Land Use Modelling in the Czech Republic: an Experimental Approach with Limited Data

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Introduction

In the Czech Republic, it only recently became an obligatory and integral part of the planning process and documentation to present an impact assessment of proposed plans. New Czech national legislation in the field of spatial planning and management has adopted European Directive 2001/42/EC on the effects of certain plans and programmes on the environment, which requires an assessment of the impact of policies, conceptions and plans on the sustainable development of the environment. It is assumed that new legal requirements will stimulate a demand for predictions of land-use development, and for an assessment of the impact of changes in land use on various aspects of the living environment. Urban simulation models are one of several options for fulfilling these requirements.

The principal approaches to urban simulation modelling have been developed over the last five decades: the urban land market models of Alonso and Mill, space-interaction models, entropy-based models, spatial input-output models, cellular automata models, as well as the present agent-based and micro-simulation modelling approaches (Alonso 1964; Wilson 1974; Batty 1976; Batty 2005; Waddell, 2002).

The ultimate objective of the project presented here is to apply the theoretical concepts and the methodology of urban modelling to a sustainability assessment of local spatial development in Czech Republic. The approach is to replicate the urban growth dynamics of a catchment area of a medium-size town in the form of a simulation model, and to predict alternative scenarios of the future land-use pattern.

The Tábor micro-region in southern Bohemia, Czech Republic, was selected for an experimental application of the simulation model. The Tábor micro-region has a population of 80 000, and consists of 79 municipalities. Tábor, a medium-size town with a population of 30 000, dominates the micro-region as the main centre of employment, and the administrative border of the micro-region generally coincides with its catchment area (Local Labour System Area).

The application of land-use models in the Czech Republic has several limitations at the present time: there is no tradition of qualitative land-use modelling and there is a lack of suitable data, i.e. data on land uses and activities on a local level, and data on the behaviour of individual households and economic actors. There is no suitable data on household demographics, the evolution of individual companies and their location behaviour. Data on land and building transactions is available only in aggregated form, which is not suitable for modelling real-estate market transactions.

The shortage of data on activities and characteristics of active agents of land-use change in Czech Republic causes the experimental model to rely on data directly describing land-use changes. A secondary output of the experimental application of a land-use model is therefore to evaluate its use in the situation of limited data availability.

The resulting model is evaluated qualitatively by visualizing the predictions as well as quantitatively implementing morphology indicators (Vorel 2007; Maier 2007; Grill 2008).

Methodology

Model outline

The basic concept of the proposed simulation model was inspired by the approach used by Lowry's model, which allocates population in the modelled territory following general accessibility measures, and then uses the allocated population as the principal attractor for the location of services. (Wilson, 1974, Batty, 1976).

The proposed model first allocates a new population, or re-allocates the existing population in the territory, on the basis of its local residential attractiveness. The local residential attractiveness is assessed on the level of cellular grids 75m in size, based on historical changes in residential land use. The overall population allocated to a cell is based on the balance of external population migration across the border of the micro-region and on the internal migration induced by demographic changes in households.

The changes in the spatial distribution of the population create location opportunities for small-scale services that are naturally mixed with the residential activities, and also for big commercial centres. Retail land uses are allocated on the basis of a spatial interaction principle that takes into consideration road accessibility (Maier 2007; Grill 2008).

The land-use model explicitly represents changes in residential and commercial land use. Other land uses are represented only in static form to test their potential impact on the land-use changes mentioned above.

The basic modelling cycle consists of the following steps:

1. Determine the attractiveness of the cells as a location for residential land uses;
2. Allocate households and housing stock and changes in derived residential land use;
3. Determine changes in retail and mixed land use.

The modelling process in detail

Determining the attractiveness of cells for residential land uses

Residential attractiveness is evaluated on the basis of factors that have historically been shown to have a significant influence on changes in residential land use. First the residential land-use changes are derived, and then the factors causing the land-use changes are analysed.

As no data directly describing land uses is available at a sufficient level of detail, the land uses are derived from data on buildings. The Register of Buildings, maintained by the Czech Statistical Office (ČSÚ 2012), is the main source for data on the location, use, age and size of buildings. Data on buildings enables us to derive several time snapshots documenting the location of buildings in selected years: 1961, 1981, 1991, 1996 and 2008.

