Transition Rules for Modelling Land-Use Change

Michel Hagoort and Stan Geertman
Urban Research centre Utrecht/Networks in the Delta Programme
Faculty of GeoSciences, Utrecht University, The Netherlands
M.Hagoort@geog.uu.nl, S.Geertman@geog.uu.nl

SUMMARY

It appears that the spatial planners' feeling of losing grip in guiding urban growth has become stronger and stronger. New geo-information related instruments like Cellular Automata (CA) can assist in this. CA land-use models can be used to simulate and assess future land-use developments and increase the much-needed understanding of urban dynamics. Presently, the transition rules in a CA, which specify the behaviour of land uses within the model, lack sufficient theoretical foundation and empirical justification. The present work aims to extend the foundation and justification of transition rules. The presentation will focus in particular on the work performed and its results concerning this extension. For a proof, a comparison of the effects on the behaviour of the CA land-use model of these rules with the rules that have been developed in previous research will be shown for the COROP region of Utrecht in the Netherlands.

KEYWORDS: *Cellular Automata, land-use model, transition rules, empirical foundation, urban dynamics, externalities*

INTRODUCTION

The ever-increasing pressure on land in Western countries has focused spatial planning strongly on minimizing spatial conflicts and achieving sustainable development. Meanwhile, the spatial planners' feeling of losing grip in guiding urban growth has become stronger and stronger (Hartog, 1999). The structure and form of today's cities are the result of numerous general and local social, economic, cultural, and physical factors (Lambin *et al.*, 2001). Therefore, there is an increased need for more insight in the spatial-temporal dynamics of the urban morphological structure. Of particular interest and complexity are the processes that initiate and direct the urban land-use pattern changes, and the influence that can be exerted hereupon by national spatial policy. In international perspective, more insight in the differences and similarities in urbanisation patterns and processes between countries and regions is desired also because of the growing interest in the European dimension of spatial policies (ESDP, 1999).

In recent years, on the national level, spatial planners are increasingly making use of land-use models from the perspective that they provide information to support the proposed spatial policy measures. In the nearby future, the use of land-use change models will probably become a standard procedure for simulating and assessing future land-use developments and increase the understanding of the processes behind urban dynamics.

Among the many methods developed in attempting to model land-use change are statistical and transition probability models, optimisation models and linear programming, dynamic simulation models, agent-based models and cellular automata (CA). A broad survey of the various methods may also be found in MODLUC (2002). CA are of special interest because of their ability, as opposed to most other methods, to both simulate existing urban form and provide procedures for the design of optimal forms (Batty, 1997). They are also dynamic and flexible, as well as intuitively useful and behaviourally realistic. In addition, CA provides a mechanism for linking micro- and macro-approaches. CA are suitable for representing the dispersal of activities and characteristics between discrete spatial units of urban infrastructure, and for defining the spatial interactions between land uses at certain locations, the conditions at these locations and the land-use types in the neighbourhood (Torrens, 2001). In short, CA comprise both pattern and process, and form and function (Torrens & O'Sullivan, 2000).

TRANSITION RULES

However, although the application of CA to urban systems seems natural and intuitive, this is not in itself sufficient justification for their use (Couclesis, 1985). A central issue of CA is the validity of the transition rules, which specify the behaviour of land uses. A rule expresses how a particular land use values the presence of another land use in its neighbourhood on a relative scale (figure 1). The rules suffer from serious limitations, the main one being their lack of theoretical foundation and empirical justification. Since explicitly geographic or urban theory is only slowly being adopted as a basis for transition rule formulation, a valuable opportunity to infuse the models with a solid theoretical foundation is gone by (O'Sullivan & Torrens, 2000). As a consequence, CA-models are largely technology-driven instead of really informing theories through the exploration of hypothetical ideas about urban dynamics (Torrens, 2000). Therefore, it is no surprise that transition rules are mainly defined on an ad hoc basis. Presently, a transition rule specifies the relationship between individual cells of land use as a function of distance. Further, the present inability to explain transition rules is inherent to the often used top-down working method. Before going into this, it is expounded what transition rules actually are.

