PLUREL

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Impact Assessment

Module 4

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PERI-URBAN LAND USE RELATIONSHIPS –
STRATEGIES AND SUSTAINABILITY ASSESSMENT
TOOLS FOR URBAN-RURAL LINKAGES,
INTEGRATED PROJECT,
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D4.1.1b

Models of rural-urban systems

A systematic compilation and review of existing methodologies in system dynamics and causality approaches for evaluating rural-urban land use relationships

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SIXTH FRAMEWORK PROGRAMME

Contents

Abstract

This deliverable within the EU-integrated project PLUREL provides a review of existing urban land use models. The aims were to highlight the main approaches, components and variables of interest in existing models, to give an overview on the respective model structures, iteration processes, input- and output-data and to show the technical background, spatial representation, programming environment etc. of the models. The main outputs of this review are the 16 data sheets, with each data sheet containing one simulation model. Based upon this review, conclusions were drawn for the operational model of the PLUREL SIAT-RUR, regarding useful causal relationships for and a first sketch of the operational model.

Introduction

A variety of land-use change models for urban areas already exists, ranging from specific case-studies to generic tools for a variety of urban regions. These models differ largely regarding their structure, their representation of both space and human decisions, and their methodological implementation. This deliverable provides a review of these models.

Purpose of the review

The **purpose** of work package WP4.1 within Module 4 is an integrated analysis framework with functional relationships between land use resources, demand and supply of land use as well as demographic, economic and policy-related contextual constraints. The present deliverable D4.1.1 was titled in the description of work as a "systematic compilation and review of existing methodologies in system dynamics approaches for evaluating rural-urban land use relationships". This review aims to provide first conclusions in order to derive an analytical framework for module 4 and the PLUREL SIAT-RUR.

The title of the deliverable within the description of work aims **at system dynamics** approaches, because within such models, driving forces and feedback loops are explicitly represented. As there are only a few system dynamics models of urban land-use relationships, the analysis described here included other causal models as well. Therefore the title of the deliverable was adjusted as well.

The main purpose is to derive ideas for causal relationships within land-use change in urban systems, with a special emphasis on integrating social and natural science models. As Verburg points out, an integration of social and biophysical systems could be enhanced by including **feedback** mechanisms in land use models, e.g.

- feedback between driving factors and effects of land use change (impacts),
- feedback between local and regional processes, and
- feedback between agents and spatial units

(Verburg 2006). "Less common in land use modelling is the simulation of feedbacks between impacts on socio-economic and environmental conditions and the driving factors of land use change" (Verburg 2006: 1173). The review presented here will include a view onto those feedbacks as well.

Conceptual views on urban systems

Apart from implemented simulation model, there exist a number of articles and book chapters on the "ideal" integrated model, theoretically necessary feedback loops et cetera. These findings are summarised in the following.

Often, frameworks like the **DPSIR-framework** (drivers, pressures, state, impact, responses) of the European Environment Agency are used to conceptualise model structure. According to Verburg, "the main drawback of using these analytical frameworks is the assumption of one-directional processes between driving factors and impacts" (Verburg 2006: 1173), because in reality, it is difficult to differentiate between impacts and drivers in a system.

Timmermans (2003) criticizes that present models focus on **functional chains** like the following: demand causes allocation across space which in turn causes traffic flows, based upon that a transportation model calculates travel times, which in turn explain residential choice. Timmermans votes to include other aspects of integration in urban land-use models, such as task allocation within households, residential choice, job choice, vehicle holding decision, scheduling of activities, competition and agglomeration of land uses and actors, co-evolutionary development of demographics, employment sectors, land use and activity profiles and a fuller treatment of varying time horizons, including anticipatory and reactive behaviour.

According to Miller et al. (2004), **an integrated urban systems model** with focus on transport should include:

- evolution of the built environment,
- evolution of population demographics (demographic change and migration into and out of region),
- location choices of households and firms,
- internal economy of the urban area (labour market, import/export of goods and services),
- activity/travel patterns of population, goods and services depending upon urban structure and economic interchanges,
- performance of road and transit systems,
- atmospheric emissions generated by transportation and industry, and
- location decisions of households and firms which are particularly important because transport depends upon these.

Bürgi et al. (2004) distinguish **five major types of driving forces**: socioeconomic, political, technological, natural, and cultural driving forces. Furthermore, they differentiate between primary, secondary and tertiary driving forces as well as between intrinsic and extrinsic driving forces (Bürgi et al. 2004).

Waddell and Ulfarsson (2004) in their introduction to urban simulation sketched urban markets and agents, choices and interactions in an “ideal” urban model (see Figure 1 and Figure 2).

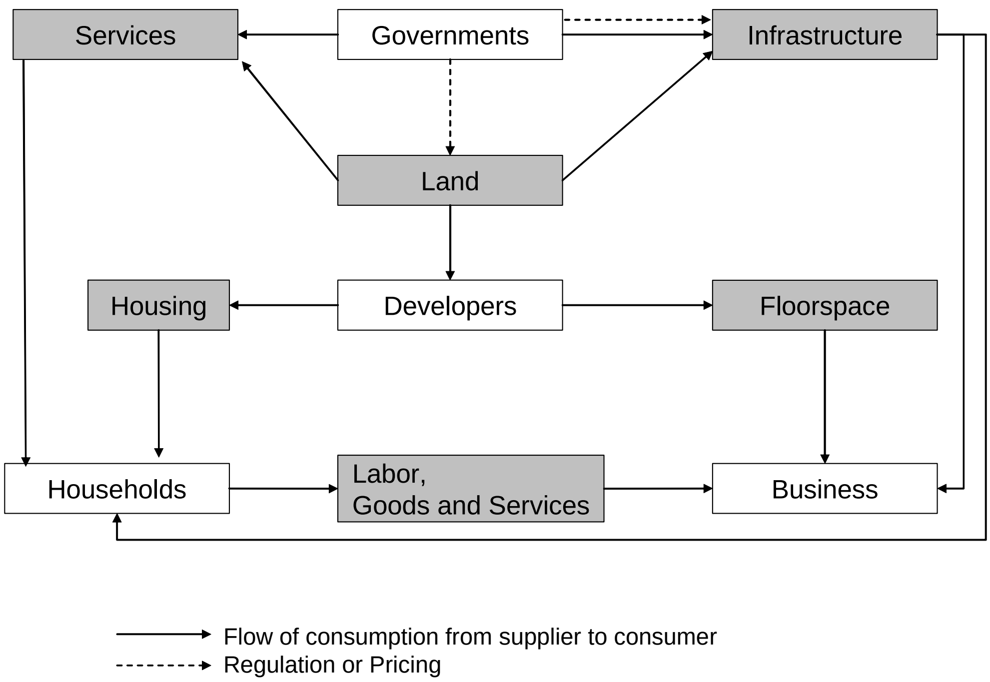

Figure 1 Linked Urban Markets (Waddell & Ulfarsson 2004: 13)