The land use for a particular cell is determined by the buildings located within the cell. Generally, the use of the cell is determined by the most frequently occurring building use. Industrial buildings (P) and public service buildings (VV) are exempt from this rule, as in reality they tend to form mono-functional areas. Each instance of a P or VV building therefore automatically determines the use of the cell, and other buildings in the same cell are not taken into consideration. The occurrence of buildings for residential, service and retail use in the same cell leads to the attribution of mixed use (S) to the cell.

Table 1. Classification of land uses and their frequencies, captured by a grid 75m in size.

Code	Cell land-use 2008	Frequencies of land uses in 2008
BH	multi-family houses	112
BI	family houses	5439
RI	individual recreation	2450
S	mixed use	226
KV	commercial facilities	11
VV	public facilities	83
P	industry and warehousing	1295
D	transportation	4
T	technical utilities	8
N	non-developed land	105239
OTHER	non-specified use	1053

Land-use changes are derived from differences between the land uses observed in 1981 and in 2008. Three types of land-use changes are derived:

- from a non-built cell to family houses (NB → BI);
- from a non-built cell to multifamily houses (NB → BH);
- from a non-built cell to individual recreation (NB → RI).

Once the land-use changes have been identified, the factors causing the land-use changes can be analysed. On the basis of a literature review, a preliminary set of land-use change factors was established (Henderson 2004; Nijkamp 1986; Briassoulis 2000; EPA 2000; Vorel 2007b, ZHAO 2006). Three generic groups of land-use change factors were identified:

- externalities between neighbouring land uses;
- spatial accessibility of public infrastructure and attractive natural elements;
- intrinsic physical characteristics of the land.

The statistical significance of each residential land-use change factor was tested by means of a binominal logit model (Train 2009; Ben-Akiva 1985). A binominal logit model establishes the relation between the land-use change factors as independent variables and the resulting probability of a change in land use.

$$P_j = \frac{1}{1 + e^{-U_j}} \tag{1}$$

The probability of a particular land-use change j depends on unobserved utility U_j related to the new land use. The linear utility function U_j consists of K characteristics x_k that are specific to each cell and β_{jk} parameters that represent the contribution of each characteristic to a specific land-use change.

$$U_j = \sum_{k=1}^{K} \beta_{jk} x_k \tag{2}$$

The following tables present the characteristics included in the final model and their estimated parameters β. The characteristics and their parameters included in the final model meet the criteria of significance based on Wald t-statistics as well as F-statistics. The characteristics of the average slope of the terrain, the natural logarithm of the proportion of multifamily houses and of the proportion of individual recreation houses in the neighbourhood does not meet the standard criteria for statistical significance (p-value < 0.05). However, they have been included in the model as their impact is in conformity with the general research findings in land-use modelling.

Table 2. Characteristics that proved to have a significant statistical influence on a change from a non-built cell to family houses (NB → BI)

Description of the characteristic	parameter β	t statistics
Euclidean distance to road class I, II and III (m)	-4,86E-04	-2,39
Natural logarithm of the proportion of multifamily houses in neighbourhood	-0,55	-3,60
Natural logarithm of the proportion of family houses in neighbourhood	1,45	21,92
Average slope of the terrain (%)	2,41E-02	0,73

Table 3. Characteristics that proved to have a significant statistical influence on a change from a non-built cell to multi-family houses (NB → BH)

Description of the characteristic	parameter β	t statistics
Natural logarithm of the proportion of family houses in neighbourhood	0,64	3,57
Natural logarithm of the proportion of public services in neighbourhood	1,34	7,90
Average slope of the terrain (%)	-0,20	-1,79

Table 4. Characteristics that proved to have a significant statistical influence on a change from a non-built cell to individual recreation houses (NB → RI)

Description of the characteristic	coefficient β	t statistics
Euclidean distance from forest (m)	-6,61E-03	-5,31
Euclidean distance from river (m)	-1,83E-03	-7,89
Natural logarithm of the proportion of multifamily houses in neighbourhood	-1,07	-1,47
Natural logarithm of the proportion of family houses in the neighbourhood	0,70	7,33
Natural logarithm of the proportion of individual recreation houses in neighbourhood	0,57	1,39

In the context of this model, the term “probability” is not equal to the probability of the implementation of a change in land use by the end of simulation cycle, as the overall demand for land-use changes does not enter into binary logit models. Overall demand for land-use change is determined by other mechanisms external to logit models. The term “probability” of land-use change in the context of the model is therefore replaced by the more appropriate term “attractiveness”, in order to indicate only the suitability of a cell as a location for a specific land use.

