn determine housing choice and travel behaviour. The hypothesis is that - irrespective of advances in resource efficiency and pollution control - continued growth in income will lead to less and less sustainable life styles unless policies make resource consumption, pollution and car mobility less attractive.

This paper discusses an approach to examining this relationship by combined modelling of household formation, housing choice and travel behaviour in urban regions. The basic rationale of the approach is that fundamental life style decisions linked to phase of life and income strongly influence spatial behaviour with respect to choice of residence and job location as well as mobility patterns.

The combined model under development proceeds in a nested fashion from modelling basic life-style decisions of individuals as a function of demographic development, career dynamics and household formation to modelling intra-urban location and housing choice of households and from there to modelling daily activities and travel decisions of household members. By using event-based microsimulation with random-utility based choice functions, short-term learning within the nested model structure becomes feasible. Medium-term and long-term adjustment of behaviour is made possible by a model structure with short simulation periods of one year duration. The model is spatially disaggregate by modelling choice behaviour at high-resolution raster or parcel level. The integrated model is to be used to model the impacts of policy packages in the fields of land use planning, transport infrastructure, transport regulation and transport taxation designed to give incentives for more sustainable life styles.

The modelling concepts presented in this paper are based on previous work of the three authors. Salomon (1983) pioneered the life-style approach in activity-based transport modelling. Waddell (2000a; 2000b) has developed an urban-economics based model of metropolitan land development and firm and household location, UrbanSim. Wegener (1985; 1999) has applied microsimulation techniques to modelling household location choice in a model of the regional housing market of Dortmund, Germany, the IRPUD model. Salomon and Wegener are currently developing a microsimulation model of urban travel behaviour for the city of Netanya in Israel.

Published in: Black, W.R., Nijkamp, P., eds. (2002): *Social Change and Sustainable Transport*.
Bloomington, Indiana: Indiana University Press, 125-131.

2 Microsimulation in Urban Modelling: State of the Art

Microsimulation was first used in social-science applications by Orcutt *et al.* (1961), yet applications in a spatial context remained occasional experiments without deeper impact, though covering a wide range of phenomena such as spatial diffusion (Hägerstrand, 1968), urban development (Chapin and Weiss, 1968), transport behaviour (Kreibich, 1979), demographic and household dynamics (Clarke *et al.*, 1980; Clarke 1981; Clarke and Holm 1987; Holm *et al.*, 2000) and housing choice (Kain and Apgar, 1985; Wegener, 1985). In recent years microsimulation has found new interest because of its flexibility to model processes that cannot be modelled in the aggregate (Clarke, 1996). Today there are several microsimulation models of urban land use and transport under development (Hayashi and Tomita 1989; Mackett 1990a; 1990b; Landis, 1994; Landis and Zhang, 1998a; 1998b; Waddell, (2000a; 2000b; Wegener and Spiekermann, 1996).

A different approach emerged from the theory of cellular dynamics. Cellular automata (CA) are objects associated with areal units or *cells*. CA follow simple stimulus-response rules to change or not to change their *state* based on the state of adjacent or near-by cells. By adding random noise to the rules, surprisingly complex patterns that closely resemble real cities can be generated (White and Engelen, 1993; Batty and Xie, 1994; Batty, 1997). More complex stimulus-response behaviour is given to CA models in multi-reactive agents models. Multi-reactive agents are complex automata with the ability to control their interaction pattern; they can change their environment but also their own behaviour, i.e. are able to learn (Ferrand, 2000). The distinction between the behaviour of multi-reactive agents and the choice behaviour generated in microsimulation models is becoming smaller.

Probably the most advanced area of application of microsimulation in urban models is travel modelling. Aggregate travel models are unable to reproduce the complex spatial behaviour of individuals and to respond to sophisticated travel demand management measures. As a reaction, disaggregate travel models aim at a one-to-one reproduction of spatial behaviour by which individuals choose between mobility options in their pursuit of activities during a day (Axhausen and Gärling, 1992; Ben Akiva *et al.*, 1996). Activity-based travel models start from interdependent 'activity programmes' of household members and translate these into home-based 'tours' consisting of one or more trips. This way interdependencies between the mobility behaviour of household members and between the trips of a tour can be modelled as well as intermodal trips that cannot be handled in aggregate multimodal travel models. Activity-based travel models do not model peak-hour or all-day travel but disaggregate travel behaviour by time of day, which permits the modelling of choice of departure time. There are also disaggregate traffic assignment models based on queuing or CA approaches, e.g. in the TRANSIMS project (Nagel *et al.*, 1998; Barrett *et al.*, 1999), which reproduce the movement of vehicles in the road network with a level of detail not known before.