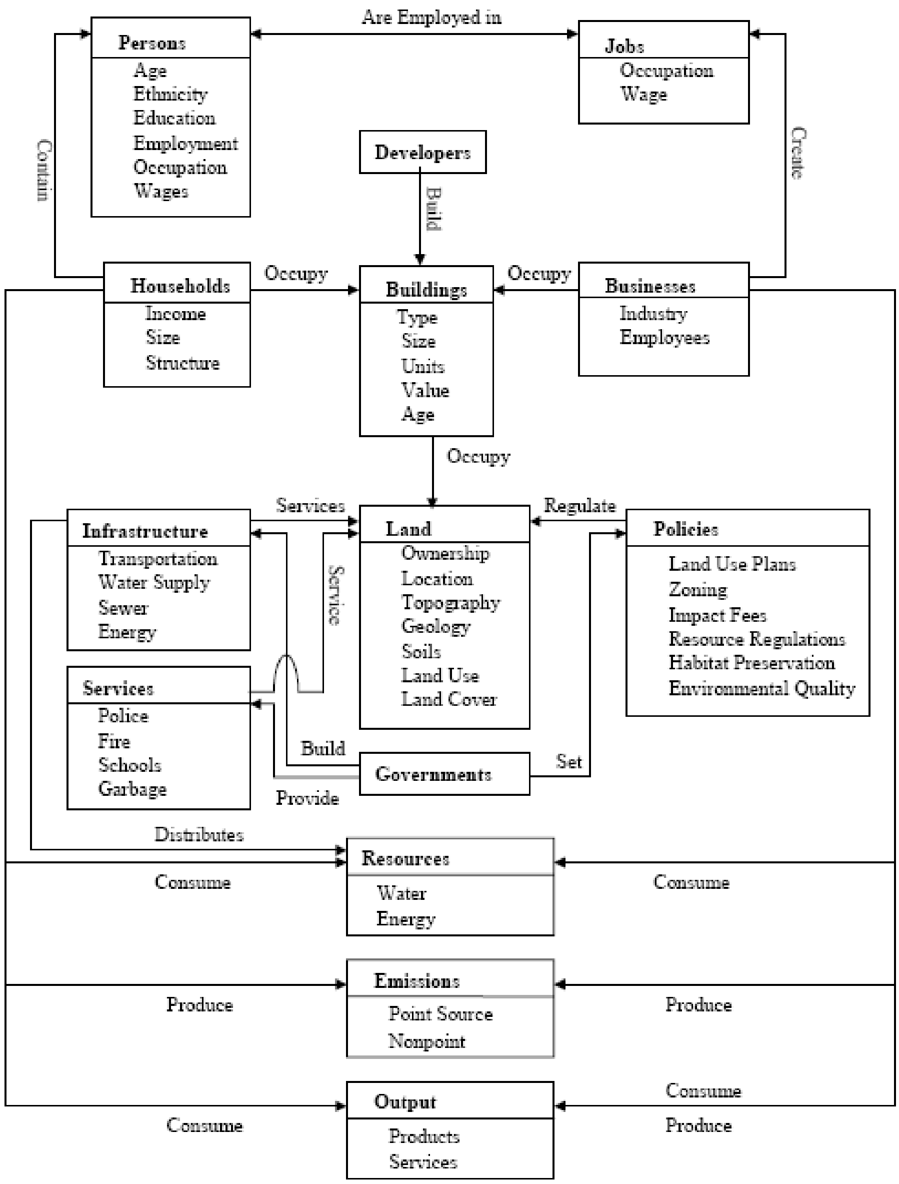

Figure 2: Agents, Choices and Interactions to Represent in a Complete Urban Model (Waddell & Ulfarsson 2004: 14)

Hunt et al. (2005) stated **eleven modelling axioms** for an "ideal model":

1. Representation of an urban system should focus on those elements that interact with transportation system.
2. Urban system consists of physical elements, actors and processes.
3. Transportation system is multimodal and involves both people and goods.
4. Markets are basic organising principle of an urban system.
5. Flows of people, goods, information and money arise out of demands.
6. Urban areas do not reach equilibrium.
7. System time must be explicitly dealt with.
8. Feedback between short- and long-run processes have to be integrated (e.g. travel and infrastructure).
9. Some factors may be treated as exogenous due to modelling purposes.
10. Some activities arise in response to external demand.
11. Very fine level of representation for actors and processes is necessary.

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Review of simulation models

Selected models

The models to be included into this review were selected in a threefold approach: (1) As the authors of this review are familiar with urban land-use models they included models well-known within the community. (2) Already existing reviews on urban land-use models were analysed and presently used or discussed models were integrated as well. (3) A search on the ISI web of science was performed, looking especially for system dynamics approaches to urban land-use. This procedure led to a total of 16 models which were included into this review.

Of all models included in this review, only the seven models
- "Urban dynamics" (Forrester's original approach),
- "Urban transformation process in the Haaglanden region",
- "Rotterdam urban dynamics",
- "Modelling biodiversity and land use",
- "A System Dynamics Approach to Land Use / Transportation System Performance Modeling",
- "SCOPE" and
- "Urban travel system"

are system dynamics models.

Existing reviews

A variety of reviews regarding urban land-use models already exists:
- Agarwal et al. (2002) review land-use models in general, also including models dealing with forestry and agriculture.
- Axhausen (2006) specialises in models on transportation demand.
- Beckmann (2006) focuses on interactions between urban land-use and transport; the author discusses modelling approaches and does not give details regarding single models.
- Berling-Wolff and Wu (2004) give an historical overview of modelling approaches and do not discuss single models.
- EPA (2000) focuses on models of urban growth but mainly includes US-American approaches and – because of its publication date – does not include recently published models.
- Geurs & van Wee (2006) as well as Hunt et al. (2005) focus on models which emphasize the interaction between urban land-use and transport.
- Timmermans (2003) gives a historical overview and describes a large number of models but does not give a comparative description of presently developed models.
- Verburg et al. (2004) exemplary sketch a few models, but their focus lies on discussing general modelling approaches.

Framework for review

In order to structure the review, the authors developed a **data sheet** including all information obtained for the purpose of this deliverable. The annex contains data sheets for all models included in the review.

Data sheets are divided into two parts: technical data and contents of the model. **Technical data** include
- extend and boundaries of the area covered by the simulation,

- spatial units and their size,
- time steps and duration of a model run, and
- simulation technique.