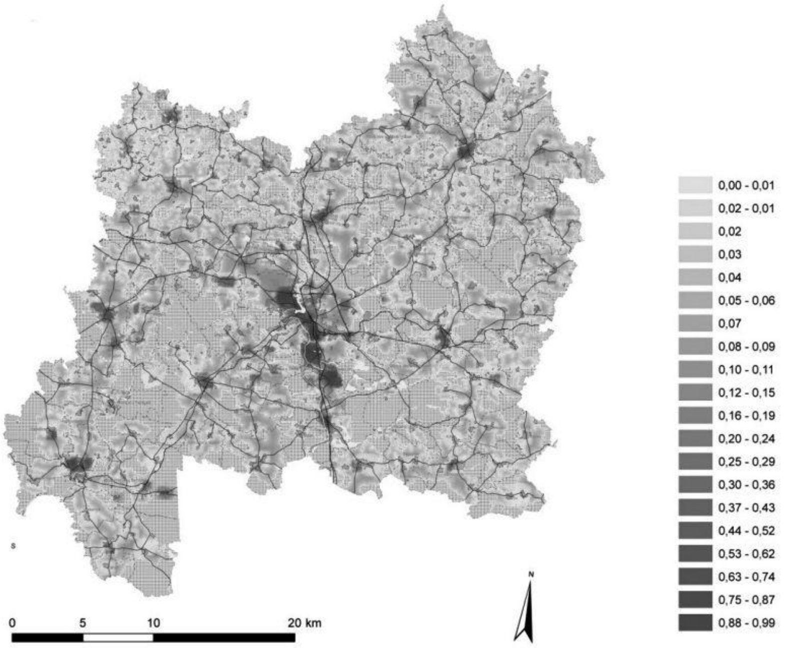

Fig. 1. An example of one of three attractiveness maps produced by the model, showing the attractiveness of a cell for family house accommodation.

Households and housing stock allocation

Household demographics and household migratory behaviour are assumed to have a major impact on the overall demand for residential land-use changes. Changes in the size of existing households induce demand for new housing. Another part of the demand for housing is generated by inward and outward migration. The demand in terms of individuals is translated to the number of households of a priori specified size that are successively allocated to cells of the highest attractiveness for specified housing types according to the preferences of the new households. The actual vacancy rate in each basic statistical unit is decisive in the choice of whether to allocate new households into the existing housing stock or to annex non-built land for constructing new houses. If the population decreases, the households are de-allocated on the basis of analogous principles, as stated above.

Before the simulation starts, the following parameters are set by the user for each simulation cycle:

- migration of population into or out of the modelled territory;
- the change in average household size of households already living in the area;
- the size of newly formed and immigrating households;
- the housing vacancy indicating the expected degree of utilization of the housing stock.

The following diagrams present the algorithms for population and housing stock allocation. First, changes in the size of existing households induce the relocation of population.