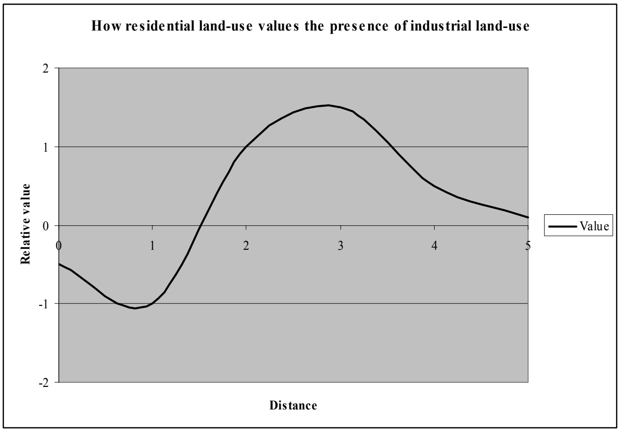

Figure 1: Example of a transition rule

EXTERNALITIES

The values in a transition rule can best be compared with how the combined, in urban theory called, spatial externalities of one land use are experienced by another land use over distance. Based on Lucas and Oort (1993), spatial externalities are the radiated priced or unpriced effects of a certain land use upon another land use. Examples are the noise and noxious fumes of an industrial plant, which create damage and inconvenience to the residential area close by. Positive externalities and negative externalities are also known as benefits and burden, betterment and worsement, external benefit and external cost, amenity and disamenity, external economies and external diseconomies, neighbourhood effects, spillover effects, and third party effects. Since much of the urban dynamics can be interpreted as an attempt by individual land uses to organize the distribution of externality effects to gain advantages, their study is very important (Harvey, 1973). It is these spatial externalities that make a transition rule.

TOP-DOWN

The most important point with the mentioned top-down method is that it tries to derive transition rules by directly measuring the net impact of one land use on another land use. When this net impact is taken as the starting point from which to explain the shape of a transition rule, the analytical problem faced involves disaggregating for the source of each externality effect, then aggregating to assess the net impact. In addition, multiple spatial externalities have coalesced to produce a net externality effect significantly different from the simple effect of each field taken separately. Moreover there is a problem of "noise" in directly measuring the net impact since it is never certain that the net impact being observed can be attributed to the land use being studied (Dear, 1977). Also, the close association of two land uses in space which is often used doesn't automatically imply a causal and logic relation. There has been little empirical work to substantiate that compatible land use pairs are, on average, closely associated in space while incompatible pairs will show spatial segregation (Millward, 1980). This has led to uncertain results, characteristic of much of the empirical research relating to the net impact of land uses and herewith transition rules.

BOTTOM-UP

The bottom-up method starts from the externality effects and their sources and aggregates them. Although this method is the most promising, there have been only limited results because of the problem of empirically identifying externality effects. Based on Engelen (2002), up till now, very little is known about the shape and form of these externality fields in an urban environment and there has been very little investigation on the nature of the spatial field of influence of particular externalities. Also, as Dear in 1977 already noted, because of the great contribution of intangibles to externality effects, it is virtually impossible to evaluate every effect and in absolute comparable units. The unique circumstances under which each externality occurs have caused most analysts to proceed on a case-by-case basis. Therefore it becomes exceedingly difficult to recognize the general net impact of a specific land use. A formal theory of shaping transition rules is thus slowly developing.