In the **contents** part of the data sheet, the following issues are described:

- main purpose of the modelling effort,
- main variables and their relationships,
- human decision making (domain, temporal range, typology of agents, decision algorithm)
- a first evaluation of achieved goals, including the opinion of the model's authors, validation, and plausibility analysis,
- model development process regarding concept and quantification of relationships.

Analysis of models

The main aim of the review was to assess **structural relationships** in already existing models. As modelling approaches were quite different, no common "ideal model structure" did emerge when compiling the review. Therefore, the data sheets presented in the annex served as a basis for the system dynamics framework to be developed within work package 4.1.

As modelling approaches are very heterogenous, no common modelling structure could be derived. Therefore, only a few conclusions will be highlighted here.

Very few models assess the **impact of land-use changes on the environment**:

- CURBA: impact of land-use changes on biodiversity.
- ILUMASS and Urban travel system: impact of transport on environment.
- Modelling biodiversity and land use: impact of decreasing wetland area on biodiversity.
- MOLAND, SCOPE, simulation of polycentric urban growth dynamics through agents, ILUMASS: implicit feedback loop because state of grid cells influences attractiveness.

These relationships are the only ones closing the loop from households/individuals as drivers of land-use changes over impacts back to the decision algorithm. Other approaches solely implement a one-way process from (external) drivers to impacts, without considering feedback loops at all.

When **human decision making** is explicitly represented main actors are

- households or individuals choosing their residential location, and
- local industries and business choosing their location, employing local people et cetera.

Governmental planning processes are never explicitly represented in a way that governmental agencies are actors within the model. In some models, planning decisions are integrated as a part of the scenario configuration, e.g. by restricting possible evolution paths for certain grid cells. In others, no planning process is represented at all. Complementary, development of **infrastructure** is seldom addressed, only transport-related infrastructure is treated in some of the simulation models.

This is maybe due to another aspect: All models reviewed implicitly or explicitly focus on **urban growth** or urbanisation. Not a single model deals explicitly with a shrinking or declining urban region, where planning processes and infrastructure-related problems are more important than in sprawling settlements, where infrastructure simply follows settlement areas.

Conclusions

The main conclusion of this review is that there is no unique approach to urban-rural systems. Each author or working group has its own view and focuses on other parts of and relationships in the system. Because of that it seems impossible to derive a consensual view on urban land-use changes out of the models published in the literature. The data sheets in the annex list the main relationships dealt with in each of the simulation models.

Furthermore, the review shows that

1. feedback loops from impacts of land-use change on environment to driving forces of land-use change are seldom integrated into simulation models,
2. representation of human decision making focuses mainly on households or individuals (residential location) and local business and industries; planning processes are no explicit part of the models,
3. infrastructure-related problems are not dealt with in these models, and
4. the focus of these models is on urban growth.

In module 4 within PLUREL, one important task is the integration of models of the natural and social sciences. Therefore, special emphasis shall be laid upon feedback loops from environmental impacts of land-use changes to driving forces of land-use changes.

Furthermore it will be discussed within module 4 to what extend other human decision making than household and industrial/commercial location choices will be modelled. Since at least Leipzig and Manchester (with Warsaw probably following soon) are shrinking cities, a shifting focus to urban shrinkage needs to be discussed, with infrastructure-related problems and planning processes probably becoming more important.

References

Agarwal, C., Green, G., Grove, M., Evans, T., Schweik, C. (2002): A Review and Assessment of Land-Use Change Models: Dynamics of Space, Time, and Human Choice. Report of United States Department of Agriculture, Forest Service. General Technical Report NE-297. http://nrs.fs.fed.us/pubs/gtr/gtr_ne297.pdf (visited on 19 of June 2007).

Alfeld, L. (1995): Urban dynamics – The first fifty years. System Dynamics Review 11(3): 199-217.

Beckmann, K. (2006): Mikro-Simulation von Raum- und Verkehrsentwicklung – Stand der Kunst und Perspektiven zwischen Forschung, Entwicklung und Praxis (microsimulation of spatially and transport development – state of the art and perspectives between research, development and practice). In: Proceedings of the 7th Aachener Colloqium "Integrierte Mikro-Simulation von Raum- und Verkehrsentwicklung. Theorie, Konzepte, Modelle, Praxis" (Integrated microsimulation of spatial and transport development. Theory, Concepts, Models, Practice). Pages 1-31.

Berling-Wolff, S. Wu, J. (2004): Modeling urban landscape dynamics: A review. Ecological Research 19(1): 119-129.

Bürgi, M., Hersperger, A., Schneeberger, N. (2004): Driving forces of landscape change – current and new directions. Landscape Ecology 19(8): 857-868.

Clarke, K. (2002): Land Use Change Modeling Using SLEUTH. Paper presented at the Advanced Training Workshop on Land Use and Land Cover Change Study, December 9-20th, Taiwan, National Central University/National Taiwan University/ START.

Dietzel, C., Clarke, K. (2007): Toward Optimal Calibration of the SLEUTH Land Use Change Model. Transactions in GIS 11(1): 29-45.

Engelen, G., Lavalle, C., Barredo, J., van der Meulen, M., White, R. (2007): The Moland Modelling Framework for Urban and Regional Land-use Dynamics. In: Koomen, E., Stillwell, J., Bakema, A., Scholten, H.J. (Eds.): Modelling Land-Use Change, Progress and Applications. Dordrecht: Springer. Pages 297-319.

EPA (United States Environmental Protection Agency) (2000): Projecting Land-Use Change. A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns. EPA-Report No. EPA/600/R-00/098. http://faculty.washington.edu/pwaddell/Models/REPORTfinal2.pdf (visited on 19th of June 2007).

Eppink, F., van den Bergh, J., Rietveld, P. (2004): Modelling biodiversity and land use: urban growth, agriculture and nature in a wetland area. Ecological Economics 51 (3-4): 201-216

Eskinasi, M. & Rouwette, E. (2004): Simulating the urban transformation process in the Haaglanden region, the Netherlands. Paper presented at the 2004 International System Dynamics Conference in Oxford, UK. http://www.roag.nl/tekst/HaaglandenFinalPaper.PDF (visited on 19 of June 2007).

Ettema, D., de Jong, K., Timmermans, H., Bakema, A. (2007): PUMA: Multi-Agent Modelling of Urban Systems. In: Koomen, E., Stillwell, J., Bakema, A., Scholten, H.J. (Eds.): Modelling Land-Use Change, Progress and Applications. Dordrecht: Springer. Pages 237-258.