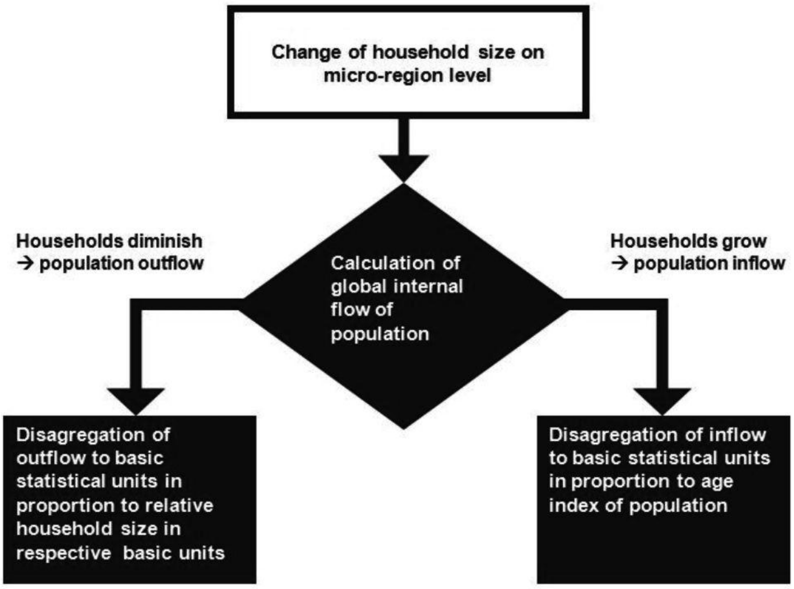

Fig. 2. The mechanism for inner population relocation based on household size change.

The resulting population leaving the original households is added to the population moving across the border of the modelled territory, and new households of a priori specified size are formed from the migrating population. If there is an overall decline in the number of households, those occupying the least attractive cells are removed from the modelled territory.

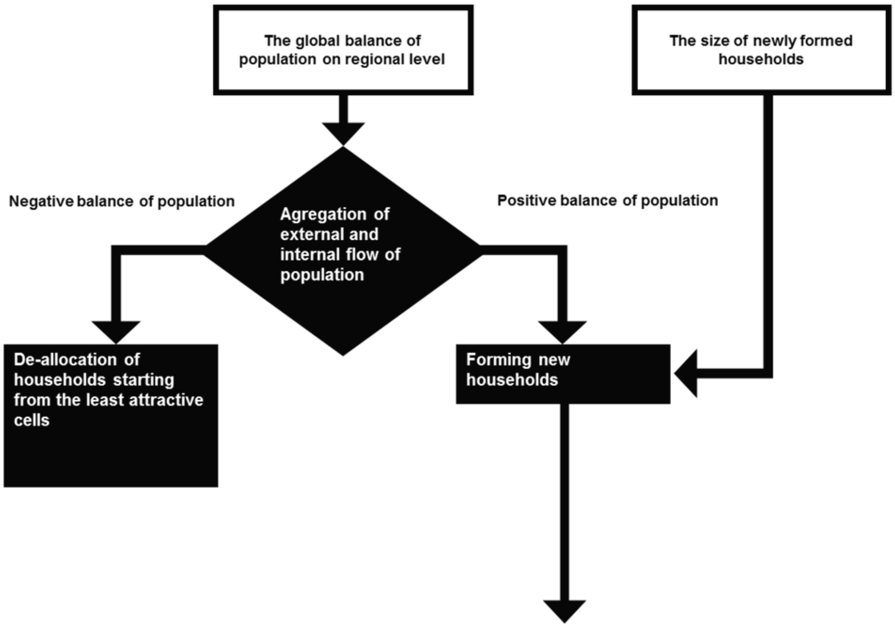

Fig. 3. The mechanism for new household formation and de-allocation of existing households.

New households are successively allocated to cells with the highest attractiveness with regard to their housing type preferences. The actual local vacancy rate in neighbourhoods is critical for the decision whether to allocate new households into the existing housing stock or to annex as yet unbuilt land for constructing new houses.

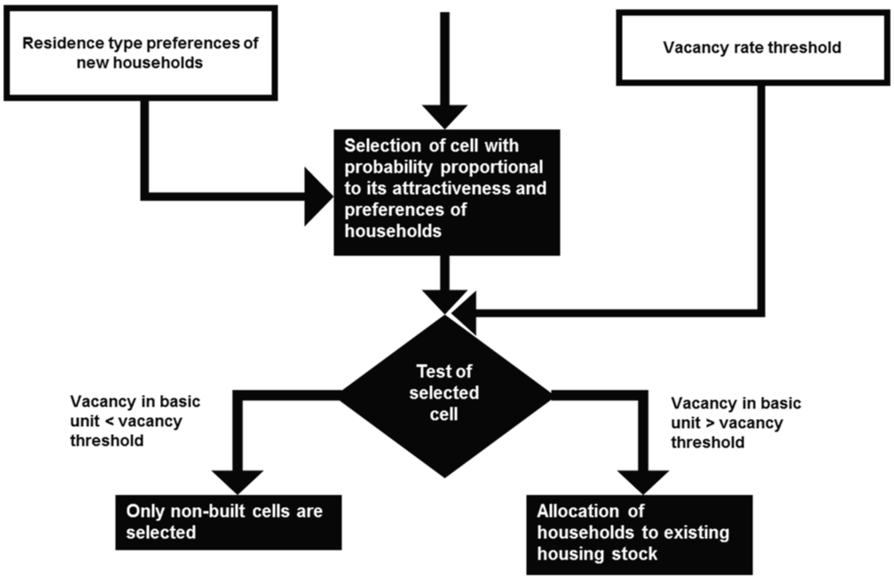

Fig. 4. The mechanism for new household allocation.