It can be concluded that getting a CA-model running is a very research-intensive exercise, though not unfeasible as shown next. The number of transition rules which has to be given shape increases exponentially with the number of land uses incorporated. For example, 15 land uses means 225 transition rules each based on multiple externality effects playing over different distances. However, great reductions can be made without compromising the result. First, the spatial influence of all land uses on the static land uses, of which change is not modelled but imposed externally, does not have to be taken into account. Second, in practice a great number of land uses do not interact and are hardly ever relevant. Per modelled land use, 2 or 3 combinations are most important and already sufficient (Engelen *et al.*, 1999 in Nijs *et al.*, 2001; Engelen, 2002). Third, the coalescence of two externality effects from one land use is less common than the coalescence of single externality effects from a large number of land uses (Millward, 1980). This means that of all externalities caused and experienced by a land use only a very selective number play a dominant role in the interaction between two land uses. Fourth, all externality effects are constrained to a spatially limited area within which they are more dominant at certain distances than others. There tends to be a systematic decline in the externality effect over distance as proximity to its source, in this case land use, diminishes (Smith, 1981). Such distance-decay effects have been observed empirically in many cases (e.g. Davies, 1974; Hammer *et al.*, 1971; Grether & Mieszkowski, 1980; Millward, 1980; Rothenburg, 1967; Tideman 1970). Fifth, from all possible externality fields, 6 different general shapes can be deduced, identifying how a externality can change over distance. Therefore further reducing the information needed to give shape to the transition rules. Sixth, it is not necessary to know the value at every distance to find out the shape of an externality and transition rule. For each effect a maximum of 5 particular points is needed to closely match the valid effect. In this study, which effects are dominant at which distances for which land uses was found out using interviews complemented with literature research on spatial plans and spatial planning laws and with statistical analysis.

INTERVIEWS

Because of the impossibility to study all externalities on a case-by-case basis and the wish to receive more generalized rules, interviews were used to get a detailed overview of which land uses interact and which spatial externalities do matter in practice. Important main factors of interaction found were among others visibility (e.g. a commercial area wants to be visible from a highway), environmental nuisance (e.g. a residential area dislikes industrial sounds and smells) and tolerable travel distances (e.g. facilities want to be within walking or biking distance of a residential area and vice versa). For this last example, next to the distances mentioned in the interviews, the tolerable travel distances can also be approximated from the importance of different transport modes in relation to the distance to facilities (figure 2). Since different actors have variable perceptions of the potential externalities of various land uses, for each land use 3 interviews were conducted, interviewing actors with a scientific, policy and commercial background. The interviews produced consistent results. For example, the interviewees strongly agreed on the influence of a highway entrance/exit on an industrial area and the way it changes over distance showing an L-shaped curve. They all indicated that relative to other land uses a highway entrance has a very positive influence that decreases steeply till about 1 km. Within this distance people can be on a highway very fast and the area will still be visible from the entrance/exit. Especially during congestion hours, the closer the better is valid. Hereafter the influence slowly decreases till 7.5 km meters, which is about the maximum distance. If an entrance/exit is 5 km or 6 km away doesn't really make a difference, but 5 km is always better. Also, the closer to an entrance/exit the lesser chance of having to pass through a built-up area, which takes a lot of time and creates nuisance. Other reasons for being close to an entrance/exit are their average number of employees per square meter resulting in a particular need for accessibility, the fact that their freight is largely moved using the road network, and that most employees and visitors prefer to come by car. All results were refined by an extensive literature research including spatial plans and spatial planning laws and by statistical analyses after which it was possible to determine the effects dominating the land use change process and to quantify externalities and found transition rules. One statistical measure used was the enrichment factor by Verburg *et al.* (2003) that characterizes the average under- or overrepresentation of different land uses in the neighbourhood of another land use. For reasons indicated in the interviews, commercial areas like to be very close to train stations. This is reflected in the relative overrepresentation of commercial areas near train stations (figure 3).