Forrester, J. (1969): Urban Dynamics. Cambridge and London: The M.I.T. Press.

Geurs, K. & van Wee, B. (2004): Land-use/transport Interaction Models as Tools for Sustainability Impact Assessment of Transport Investments: Review and Research Perspectives. European Journal of Transport and Infrastructure Research 4(3): 333-355.

Haghani, A., Lee, S., Byun, J. (2003a): A System Dynamics Approach to Land Use / Transportation System Performance Modeling, Part I: Methodology. Journal of Advanced Transportation 37(1): 1-41.

Haghani, A., Lee, S., Byun, J. (2003b): A System Dynamics Approach to Land Use / Transportation System Performance Modeling, Part II: Application. Journal of Advanced Transportation 37(1): 43-82.

Hunt, J.D., Kriger, D.S., Miller, E.J. (2005): Current Operational Urban Land-Use-Transport Modelling Frameworks: A Review. Transport Reviews 25(3): 329-376.

Landis, J., Monzon, J., Reilly, M., Cogan, C. (no year): Development and Pilot Application of the California Urban and Biodiversity Analysis (CURBA) Model. http://gis2.esri.com/library/userconf/proc98/PROCEED/TO600/PAP571/P571.htm (visited on 18th of June 2007).

Landis, J., Zhang, M. (1998a): The second generation of the California urban futures model. Part I: Model logic and theory. Environment and Planning B 25 (5): 657-666.

Landis, J., Zhang, M. (1998b): The second generation of the California urban futures model. Part II: Specification and calibration results of the land-use change model. Environment and Planning B 25 (6): 795-824.

Loibl, W., Tötzer, T., Köstl, M., Steinnocher, K. (2007): Simulation of Polycentric Urban Growth Dynamics through Agents. In: Koomen, E., Stillwell, J., Bakema, A., Scholten, H.J. (Eds.): Modelling Land-Use Change, Progress and Applications. Dordrecht: Springer. Pages 219-235.

Miller, E., Hunt, J.D., Abraham, J., Salvini, P. (2004): Microsimulating urban systems. Computers, Environment and Urban Systems 28(1): 9-44.

Moeckel, R., Schwarze, B., Wegener, M. (2006): Das Projekt ILUMASS – Mikrosimulation der räumlichen, demografischen und wirtschaftlichen Entwicklung (The ILUMASS project – microsimulation of spatial, demographic and economic development). In: Proceedings of the 7th Aachener Colloqium “Integrierte Mikro-Simulation von Raum- und Verkehrsentwicklung. Theorie, Konzepte, Modelle, Praxis” (Integrated microsimulation of spatial and transport development. Theory, Concepts, Models, Practice). Pages 53-61.

Onsted, J. (2002): SCOPE: A Modification and Application of the Forrester Model to the South Coast of Santa Barbara County. http://www.geog.ucsb.edu/%7Eonsted/title.html (visited on 18th of June 2007).

Raux, C. (2003): A system dynamics model for the urban travel system. Paper presented at the European Transport Conference 2003, Strasbourg 8-10 October 2003. http://ideas.repec.org/p/hal/papers/halshs-00092186_v1.html (visited on 18th of June 2007).

Salvini, P. & Miller, E. (2005): ILUTE: An Operational Prototype of a Comprehensive Microsimulation Model of Urban Systems. Networks and Spatial Economics 5(2): 217-234.

Sanders, P. & Sanders, F. (2004): Spatial urban dynamics. A vision on the future of urban dynamics: Forrester revisited. Paper presented at the 2004 International System Dynamics Conference at Oxford, UK. http://www.systemdynamics.org/conferences/2004/SDS_2004/PAPERS/119SANDE.pdf (visited on 18th of June 2007).

Silva, E.A., Clarke, K. (2002): Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal. Computers, Environment and Urban Systems 26 (6): 525-552.

Strauch, D., Moeckel, R., Wegener, M., Gräfe, J., Mühlhans, H., Rindsfüser, G., Beckmann, K.-J. (2003): Linking Transport and Land Use Planning: The Microscopic Dynamic Simulation Model ILUMASS. Proceedings of the 7th International Conference on GeoComputation, University of Southampton, United Kingdom, 8-10 September 2003. http://www.geocomputation.org/2003/Papers/Strauch_Paper.pdf (visited on 18th of June 2007).

Timmermans, H. (2003): The Saga of Integrated Land Use-Transport Modeling: How Many More Dreams Before We Wake Up? Paper presented at the 2003 10th International Conference on Travel Behaviour Research, Lucerne, Switzerland. http://www.ivt.baug.ethz.ch/allgemein/pdf/timmermans.pdf (visited on 19 of June 2007).

Verburg, P. (2006): Simulating feedbacks in land use and land cover change models. Landscape Ecology 21(8): 1171-1183.

Verburg, P. & Overmars, K. (2007): Dynamic Simulation of Ladn-use change Trajectories with the CLUE-s Model. In: Koomen, E., Stillwell, J., Bakema, A., Scholten, H.J. (Eds.): Modelling Land-Use Change, Progress and Applications. Dordrecht: Springer. Pages 321-335.

Verburg, P., Schot, P., Dijst, M., Veldkamp, A. (2004): Land use change modelling: current practice and research priorities. GeoJournal 61(4): 309-324.

Waddell, P. (2006): UrbanSim: Status and Further Development. In: Proceedings of the 7th Aachener Colloqium “Integrierte Mikro-Simulation von Raum- und Verkehrsentwicklung. Theorie, Konzepte, Modelle, Praxis” (Integrated microsimulation of spatial and transport development. Theory, Concepts, Models, Practice). Pages 81-89.

Waddell, P., Borning, A., Noth, M, Freier, N., Becke, M. and Ulfarsson, G. (2003): Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim. Preprint of an article that appeared in Networks and Spatial Economics, Vol. 3 No. 1, 2003, pages 43-67. http://www.urbansim.org/papers/UrbanSim_NSE_Paper.pdf (visited on 19 of June 2007).

Waddell, P. & Ulfarsson, G. (2004): Introduction to urban Simulation: Design and Development of Operational Models. http://www.urbansim.org/papers/waddell-ulfarsson-ht-IntroUrbanSimul.pdf (visited on 19th of June 2007).

Annex: Data sheets for all models

Within the following tables, empty cells indicate that no information was found in the literature on this issue. “-“ in a cell means that this issue is not applicable to the model in question.