Determining retail and mixed land-use changes

If the increase in the local population in individual neighbourhoods is big enough to provide economic justification for the extension of basic services, then the cells with residential use, which at the same time have the highest accessibility to the local population, are transformed to mixed land use. Accessibility is defined as a non-linear function of the distance of a cell from the population residing in residential cells in the neighbourhood. An origin-based interaction model is used for deriving the attractiveness of cells:

$$P_i^S = \sum_{j \in B_i} N_j e^{-\beta d_{ij}} \tag{3}$$

P_i^S attractiveness of cell i for mixed land use (S);
i index of a calculated cell;
j index of residential land use cells (BI) or (BH), only cells in the neighbourhood B_i of the calculated cell i are considered;
N_j the number of inhabitants living in cell j of residential land use (BI) or (BH);
β distance decay parameter;

d_{ij} road distance between cells i and j;
B_i neighbourhood of cell i.

The number of residential cells to be transformed into mixed land uses is defined by the number of inhabitants in the neighbourhood, the per capita expenditure and the productivity of the retail units.

Large scale retail facilities have specific location behaviour. The attractiveness of a cell P_i^{KV} is calculated using the origin-based interaction model, taking into consideration the population of the whole modelled territory.

$$P_i^{KV} = \sum_{j \in R} N_j e^{-\beta d_{ij}} \tag{4}$$

P_i^{KV} the attractiveness of cell i for locating regional-scale retail services (KV);
i index of the calculated cell;
j index of cells having residential use;
N_j number of inhabitants living in cell j of residential land use (BI) or (BH);
β distance decay parameter;
d_{ij} distance between cells i and j;
R modelled territory .

According to the economy of scale principle, regional retail premises usually occupy clusters of several adjacent cells. The model uses the attractiveness of adjacent cells as positive feedback amplifying the attractiveness of the calculated cell. The resulting attractiveness (clustered attractiveness) is equal to the product of the attractiveness of the cells in the direct vicinity:

$$P_i^{KV_c} = P_i^{KV} \prod_{j \in S_i} P_j^{KV} \tag{5}$$

$P_i^{KV_c}$ concentrated attractiveness of cell i for locating regional-scale retail services (KV);

i	index of a calculated cell;
j	index of cells that are directly adjacent to the calculated cell;
S_i	the neighbourhood of cells directly adjacent to cell i;
P_j^{KV}	attractiveness of cell j belonging to S_i;
P_i^{KV}	attractiveness of cell i for locating of regional scale retail services (KV) from equation 4.

The total amount of allocated regional-scale retail services is proportional to the changes in the size of the population in the modelled territory.

In the present application of the land-use model, the distance decay parameter values β are arbitrarily set to 2. An automatic calibration technique will be employed in future applications.

Model validation

The simulation model was validated by comparing simulated land uses with observed land-use changes in the period from 1981 to 2008. For the purposes of model validation, the initial model parameter values approximate as closely as possible the real values of the parameters in the simulated period 1981-2008.

Table 5. The assumptions for each simulation cycle for scenario 1 of the Tábor model. Year 1981 is the baseyear

Parameters of the model	1981	1991	2001	2008
Population	79319	79646	79973	80201
Size of immigrating or newly formed households	-	2,33	2,33	2,33
Vacancy rate threshold for family houses	21,23%	25%	25%	25%
Vacancy rate threshold for multi-family houses	4,88%	5%	5%	5%
Preferences for multi-family houses		60,6%	60,6%	60,6%
Size of households living in family houses	3,26	3,00	2,94	2,78
Size of households living in multi-family houses	2,81	2,64	2,50	2,3

A visual comparison of simulated land-use patterns and the present land-use patterns points to several interesting issues:

- family houses form bigger clusters in the simulated pattern than in the observed pattern (figure 5);
- the opposite is true for multi-family houses (figure 6);
- the simulated mixed land uses are more evenly distributed than the observed mixed land uses;
- the opposite is true for commercial (retail) facilities (figure 7).

