Computers, Environment and Urban Systems 41 (2013) 55–64

Contents lists available at SciVerse ScienceDirect

Computers, Environment and Urban Systems

journal homepage: www.elsevier.com/locate/compenvurbsys

Measuring the neighbourhood effect to calibrate land use models

Jasper van Vliet [a,b,*], Nick Naus [c], Ron J.A. van Lammeren [c], Arnold K. Bregt [c], Jelle Hurkens [a], Hedwig van Delden [a]

[a] Research Institute for Knowledge Systems bv, Maastricht, The Netherlands
[b] Institute for Environmental Studies and Amsterdam Global Change institute, VU University, Amsterdam, The Netherlands
[c] Wageningen University, Centre for Geo-Information, Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 13 November 2012
Received in revised form 24 March 2013
Accepted 25 March 2013

Keywords:
Land use change
Constrained cellular automata
Calibration
Neighbourhood rules
Enrichment factors

ABSTRACT

Many spatially explicit land use models include the neighbourhood effect as a driver of land use changes. The neighbourhood effect includes the inertia of land uses over time, the conversion from one land use to another, and the attraction or repulsion of surrounding land uses. The neighbourhood effect is expressed in the neighbourhood rules, but calibration of the neighbourhood rules is not straightforward. This paper aims to characterise the neighbourhood effect of observed land use changes and use this information to improve the calibration of land use models. We measured the over- and underrepresentation of land uses in the neighbourhood of observed land use changes using a modified version of the enrichment factor. Enrichment factors of observed land use changes in Germany between 1990 and 2000 indicate that the neighbourhood effect exists. This suggests that it is appropriate to use neighbourhood rules to simulate urban land use changes. Observed enrichment factors were used to calibrate a land use model for Germany from 1990 to 2000 and the obtained neighbourhood rules were validated independently from 2000 to 2006. The results show that both the allocation accuracy and the pattern accuracy of the land use model improved for the calibration period, as well as for the independent validation period. This indicates that enrichment factors can be used to improve the calibration of the neighbourhood rules in land use models.

1. Introduction

Land use models typically include a combination of drivers to simulate land use changes over time (Poelmans & van Rompay, 2010; Wang, Hasbani, Wang, & Marceau, 2011), often including the interaction between land uses in space and in time (Irwin & Bockstael, 2002; Verburg, Ritsema van Eck, de Nijs, Dijst, & Schot, 2004b). This spatial and temporal interaction between land uses is known as the neighbourhood effect, which is represented in many land use models by the neighbourhood rules (Hagoort, Geertman, & Ottens, 2008). Examples of land use models that include a neighbourhood effect are LUCIA (Hansen, 2007), Dyna-CLUE (Verburg & Overmars, 2009), and LUMOCAP (Van Delden et al., 2010).

These land use models often exist as generic modelling frameworks, which can be calibrated for a specific case study application. This calibration includes the definition of the shape and parameter values of the neighbourhood rules. However, the calibration of neighbourhood rules is not straightforward. Several automated methods have been developed (Arai & Akiyama, 2004; Jenerette & Wu, 2001; Li & Yeh, 2002, 2004; Straatman, White, & Engelen, 2004), but, despite these efforts, Hagoort et al. (2008) observe that the current practice of calibrating neighbourhood rules is predominantly manual. This is inherently subjective, not repeatable and highly dependent on the knowledge and skills of the modeller. One limitation of automated calibration methods is that most methods deal with the allocation of one land use type only and cannot handle the interaction between multiple land uses, while many contemporary CA models represent multiple types of land use changes (Arai & Akiyama, 2004; Van Delden & Hurkens, 2011; Wang et al., 2011). Another drawback of these calibration methods is that model parameters are assessed indirectly from the predictive accuracy of the simulation result: such assessment does not indicate directly which parameters should be changed and in what direction.

The research presented in this paper aimed to measure the neighbourhood effect of observed land use changes and use this information to improve the calibration of land use models. To do this, we measured the over- and underrepresentation of land uses in the neighbourhood of observed land use changes using a modified version of the enrichment factor (Verburg, de Nijs, van Ritsema Eck, Vis-

* Corresponding author at: Institute for Environmental Studies and Amsterdam Global Change Institute, VU University, Amsterdam, The Netherlands. Tel.: +31 20 59 83052.
E-mail address: jasper.van.vliet@vu.nl (J. van Vliet).

0198-9715/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compenvurbsys.2013.03.006

ser, & de Jong, 2004a). First, enrichment factors were measured for observed land use changes to test the existence of the neighbourhood effect. The enrichment factors of the observed land use changes were subsequently used to calibrate the neighbourhood rules in a cellular automata land use model. Two methods were employed to calibrate an application for land use changes in Germany between 1990 and 2000: an automated procedure and a manual procedure. Both methods were validated independently by simulating land use changes in Germany between 2000 and 2006. Calibration and validation results for both methods were compared with results from a null calibration to assess their accuracy.

In the next section we discuss the neighbourhood effect in more detail and how this is reflected in the neighbourhood rules in land use models. Section three presents the methodology for this study, including a description of the land use model, the case study application, and the details of both calibration procedures. Section four presents the simulation results and discusses these in relation to the applied calibration methods. In section five we draw conclusions and provide some directions for further research.