3 The Three Microsimulation Modules

The model under development will go beyond the approaches reviewed in the previous section by bringing together approaches that have been developed in different streams of research in urban and transport modelling: microsimulation of household formation, housing choice and travel behaviour. In doing so it will stay below the level of disaggregation of vehicle movements in TRANSIMS, but in its spatial and temporal resolution it will exceed current aggregate land-use transport models.

3.1 Household Formation

The household formation microsimulation module models the evolution of household attributes associating each household with a particular *life style*.

Life style is an empirical concept that attempts to capture human spatio-temporal behaviour. It can be viewed as the sum of activities, distributed in time, space, inter-personal and intra-personal dimensions. It is a physical expression of the pattern of activities which the individuals aspire to engage in subject to constraints (Salomon, 1983; 1997). For the purpose of forecasting behaviour, the concept of life style seems to be richer in information than the conventional classification of market segments along socio-demographic and economic (SDE) variables. As life style expresses the aspiration one has with regard to the way of living (i.e. activities in time and space), peoples' revealed behaviour is either consistent with their aspirations or a deviation thereof in the presence of constraints. Thus, identifying a person's life style is expected to be instrumental in predicting her behavioural response to new situations.

In the social sciences life styles usually are represented in the form of free-form narratives or 'stories'. The story format, though open and potentially rich in content, is not suitable for mathematical modelling. Therefore life styles need to be translated from the open narrative format to some kind of quantitative representation which, however, should preserve as much of the variation in life styles found in reality as possible. Such a representation is the representation of life styles as fuzzy objects. In the proposed model a 'life style' therefore is a fuzzy object defined by a set of probabilistic membership functions. A probabilistic membership function is a vector of probabilities specifying the likelihood that individuals with a particular life style belong to a particular category of a set of classified attributes.

The probabilities of the membership functions can be found as observed frequencies in empirical investigations, e.g. household surveys. In the absence of such surveys they are determined by expert judgement and calibrated against observed aggregate distributions. The calibration is performed by microsimulation by which a fictitious spatially disaggregated population of individuals and households is generated that as far as possible conforms to the membership functions defining each life style, aggregate observed distributions such as population by age and sex, and the observed spatial distribution of land use and activities by zone.

In the household formation module the following household events are modelled simultaneously for households and household members (see Figure 1a): birth, ageing, death; new household, dissolution of household; marriage/divorce, cohabitation/separation, separation of child, person joins household; new job, retirement, unemployment; change of income. Even though household formation events in reality are the outcome of more or less rational decisions, most of them will not be modelled as decisions but simply as the result of the passage of time, i.e. as transitions (Wegener, 1985). Typical transitions are changes of the state of a household with respect to age or size conditional on the relevant probabilities for events such as ageing/death, birth of child, relative joins or leaves household. Also clearly choice-based events such as marriage or divorce are modelled as transitions because the causal chain behind them is not represented in the model. Some events result in the dissolution of households or the creation of new households. Other events, such as a new job or unemployment are triggered by external events such as hiring or firing in the labour market represented in another part of the model not described here. Change of income is a consequence of employment-related events.

Beyond these straightforward relationships there is wide scope in the model for introducing more complex interdependencies between household and economic events. For instance, the rise of dual worker households may be in part a life style choice and in part a necessity dictated by rising housing costs and stagnant real incomes. Children may delay new household formation or marriage. Childbearing may be postponed based on some combination of life style preferences and response to housing cost and income expectations. The role of labour market expectations in shaping these choices is an area of considerable policy implication.