Field “Duration of model run”:

C: Calibration to fit model parameters
S: Scenarios for projections of future trends
V: Validation using independent data

A System Dynamics Approach to Land Use / Transportation System Performance Modeling

<table>
<tr><td>Name of model</td><td colspan="4">A System Dynamics Approach to Land Use / Transportation System Performance Modeling</td></tr>
<tr><td>Sources</td><td colspan="4">Haghani et al. 2003a, b</td></tr>
<tr><td colspan="5">Technical data</td></tr>
<tr><td rowspan="2">Application area</td><td>Covered area, physical boundaries</td><td>Varies with application area
Case study: Montgomery County</td><td>Extent of area</td><td>
About 800,000 people</td></tr>
<tr><td>Spatial units</td><td>none</td><td>Size or grain of grids/zones</td><td>-</td></tr>
<tr><td>Time horizon</td><td>Time step</td><td></td><td>Duration of model run</td><td>C: 1970-80
V: 1980-90</td></tr>
<tr><td>Modelling approach</td><td>Simulation technique</td><td>System dynamics</td><td>Qualitative or quantitative</td><td>Quantitative</td></tr>
<tr><td colspan="5">Contents</td></tr>
<tr><td>Main purpose</td><td colspan="4">Integrated land-use and transportation model for estimating scenarios regarding transport policies</td></tr>
<tr><td>Main variables with relationships</td><td colspan="4">Seven sub-models: (1) population, (2) migration, (3) household, (4) job growth, employment and commercial land development, (5) housing development, (6) travel demand and (7) congestion.</td></tr>
<tr><td rowspan="3">Human decisionmaking</td><td>Domain</td><td>Not explicitly.</td><td>Temporal range</td><td>-</td></tr>
<tr><td>Typology (classes) of agents?</td><td>Cohorts within population sub-model</td><td>→ if yes: what kind of types?</td><td>Persons: age 0-17, 18-44, 45-64, 65 male and female
Households: single, married with children, married without children, male or female with children, other</td></tr>
<tr><td>Decision algorithm</td><td>-</td><td>Input into decision</td><td>-</td></tr>
<tr><td rowspan="2">Goals</td><td>Authors opinion</td><td colspan="3">First step is achieved, successful validation and scenarios.</td></tr>
<tr><td>Validation</td><td>Yes, model was tested using independent statistical data.</td><td>Plausibility analysis</td><td>Yes</td></tr>
<tr><td>Model development process</td><td>Concept</td><td>Not stated.</td><td>Quantification of relationships</td><td>Empirical data</td></tr>
</table>

CLUE-s

Name of model	CLUE-s (Conversion of Land Use and its Effects)			
Sources	Verburg & Overmars (2007)			
Technical data				
Application area	Covered area, physical boundaries	User-specified Several examples published	Extent of area	User-specified User-specified
	Spatial units	CLUE: soft-classified data (large pixels with fraction of land-uses) CLUE-s: only one land-use type per cell	Size or grain of grids/zones	User-specified CLUE: 7 to 32 km CLUE-s: 20 to 1,000 m
Time horizon	Time step	Iterative process stops when demand for land-use meets allocated area	Duration of model run	-
Modelling approach	Simulation technique	Cellular automata	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Tool for understanding land-use patterns, possible future scenarios for given demand			
Main variables with relationships	Input: Pre-defined change in demand for land by different sectors for whole simulation area → CLUE-s assigns new land-uses per grid Each cell: most preferred land-use based on suitability of location and competitive advantage of different land-use types (demand), check: is land-use change allowed? If no: next most preferred land-use is chosen			
Human decisionmaking	Domain	No explicit decisionmaking	Temporal range	-
	Typology (classes) of agents?	-	→ if yes: what kind of types?	-
	Decision algorithm	-	Input into decision	-
Goals	Authors opinion	Case-study specific		
	Validation	Case-study specific	Plausibility analysis	Case-study specific
Model development process	Concept	Not mentioned	Quantification of relationships	User-specified: empirical analysis, expert knowledge, spatial interactions, conversion elasticities

CUF 2

Name of model	CUF-2 (California Urban Futures)			
Sources	Landis & Zhang 1998a, b			
Technical data				
Application area	Covered area, physical boundaries	San Francisco Bay Area (California)	Extent of area	1.8 million hectares
	Spatial units	Grid cells	Size or grain of grids/zones	100 x 100 m
Time horizon	Time step	Econometric: 10 years Probabilities for land-use change: once per simulation	Duration of model run	C: 1985-1995 S: ?
Modelling approach	Simulation technique	Cellular automata	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Simulating urban growth, scenarios for future development			
Main variables with relationships	Top-down approach: future trends of population, household, jobs → are assigned to grid cells Econometric models predict future population, households, employment (10 year intervals) LUC-model: estimates probabilities for land-use change out of historical data, and simulation engine assigns probabilities to cells Probability of land-use change (multinomial logit models) for a cell from i to j = f(initial site use, site characteristics, site accessibility, community characteristics, policy factors, relationships to neighbouring sites) → probabilities are interpreted as bids for (re-) development → population and jobs are assigned to cells by bids 7 urban land-use categories: undeveloped, single-family residential, multifamily residential, commercial, industrial, transportation, public			
Human decisionmaking	Domain	No explicit decisionmaking	Temporal range	-
	Typology (classes) of agents?	-	→ if yes: what kind of types?	-
	Decision algorithm	-	Input into decision	-
Goals	Authors opinion	Achieved		
	Validation	Validation = goodness of fit of statistical calibration, no independent data	Plausibility analysis	Not mentioned
Model development process	Concept	Not mentioned	Quantification of relationships	Calibration using maps of land use change

CURBA

Name of model	CURBA (California Urban and Biodiversity Analysis)			
Sources	Landis et al. (no year)			
Technical data				
Application area	Covered area, physical boundaries	San Francisco Bay Area (California)	Extent of area	See CUF-2 See CUF-2
	Spatial units	Grid cells	Size or grain of grids/zones	100 x 100 m
Time horizon	Time step		Duration of model run	
Modelling approach	Simulation technique	Cellular automata	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Development of policy scenarios of urban growth, impact on habitat change/biodiversity			
Main variables with relationships	Two components: (1) urban growth model and (2) policy simulation and evaluation model Urban growth model is based upon CUF-2 Policy simulation and evaluation: several growth scenarios → impact on habitat change and habitat fragmentation			
Human decisionmaking	Domain	No explicit decisionmaking	Temporal range	-
	Typology (classes) of agents?	-	→ if yes: what kind of types?	-
	Decision algorithm	-	Input into decision	-
Goals	Authors opinion	Achieved		
	Validation	See CUF-2	Plausibility analysis	Yes
Model development process	Concept	See CUF-2	Quantification of relationships	See CUF-2