2. The neighbourhood effect

2.1. Inertia, conversion, and attraction/repulsion

Existing land use patterns influence future land use patterns in three ways: (1) through the inertia of land uses in a location, (2) through the ease of conversion from one land use to another, and (3) through the attraction or repulsion effects exerted by land uses situated in the neighbourhood of a location. The combined influence of inertia, conversion and the attraction/repulsion effects of existing land uses is known as the neighbourhood effect, which therefore includes the effects of land uses in a location as well as land uses in surrounding locations.

The existing land use pattern is a good indication for future land use patterns, first and foremost because the land use in most locations persists over time, at least when time is limited to periods from years to decades (Pontius, Shusas, & McEachren, 2004). The reasons for this inertia are socioeconomic as well as biophysical. Many land uses, such as residential areas or industrial activities, require a large initial investment and are therefore unlikely to change again afterwards. Similarly, some agricultural uses, like viticulture, are only profitable after some years or decades. Other land uses, such as natural land uses, are influenced by biophysical circumstances, such as soil conditions and aspect; these circumstances change relatively little over time, which means inertia is the rule rather than the exception for these land use types.

When the land use in a location does change, this change is highly dependent on the land use types concerned. In areas where space is scarce or where land use is very dynamic, there may be competition between land uses for the best location. In this competition, the land uses likely to be converted are the less powerful ones, mostly in economic or political terms (Torrens, 2011). For example, urban development is often located on former agricultural land, even when the soils are very productive, because real estate developers typically have more economic influence than farmers. Similarly, many unprotected natural areas are developed for agricultural uses, even when these natural areas have a high ecological value. Hence, there is a hierarchy of land uses based on the economic or political power of the associated actors. Another factor that influences the likeliness of land conversion is the ease of conversion itself. For example, arable lands are usually flat and therefore easier to develop into urban land than dense forests on steep slopes.

The attractiveness of a location for a new use is influenced not only by the existing land use in the location itself, but also by the surrounding land uses. For instance, while it is mostly agricultural land that is converted into urban land, it is typically only those locations in the vicinity of existing urban land that are urbanised. More generally, the interaction between land uses and their associated actors can be expressed as a mutual attraction or repulsion that shape land use patterns (Anas, Arnott, & Small, 1998; Hagoort et al., 2008; Hansen, 2012). Examples of land use relations are nuisances like noise and smoke from industrial sites that have a repulsive influence on adjacent locations for residential land use, and nearby forests that have an attracting effect as they provide clean air and opportunities for recreation.

2.2. Representation of the neighbourhood effect in land use models

The notion that land uses are in competition for the most favourable locations was already acknowledged in some of the earliest land use models: the Von Thünen model (Von Thünen, 1826) and Alonso type models (Alonso, 1964; Anas et al., 1998) allocate the economically most powerful land uses to the most favourable locations. The most favourable location in these cases is the location closest to the city centre, which is taken as the central market, because the distance to this central market determines transportation costs. These models implicitly include the competitive hierarchy of land uses and their associated actors. However, they describe a static situation and do not treat land use change explicitly: inertia, conversion and attraction/repulsion are not included.

Another type of land use model, which is dynamic but includes only inertia and transitions, is based on Markov Random Fields (Rutherford, Bebi, Edwards, & Zimmerman, 2008; Zhang, Ban, Liu, & Hu, 2011). They do not explicitly include hierarchy and competition between land uses, but their combined effect is expressed in the transition probabilities, which can be measured from data. For example, a study by Rutherford et al. (2008) indicates that most land uses persist year on year, while a study by Zhang et al. (2011) shows that new urban land is mostly allocated on agricultural land. The attraction or repulsion of neighbouring land uses, however, is not included in Markov Random Field based models.

On the other hand, land use models based on cellular automata (CA) include inertia, conversion and attraction/repulsion as drivers for land use changes (White, Engelen, & Uljee, 1997). The defining element of CA are the neighbourhood rules, which express the influence exerted on land use dynamics by both the land use in a location and the land uses in neighbouring locations. It should be noted that CA models often include other drivers for land use change as well, such as accessibility to transport networks, landscape elements, and zoning plans.

2.3. Neighbourhood rules

Spatially explicit land use models, such as CA models, typically consist of a lattice of square cells, where the cell state represents the predominant land use in that location. The neighbourhood rules can therefore be defined as a function of the land uses in all cells in the neighbourhood and their distance to the location of interest. Inertia and conversion are the effects exerted by the land use in a cell itself, while attraction or repulsion are the effects exerted by cells at distance >0. Because spatial actors typically consider a larger area in their allocation decisions (Van Vliet, White, & Dragicevic, 2009; Verburg et al., 2004b; White et al., 1997), neighbourhood rules often include more locations than only the directly adjacent ones. Consistent with Tobler's first law of geography (Tobler, 1970), the influence of neighbouring land uses typically decreases with increasing distance, and will eventually approach zero.

The influence of a land use on its own location and the influence the same land use exerts in the vicinity of its location can be