The housing choice microsimulation module models location and housing choice decisions of households who move into the region (immigration), move out of the region (outmigration), move into a dwelling for the first time (starter households) or have a dwelling and move into another dwelling (moves). Dwellings are affected by ageing and by decisions on new construction, upgrading and demolition modelled in other submodels not described here.

The housing choice model is a Monte Carlo microsimulation of transactions in the housing market. A market transaction is any successfully completed operation by which a household moves into or out of a dwelling or both. There are two types of actors in the housing market: households looking for a dwelling ('dwelling wanted') and landlords looking for tenants or buyers ('dwelling for rent or sale'). The household looking for a dwelling behaves as a satisficer, i.e. it accepts a dwelling if this will improve its housing situation by a considerable margin. Otherwise, it enters another search phase, but after a number of unsuccessful attempts it abandons the idea of a move. (Figure 1b). The amount of improvement necessary to make a household move is assumed to depend on its prior search experience, i.e. to go up with each successful and down with each unsuccessful search. In other words, households adapt their aspiration levels to supply conditions on the market. The attractiveness of a dwelling for a household is a weighted aggregate of the attractiveness of its location, its quality and its rent or price in relation to the household's housing budget. The attractiveness of the location and the quality of the dwelling are themselves multiattribute encompassing relevant attributes of the neighbourhood and of the dwelling.

3.2 Housing Choice

3.3 Travel Behaviour

The travel behaviour microsimulation models for each member of each household the selection of an activity programme (defined as a schedule of tours), car availability and, subject to that, for each trip departure time, destination, mode and route (see Figure 1c): Each household is defined by its household attributes, its life style and its residential location, and by the personal attributes of its members. A location in the model is a micro location, i.e. street address, geographical coordinates or a raster cell. The destination of a trip is selected by logit choice, where locations of destinations are also micro locations.

Generalised costs of travel to the destinations are calculated as the logsum of minimum paths of relevant modes walk, cycling, public transport and car (if available) with a random disturbance term added to each link impedance and waiting/transfer time in the public transport network (stochastic minimum paths). For work, school and university trips the destinations are already known. Mode choice is performed by logit choice based on the generalised costs of stochastic minimum paths; the selected route is the stochastic minimum path.