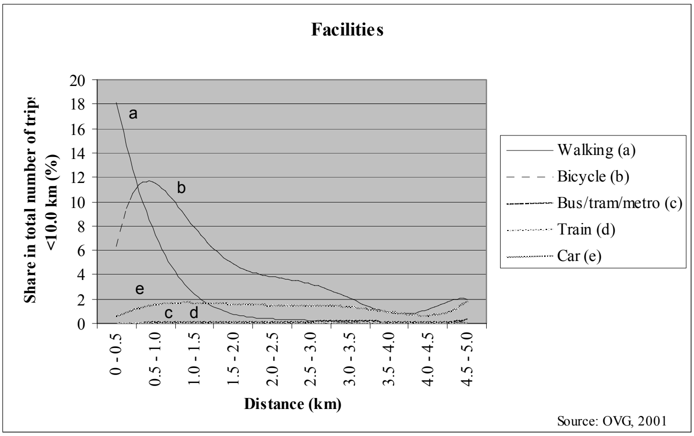

Figure 2: Importance of transport modes in relation to the distance for the trips to facilities

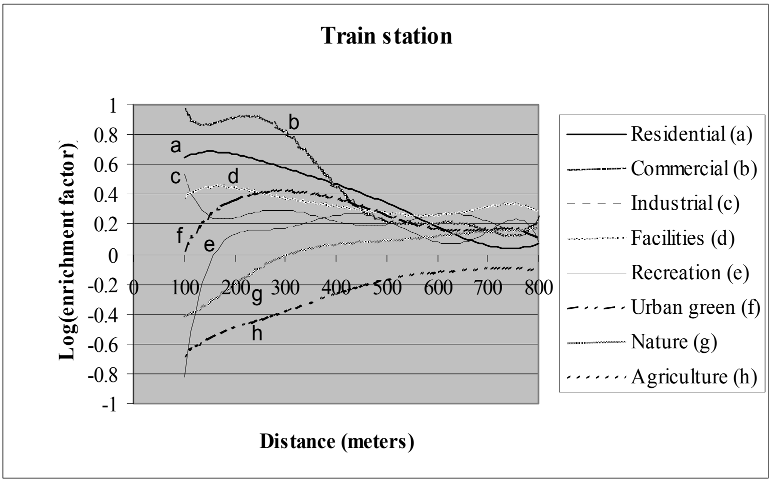

Figure 3: The under- or overrepresentation of land uses in the neighbourhood of train stations

Recently, different attempts have been made to define transition rules though not all satisfying (e.g. Messina & Walsh, 2001; Sui & Zeng, 2001; Steen, 2002). The present research tries to eliminate many uncertainties in the land-use model outcomes by introducing improved empirically founded transition rules.

CURRENT DEVELOPMENT WORK

The present work extends the first attempts of defining transition rules, thus increasing the foundation of land-use simulation models. In addition, an effort is made to improve the insight into the effects of proposed spatial policy measures and it is aimed at getting a better understanding of urban dynamics and possible future land-use patterns. The presentation will focus in particular on the work performed and its results concerning this extension of the foundation and justification of transition rules. For a proof, a comparison of the effects on the behaviour of the CA land-use model of these rules with the rules that have been developed in previous research will be shown for the COROP region of Utrecht in the Netherlands.

BIBLIOGRAPHY

Batty, M., 1997 Cellular Automata and Urban Form: A Primer. Journal of the American Planning Association, 63(2): 266-274.

Couclesis, H., 1985 Cellular Worlds: A Framework for Modelling Micro-Macro Dynamics. Environment and Planning A, 17: 585-596.

Davies, G., 1974 An Econometric Analysis of Residential Amenity. Urban studies, 11: 217-225.

Dear, M. Spatial Externalities and Locational Conflict. In: D.B. Massey and P.W.J. Batey (ed.). Alternative Frameworks for Analysis, Londen Papers in Regional Science 7. Pion: 152-167, 1977

Engelen, G., Geertman, S., Smits, P. and Wessels, C., Dynamic GIS and Strategic Physical Planning Support: A Practical Application. In: J. Stillwell, S. Geertman and S. Openshaw (ed.). Geographical Information and Planning. Springer-Verlag: 87-111, 1999

Engelen, G., 2002 Presentation at MODLUC, Advanced Study Course on Modelling Land-Use Change, European Commission, Environment and Climate Programme. University of Louvain-la-Neuve, Belgium, 27 October - 2 November. RIKS, Maastricht.