ILUMASS

Name of model	ILUMASS (Integrated Land-Use Modelling and Transportation System Simulation)			
Sources	Strauch et al. 2003, Moeckel et al. 2006			
Technical data				
Application area	Covered area, physical boundaries	Dortmund and its 25 surrounding municipalities	Extent of area	About 2,000 km² 2.6 million people
	Spatial units	Statistical zones (total: 246) and grid cells	Size or grain of grids/zones	Grid cells: 100 x 100 m
Time horizon	Time step	One year	Duration of model run	S: 2000-2030
Modelling approach	Simulation technique	Coupled simulation system including agent-based simulations	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Dynamic simulation model with a focus on urban traffic flows, including activity behaviour, changes in land-use, and effects on environment			
Main variables with relationships	Five modules (+ integration module): 1. changes in land-use, 2. activity patterns and travel demand, 3. traffic flows, 4. goods transport, 5. environmental impacts of transport and land-use Land-use → demand for spatial interaction (work, shopping trips etc.) → traffic → environmental impacts Feedbacks: (a) transport → accessibility of locations → location decisions of households, firms, developers. (b) environmental factors → location decisions (e.g. clean air, traffic noise) Land use module: moving households, location of firms, investment of developers, new industrial area			
Human decisionmaking	Domain	Various, e.g. transport, household location, daily activity plans	Temporal range	Depending upon domain (daily travel behaviour vs. moving)
	Typology (classes) of agents?	Yes	→ if yes: what kind of types?	Not mentioned
	Decision algorithm	Various (markov, logit, monte-carlo)	Input into decision	Depending upon domain, feedbacks included
Goals	Authors opinion	Time of report: work in progress, later paper all focus on single modules		
	Validation	Not mentioned	Plausibility analysis	Not mentioned
Model development process	Concept	Not mentioned	Quantification of relationships	Not mentioned

ILUTE

Name of model	ILUTE (Integrated Land Use, Transportation, Environment model)			
Sources	Salvini & Miller 2005, Miller et al. 2004			
Technical data				
Application area	Covered area, physical boundaries	Tests for Toronto area	Extent of area	5 million people
	Spatial units	Two versions: grids and buildings	Size or grain of grids/zones	2 parallel approaches: - Grid: 30 x 30 m - Buildings as objects
Time horizon	Time step	Varying with sub-models	Duration of model run	V: 1986-2001 S: 10 - 20 years into future
Modelling approach	Simulation technique	Agent-based simulation	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Evolution of an entire urban region with emphasis on transport			
Main variables with relationships	Land development → location choice → activity schedule → activity patterns → back to land development and all other variables in chain transportation network → automobile ownership → travel demand → network flows → back to transportation network and all other variables in chain influences			
Human decisionmaking	Domain	Activity/travelling scheduling, route choice, real estate market, behaviour of economy, land development, household ownership	Temporal range	Depends upon domain. E.g.: typical travel day is computed once per simulation year per agent type.
	Typology (classes) of agents?	Yes	→ if yes: what kind of types?	For households, individuals, firms
	Decision algorithm	Rule-based: reducing number of choices logit model for selecting the “best” option	Input into decision	Not mentioned
Goals	Authors opinion	Work in progress		
	Validation	Is planned	Plausibility analysis	Not mentioned
Model development process	Concept	Not mentioned	Quantification of relationships	Empirical data

Modelling biodiversity and land use

Name of model	Modelling biodiversity and land use			
Sources	Eppink et al. 2004			
Technical data				
Application area	Covered area, physical boundaries	No explicit representation of a specific area. Urban region with surrounding area including wetlands	Extent of area	- -
	Spatial units	No spatial resolution	Size or grain of grids/zones	-
Time horizon	Time step	1 year	Duration of model run	S: 100 years
Modelling approach	Simulation technique	System dynamics	Qualitative or quantitative	Qualitative
Contents				
Main purpose	Assessing the impact of urban sprawl on wetland biodiversity and social welfare			
Main variables with relationships	Population growth within city → higher population density and more need for agricultural land → expansionists attempt to buy surrounding area → change of wetland area to urban area & more agriculture decrease wetland biodiversity → conservationists' valuation of remaining biodiversity increases → conservationists buy wetland area for nature protection			
Human decisionmaking	Domain	Human decisionmaking is represented within system dynamics equations	Temporal range	1 year
	Typology (classes) of agents?	Yes	→ if yes: what kind of types?	Expansionists, conservationists (see above) and owners of land
	Decision algorithm	Land is sold to the highest bidder	Input into decision	Prices offered by conservationists and expansionists.
Goals	Authors opinion	First step for improving relationship between economic development and biodiversity		
	Validation	Not mentioned	Plausibility analysis	Not mentioned
Model development process	Concept	Not mentioned	Quantification of relationships	Not mentioned

MOLAND

Name of model	MOLAND			
Sources	Engelen et al. (2007)			
Technical data				
Application area	Covered area, physical boundaries	Several examples across Europe and elsewhere	Extent of area	User-specified User-specified
	Spatial units	global: 1 zone regional: zones, typically NUTS local: grid cells	Size or grain of grids/zones	User-specified
Time horizon	Time step	annual	Duration of model run	C: last 40-50 years S: user-specified, normally 30 years
	Simulation technique	Mainly rule-based cellular automata	Qualitative or quantitative	Quantitative
Contents				
Main purpose	To monitor developments of urban areas and identify trends at the European Scale, focus is on growth scenarios			
Main variables with relationships	Growth of economy and population (global level) → growth in competing regions (regional level), sets boundaries for all cells in a region → rules for land use change at the grid-level: physical suitability, institutional suitability (e.g. planning documents), accessibility (via transport network), dynamics at the local level (land use functions attracting or repelling each other) Feedback from grid level to regional level: spatial distribution leads to quality and availability of space for different activities, which influences attractiveness of a region when compared to one another			
Human decisionmaking	Domain	No explicit decisionmaking	Temporal range	-
	Typology (classes) of agents?	-	→ if yes: what kind of types?	-
	Decision algorithm	-	Input into decision	-
Goals	Authors opinion	Achieved		
	Validation	Yes	Plausibility analysis	-
Model development process	Concept	Not mentioned	Quantification of relationships	Calibration with historical data