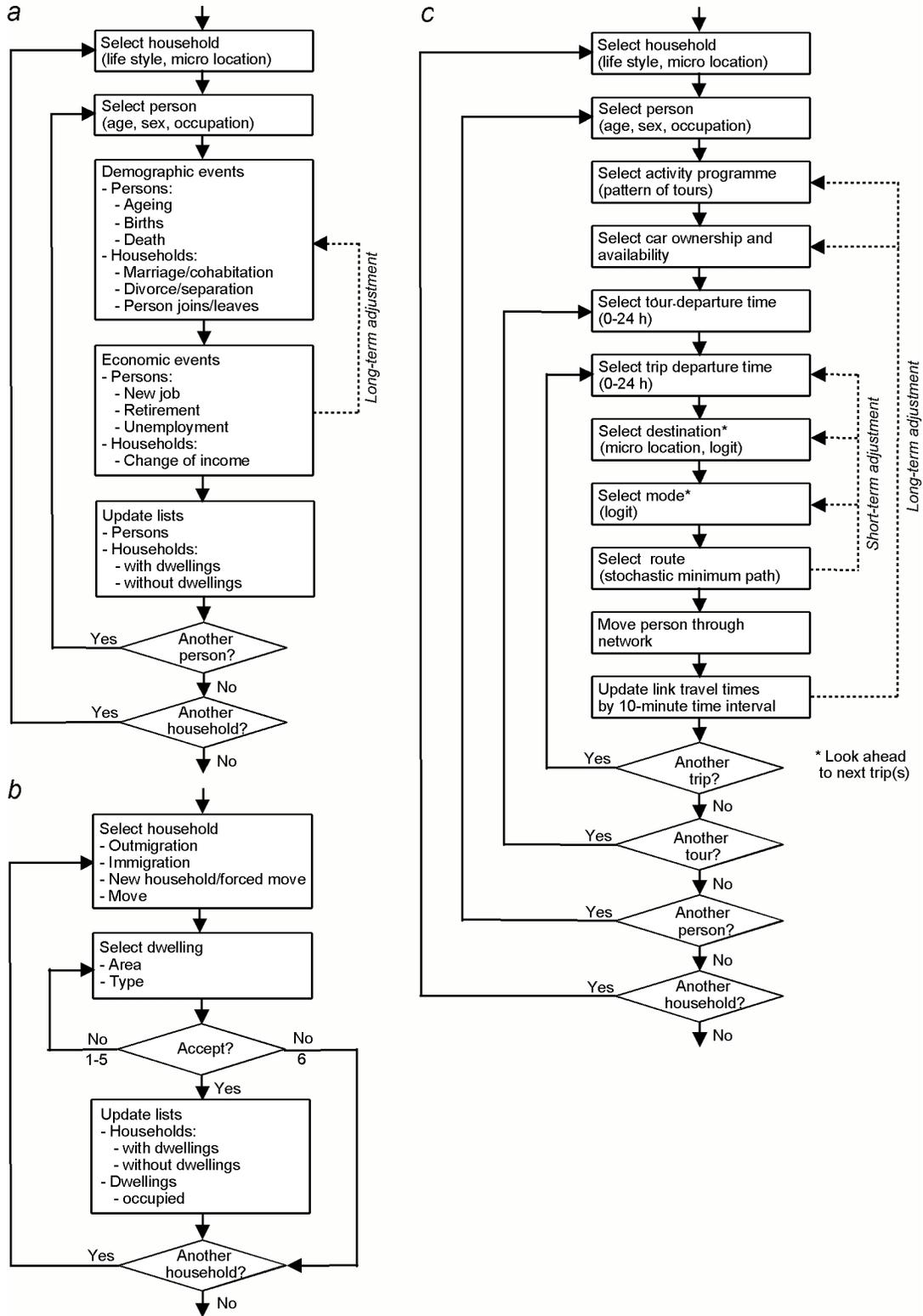


Figure 1. Microsimulation of household formation (a), housing choice (b) and travel (c)

After each trip, the travel times of all traversed road links are updated to account for congestion. If congestion is encountered during a trip, short-term adjustment resulting in a postponement of the trip or a change of mode or route may occur. In order to facilitate long-term learning, information on the generalised costs of the congested network by time of day of the current simulation period is used in the next period.

One important objective of this approach to traffic microsimulation will be to accomplish realistic assignment of travellers to modes and routes without extensive iteration, as computing requirements of iterative assignment in large urban road networks has proved to be a serious problem in TRANSIMS (Nagel *et al.*, 1998; Barret *et al.*, 1999).

4 Planned Work

The development of the model is based on previous work by the authors. The life style concept is implemented for the first time in the activity-based transport model for Netanya. All three microsimulation modules are planned to be integrated in both UrbanSim and the IRPUD model.

4.1 Life Styles in Netanya

The city of Netanya (population 150,000) is situated at the northern rim of the metropolitan area of Tel Aviv. It was founded in 1928 as an independent resort town, which over the years, with the sprawl of the metro region, has become part of it. Given this biography, Netanya is clearly not the typical suburban community. It consists of a mix of life styles, which to a great extent represents the Israeli urban scene.

To identify the life-style based market segments in Netanya and the proxy variables which indicate membership, a small survey was conducted in which individuals had to identify four life style groups in Netanya, and to provide a short narrative description of the group. Then they were requested to provide a quantitative assessment for one of the life style groups. This pilot study was performed with the co-operation of Israeli students of geography at the Hebrew University.

Some 24 students filled out the questionnaire. In total they provided 58 responses to the question requesting four life-style labels, but these referred to 41 different life styles. This large number indicates that either the respondents had not internalised the concept of life style and actually provided simple SDE variables as the relevant classification basis, or that there are many diverse life style segments in the Israeli (or Netanya) population.

An analysis of the responses suggests, based on an acquaintance with the Israeli society, that in some cases, a single variable is sufficiently powerful to discriminate a group out of the population as a life style segment. For example, being labelled as an ultra-orthodox person provides sufficient information to reveal the life style of that person. This group was mentioned in eight out of 58 responses. However, being labelled as a member of the middle class conveys very little information about the person's or household's life style. Further analysis of the classification provided in this experiment is underway.