ESDP, 1999 European Spatial Development Perspective, Towards Balanced and Sustainable Development of the Territory of the European Union. European Commission, Office for Official Publications of the European Communities, Luxembourg.
Grether, D. and Mieszkowski, P., 1980 Determinants of Real Estate Values. Journal of Urban Economics, 1: 127-146.
Hammer, T.R., Coughlin, R.E. and Horn, E.T. IV, 1971 The Effect of a Large Urban Park on Real Estate Value. Journal of American Institute of Planners, 40: 274-277.
Hartog, R., 1999 Growth without Limits: Some Case Studies of 20th-century Urbanization. International Planning Studies, 4(1): 95-130.
Harvey, D., 1973 Social Justice and the City. Edward Arnold, London.
Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skanes, H., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel, C. and Xu, J., 2001 The Causes of Land-Use and Land-Cover Change Moving Beyond the Myths. Global Environmental Change, 11: 261-269.
Lucas, P.G. and Oort, G. van, 1993 Dynamics in the Urban Fringe (in Dutch). Netherlands Geographical Studies, 154.
Messina, J.P. and Walsh, S.J., 2001 2.5D Morphogenesis, Modelling Land-Use and Land-Cover Dynamics in the Ecuadorian Amazone. Plant Ecology, 156: 75-88.
Millward, H.A., 1980 Externality Effects and the Spatial Association of Land Uses. Ontario Geography, 15: 17-33.
MODLUC, 2002 Advanced Study Course on Modelling Land-Use Change, European Commission, Environment and Climate Programme. University of Louvain-la-Neuve, Belgium, 27 October - 2 November.
Nijs, T. de, Engelen, G., White, R., Delden, H. van and Uljee, I., 2001 The Environment Explorer, Technical Documentation (in Dutch). National Institute of Public Health and the Environment, De Bilt, RIVM report 408505007/2001.
O'Sullivan, D and Torrens, P.M., 2000 Cellular Models of Urban Systems. Centre for Advanced Spatial Analysis, University College London, Paper 22.
Rothenburg, J., 1967 Economic Evaluation of Urban Renewal. Brookings Institution, Washington, DC.
Smith, 1981 Residential Proximity and Community Acceptance of the Mentally Ill. Journal of Operational Psychiatry, 12(1): 2-12.
Steen, I. van den, 2002 Spatial Autocorrelation. University of Leuve, Belgium.
Sui, D.Z. and Zeng, H., 2001 Modelling the Dynamics of Landscape Structure in Asia's Emerging Desakota Regions, a Case Study in Shenzhen. Landscape and Urban Planning, 52: 37-52.
Tideman, N.T., 1970 Land Use Control through Administered Compensation. Program on Regional and Urban Economics, Harvard University, Discussion Paper 59.
Torrens, P.M., 2000 How Cellular Models of Urban Systems Work, 1. Theory. Centre for Advanced Spatial Analysis, University College London, Paper 28.
Torrens, P. M. and O'Sullivan, D., 2000 Cities, Cells, and Complexity: Developing a Research Agenda for Urban Geocomputation, GeoComputation 2000, University of Greenwich, 25-28 August.
Torrens, P. M., 2001 Can Geocomputation Save Urban Simulation? Throw Some Agents into the Mixture, Simmer, and Wait..., Paper 32, Centre for Advanced Spatial Analysis, University College London.
Verburg, P.H., Nijs, T.C.M. de, Ritsema van Eck, J., Visser, H. and Jong, K. de, 2003 A Method to Analyse Neighbourhood Characteristics of Land Use Patterns. Computers, Environment and Urban Systems, In Press.