PUMA

Name of model	PUMA – Predicting Urbanisation with Multi-Agents			
Sources	Ettema et al. (2007)			
Technical data				
Application area	Covered area, physical boundaries	North Dutch Ranstadt (including Amsterdam, Utrecht, Schiphol airport)	Extent of area	3.16 million inhabitants
	Spatial units	Grid cells (and travel zones)	Size or grain of grids/zones	500 x 500 m
Time horizon	Time step	1 year later: up to daily	Duration of model run	S: 2000 to approx. 2050
Modelling approach	Simulation technique	Agent-based simulation	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Predicting urbanisation with behavioural agents			
Main variables with relationships	Demographic change → decisions of individuals → land use change Not yet implemented: developers, authorities and firms/institutions (so far exogenous) [impact of household’s decisions on land use not described]			
Human decisionmaking	Domain	1. demographic events (no decisions, just stochastic) 2. residential relocation 3. job changes	Temporal range	Annual [Daily decisions in future work]
	Typology (classes) of agents?	Yes	→ if yes: what kind of types?	Households: Number of adults and children; age of household head [dwellings are agents as well]
	Decision algorithm	Rational choice with utility maximisation	Input into decision	Residential relocation: characteristics of dwelling, commuting distance, socio-demographics Job choice: salary, job type, distance to dwelling, personal preferences…
Goals	Authors opinion	Promising approach, still work in progress		
	Validation	Is planned	Plausibility analysis	Is planned using scenarios
Model development process	Concept	Empirical data	Quantification of relationships	Empirical data

Rotterdam urban dynamics

Name of model	Rotterdam urban dynamics			
Sources	Sanders & Sanders 2004			
Technical data				
Application area	Covered area, physical boundaries	Rotterdam	Extent of area	100,000 acres
	Spatial units	16 grid cells called "zones"	Size or grain of grids/zones	Squares with 3,125 miles each side
Time horizon	Time step		Duration of model run	S: 250 years
Modelling approach	Simulation technique	System dynamics	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Redefining Forresters (1969) model of urban dynamics, including: 1. spatial dimension (16 squares) and 2. disaggregation: different types of housing, industry, and people in zones			
Main variables with relationships	Bi-directional causal loops between: population, housing availability, houses, land availability, business structures, and job availability (linked with population) Two markets: labor market and housing market compete for land (no transport)			
Human decisionmaking	Domain	No explicit decisionmaking	Temporal range	-
	Typology (classes) of agents?	-	→ if yes: what kind of types?	-
	Decision algorithm	-	Input into decision	-
Goals	Authors opinion	Case of Rotterdam only as an example for generic results		
	Validation	No validation	Plausibility analysis	Yes
Model development process	Concept	Not mentioned	Quantification of relationships	Out of statistical data and expert knowledge

SCOPE

<table>
<tr><td>Name of model</td><td colspan="4">SCOPE (South Coast Outlook and Participation Experience)</td></tr>
<tr><td>Sources</td><td colspan="4">Onsted 2002</td></tr>
<tr><td colspan="5">Technical data</td></tr>
<tr><td rowspan="3">Application area</td><td rowspan="2">Covered area, physical boundaries</td><td rowspan="2">South Coast of Santa Barbara County</td><td rowspan="2">Extent of area</td><td>137,000 acres</td></tr>
<tr><td>Approx. 200,000 inhabitants</td></tr>
<tr><td>Spatial units</td><td>No spatial resolution</td><td>Size or grain of grids/zones</td><td>-</td></tr>
<tr><td>Time horizon</td><td>Time step</td><td></td><td>Duration of model run</td><td>V: 1960-2000
S: 2000-2040</td></tr>
<tr><td>Modelling approach</td><td>Simulation technique</td><td>System dynamics</td><td>Qualitative or quantitative</td><td>Quantitative</td></tr>
<tr><td colspan="5">Contents</td></tr>
<tr><td>Main purpose</td><td colspan="4">Simulation model to provide scenarios for future land use in Santa Barbara, e.g. with restrictions to urban growth</td></tr>
<tr><td>Main variables with relationships</td><td colspan="4">Five sectors: housing, population, business, quality of life, land use</td></tr>
<tr><td rowspan="3">Human decisionmaking</td><td>Domain</td><td>No explicit decisionmaking</td><td>Temporal range</td><td>-</td></tr>
<tr><td>Typology (classes) of agents?</td><td>-</td><td>→ if yes: what kind of types?</td><td>-</td></tr>
<tr><td>Decision algorithm</td><td>-</td><td>Input into decision</td><td>-</td></tr>
<tr><td rowspan="2">Goals</td><td>Authors opinion</td><td colspan="3">Achieved, but should still become more differentiated.</td></tr>
<tr><td>Validation</td><td>Yes</td><td>Plausibility analysis</td><td>Yes</td></tr>
<tr><td>Model development process</td><td>Concept</td><td>Expert knowledge</td><td>Quantification of relationships</td><td>Assumptions and statistical data</td></tr>
</table>

Simulation of polycentric urban growth dynamics through agents

Name of model	Simulation of polycentric urban growth dynamics through agents			
Sources	Loibl et al. (2007)			
Technical data				
Application area	Covered area, physical boundaries	Austrian Rhine valley with medium-sized centres and rural villages	Extent of area	7,330 hectares built-up area 260,000 inhabitants
	Spatial units	Grid cells	Size or grain of grids/zones	50 x 50 m cells
Time horizon	Time step	Simulation stops when certain household, popu-lation and workplace growth numbers are achieved	Duration of model run	V: 1990-2000 S: user-specified
Modelling approach	Simulation technique	Agent-based simulation	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Development of built-up area in peri-urban region, driven by households and entrepreneurs; urban growth with different growth rates			
Main variables with relationships	Initialisation: increase of household and workplace numbers is defined 1. Municipality choice depending on regional attractiveness criteria (numbers of people, households and workplaces in start year, average travel time to district centres and capital city, average share of attractive land-use classes in the municipality (open space, forest area) → household growth and workplace growth per municipality → transformation of absolute values into relative search frequencies → agents choose municipality via discrete choice 2. Local target area search: start with random cell, choosing most attractive cell 3. land-use change (new built-up area, higher density) → influencing local attractiveness			
Human decisionmaking	Domain	Causing the construction of new built-up area or the densification of existing area, no moving as 'exchange' of dwellings	Temporal range	Long-term (moving / start-up of companies)
	Typology (classes) of agents?	Yes	→ if yes: what kind of types?	Four household types (1,2,3 or 4 persons) and two entrepreneurs (small and large)
	Decision algorithm	Discrete choice	Input into decision	Regional and local attractiveness
Goals	Authors opinion	Achieved		
	Validation	Both on municipality level and grid cell level	Plausibility analysis	No
Model development process	Concept	Empirical data	Quantification of relationships	Empirical data