4.2 Integration of Microsimulation into UrbanSim

The design and implementation of the UrbanSim model is highly disaggregate, and applies a behavioral and dynamic disequilibrium approach using annual time steps. The initial beta version contained a microsimulation of land development at the parcel level, and modeled location choice of households at the level of household groups of similar socio-demographic and economic type. Location choice was simulated with a logit model of housing type and zone (Waddell, 2000a). In the current implementation, the residential and employment location components have been fully converted to microsimulation of lists of individual households and jobs. Location choice, land development and price adjustment are now simulated at the level of raster cells of 150 by 150 m, though the resolution is arbitrary and can be changed according to data and computing resources (Waddell, 2000b).

Further changes to the UrbanSim model will require implementing model components to simulate household formation and travel, since the current model implementation takes both as exogenous and links to external models for these attributes. The current housing choice model component is already close to the proposed specifications, simulating housing choice with a logit model of development type and micro-location at the grid cell level. The major difference in the data structure required to implement the proposed specifications is the incorporation of individual persons, since only households are now modelled. The current model design is being applied in four metropolitan areas in the United States: Eugene-Springfield, Oregon; Honolulu, Hawaii; Salt Lake City, Utah; and Seattle, Washington.

In addition, a new software architecture for urban simulation has now been completed that greatly facilitates the creation, evolution and co-ordination of model components (Noth *et al.*, 2000). The model system is implemented in Java and available as open source software (like Linux) to facilitate extension and collaboration without proprietary restrictions (Waddell, 2000b).

4.3 Integration of Microsimulation into the IRPUD Model

Because of its modular structure, the IRPUD model (Wegener, 1999) is well suited for the integration of microsimulation modules. The present aggregate submodels of household formation and travel behaviour are presently being replaced by microsimulation modules. The microsimulation of housing choice will replace the present hybrid microsimulation which is disaggregate in its modelling of behaviour but aggregate in its data.

Certain complications arise with respect to the spatio-temporal database underlying the model. In the present model all simulation results of each simulation period are written into the database on a zonal basis for use in the next simulation period. After the simulation all results are retained in the database for ex-post analysis and the production of diagrams and maps. This implies that the microsimulation modules of household formation and housing choice have to maintain their own disaggregate database consisting of the lists of households, household members and dwellings but that the microsimulation data are also stored in aggregate form in the present database.

The micro locations used in the microsimulation modules are implemented in the IRPUD model by raster cells, where a micro location is a pair of coordinates indicating the row and column in a matrix of raster cells. The size of the raster cells are 100 m by 100 m. As no household and workplace data at this level of spatial disaggregation are available for the Dortmund urban region, aggregate data for statistical districts and sub-districts are disaggregated using Monte-Carlo

simulation with GIS-based land use polygon data as ancillary information. The method is described in Wegener and Spiekermann (1996) and Spiekermann and Wegener (2000).

The integration of the three microsimulation modules into the IRPUD model is a step towards making the whole model disaggregate (Wegener and Spiekermann, 1996). For the future it is planned to apply the same principles also to the existing aggregate submodels of industrial and services location and industrial, commercial and residential construction.

5 Conclusions

This paper has outlined a modelling framework in which household formation, housing choice and daily mobility are modelled in three microsimulation modules interlinked by a common disaggregate database.

The modelling framework permits the application of the principle of microscopic activity-based transport modelling to changes in the life cycle of households and individuals and to decisions on residential location. This opens the way for modelling the links between long-term life style decisions and medium- and short-term residential and daily mobility.

Microsimulation will make urban models richer in behavioural content and more responsive to land use and travel demand management policies. The higher spatial and temporal resolution will make them also suitable to model micro-scale environmental phenomena such as traffic noise and air pollution. This will be an important prerequisite for using the models for the identification of more sustainable life styles.

6 Acknowledgments

The research reported here has in part been supported by the German-Israeli Foundation for Scientific Research and Development in the project 'Sustainable Mobility in Cities', and National Science Foundation (US) grant CMS-9818378: 'Reusable Modeling Components for Land Use, Transportation and Land Cover'.

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