SLEUTH

Name of model	SLEUTH (Slope, Landuse, Exclusion, Urban Extend, Transportation and Hillshade)			
Sources	Clarke (no year), Silva & Clarke 2002, Dietzel & Clarke 2007			
Technical data				
Application area	Covered area, physical boundaries	Numerous applications, mostly US	Extent of area	User-specified User-specified
	Spatial units	Grid cells	Size or grain of grids/zones	Input for model: 8-bit GIF (100x100m cells can be converted)
Time horizon	Time step	1 year	Duration of model run	C: at least 4 time steps S: User-specified
Modelling approach	Simulation technique	Cellular automata	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Modelling urban growth, scenarios for future development of an urban region			
Main variables with relationships	Two components (use depends on available data): (1) Urban growth: cells have one of two states: urban or non urban (2) Urban land use change with different land-use types Four types of growth behaviour: spontaneous, diffusive (with new growth centres), organic (into surroundings) and road-influenced Five main coefficients: diffusion, breed, spread, slope, and road coefficient (need to be calibrated for each case study) Self modification rules: e.g.: concerning the kind of exponential or S-curve growth; denser road network → road gravity factor increases; land availability decreases → slope resistance factor is decreased (more hilly areas); spread factor increases over time			
Human decisionmaking	Domain	No explicit decisionmaking	Temporal range	-
	Typology (classes) of agents?	-	→ if yes: what kind of types?	-
	Decision algorithm	-	Input into decision	-
Goals	Authors opinion	Achieved		
	Validation	Emphasis on calibration, not validation	Plausibility analysis	Not mentioned.
Model development process	Concept	Not mentioned	Quantification of relationships	Calibration using historical maps

Urban dynamics

Name of model	Urban dynamics			
Sources	Forrester, 1969, Alfeld, 1995			
Technical data				
Application area	Covered area, physical boundaries	Either suburban or core area (Forrester 1969: 2) Examples mentioned in Alfeld, 1995: Lowell, Boston, Concord, Marl-borough, Palm Coast	Extent of area	User-specified User-specified
	Spatial units	No spatial resolution	Size or grain of grids/zones	-
Time horizon	Time step		Duration of model run	S: Up to 250 years
Modelling approach	Simulation technique	System dynamics	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Modelling urban system in general, explicitly including “urban decline”. Examples: focus on a specific topic, e.g. rapid population growth, demolition et cetera and therefore need specific models.			
Main variables with relationships	Original model by Forrester: Three subsystems: business, housing, population			
Human decisionmaking	Domain	No explicit decisionmaking	Temporal range	-
	Typology (classes) of agents?	-	→ if yes: what kind of types?	-
	Decision algorithm	-	Input into decision	-
Goals	Authors opinion	Achieved		
	Validation	Not mentioned	Plausibility analysis	Yes
Model development process	Concept	Expert knowledge	Quantification of relationships	Statistical data and own estimation

Urban transformation process in the Haaglanden region

Name of model	Simulating the urban transformation process in the Haaglanden region in the Netherlands			
Sources	Eskinasi & Rouwette 2004			
Technical data				
Application area	Covered area, physical boundaries	The Haaglanden region, including the Hague and surrounding suburbs	Extent of area	
	Spatial units	No spatial resolution	Size or grain of grids/zones	-
Time horizon	Time step		Duration of model run	S: 1998-2010
Modelling approach	Simulation technique	System dynamics	Qualitative or quantitative	Qualitative
Contents				
Main purpose	Assessing the impact of future policy interventions on the social housing market (specific: rate of building new dwellings)			
Main variables with relationships	Four stocks: 1 Commericial housing stock 2 Social housing stock 3 Waiting families 4 Supply of available social houses Processes involved: Migration, demolition, construction			
Human decisionmaking	Domain	No explicit decisionmaking	Temporal range	-
	Typology (classes) of agents?	-	→ if yes: what kind of types?	-
	Decision algorithm	-	Input into decision	-
Goals	Authors opinion	Model is useful for its goal		
	Validation	No (but impact of process on stakeholders is monitored)	Plausibility analysis	With stakeholders
Model development process	Concept	Participation of stakeholders, narrative approach	Quantification of relationships	Empirical data or expert guesses.

Urban travel system

Name of model	A system dynamics model for the urban travel system			
Sources	Raux 2003			
Technical data				
Application area	Covered area, physical boundaries	Hypothetical city	Extent of area	- -
	Spatial units	No spatial resolution	Size or grain of grids/zones	-
Time horizon	Time step		Duration of model run	S: 20 years into the future
Modelling approach	Simulation technique	System dynamics	Qualitative or quantitative	Quantitative
Contents				
Main purpose	To simulate medium- and long-term effects of urban transport policies with reference to sustainable travel			
Main variables with relationships	Seven major blocks: urbanisation, internal travel demand (trips within system), car ownership, external travel demand (inflowing, outflowing and through traffic), transportation (comparing supply and demand) and evaluation (socioeconomic and environmental appraisals)			
Human decisionmaking	Domain	No explicit decisionmaking	Temporal range	-
	Typology (classes) of agents?	-	→ if yes: what kind of types?	-
	Decision algorithm	-	Input into decision	-
Goals	Authors opinion	Work in progress		
	Validation	Not mentioned	Plausibility analysis	Yes
Model development process	Concept	Expert knowledge	Quantification of relationships	Expert knowledge and statistical values

UrbanSim

Name of model	UrbanSim			
Sources	Waddell 2006, Waddell et al., 2003			
Technical data				
Application area	Covered area, physical boundaries	Several examples in the US, Europe and Asia	Extent of area	User-specified User-specified
	Spatial units	Initially: mixture of parcels and zones later: grid	Size or grain of grids/zones	User-specified Cell: 150 x 150 meters regarded as default
Time horizon	Time step	1 year	Duration of model run	User-specified
Modelling approach	Simulation technique	Coupled simulation models including agent-based simulations	Qualitative or quantitative	Quantitative
Contents				
Main purpose	Link between transport and land use; impact of different planning strategies			
Main variables with relationships	Exogenous: (1) macroeconomics (population, employment) and (2) travel demand (travel conditions). Six models: 1 Accessibility (output: access to workplaces and shops for each cell) 2 Transition (output: number of new jobs and new households per year) 3 Mobility (output: number of moving (existing) jobs / households) 4 Location (output: location of new or moving jobs / households) 5 Real Estate Development (output: land use change) 6 Land price (output: land prices)			
Human decisionmaking	Domain	Mobility and location	Temporal range	Depends on issues
	Typology (classes) of agents?	Initially households / firms, later persons / jobs	→ if yes: what kind of types?	User-specified
	Decision algorithm	Multinomial logit model	Input into decision	Land-use itself, socio-demographics, dwellings
Goals	Authors opinion	Achieved		
	Validation	Depends on application	Plausibility analysis	Depends on application
Model development process	Concept	Not mentioned	Quantification of relationships	Out of empirical data