Fig. 5. The allocation of family houses (BI) land-use changes in the period 1981-2008: observed land-use changes on the left, simulated land-use changes on the right. the grey cells represent the built up areas in 2008

Fig. 6. The allocation of family houses (BH) land-use changes in the period 1981-2008: observed land-use changes on the left, simulated land-use changes on the right. the grey cells represent the built up areas in 2008

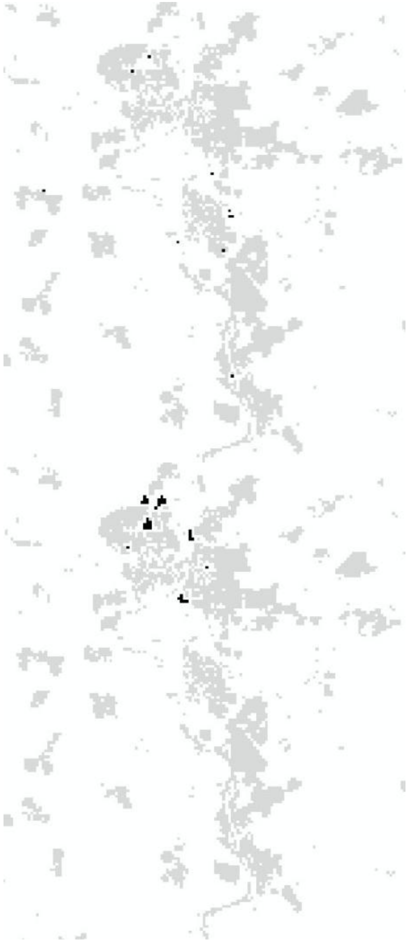

Fig. 7. The allocation of family houses (KV) land-use changes in the period 1981-2008: observed land-use changes on the left, simulated land-use changes on the right. the grey cells represent the built up areas in 2008

A visual, qualitative comparison of the fit between simulated and observed land-use patterns is accompanied by a quantitative evaluation using the following quantitative descriptors:

- kappa κ
- fuzzy kappa κ_{fuzzy}
- fractal dimension D

Kappa statistics κ assess the pixel-by-pixel similarity of two land use maps. Kappa κ can be broken down into two components:

$$\kappa = \kappa_{loc}\kappa_{hist} \tag{6}$$

Kappa location κ_{loc} ignores the fact that the frequencies of simulated land uses of a particular land-use category differ from the observed frequencies and it measures only how the land uses differ by their location. The kappa histogram κ_{hist} , on the other hand, expresses the fraction of agreement between two land use maps only with regard to the number of land uses of the same category in both maps, ignoring differences in their location.

Fuzzy kappa κ_{fuzzy} indicates not only the displacement between the simulated and observed land uses, but also its degree, where the degree of displacement is measured on the basis of the predefined distance decay function, and the resulting statistics is somewhere between 1 (perfect match) and 0 (total displacement).

The fractal dimension D is an indicator of the shape complexity of patches that are clusters of adjacent cells with the same land use. Values close to one indicate a simple and even shape of the patch border, whereas values close to two indicate more complex and convoluted shapes of the patch border. A detailed definition of each descriptor can be found in other publications (Jasper 2006, RIKS 2005).

The resulting values for goodness-of-fit measures are presented in table 6. Land uses already existing before 1981, and also more recent land-use changes in the period 1981-2008, have been included in the comparison.

Table 6. Comparison of the resulting patterns of the Tábor model utilizing the goodness-of-fit measures: kappa κ, kappa histogram κ_{hist}, kappa location κ_{loc} fuzzy kappa κ_{fuzzy} and fractal dimension D

Land use categories	κ	κ_{loc}	κ_{hist}	κ_{fuzzy}	**D** (observed/simulated)
Family houses (BI)	0,796	0,849	0,937	0,855	1,485 / 1,477
Multi-family houses (BH)	0,316	0,809	0,391	0,366	1,614 / 1,741
Recreation houses (RI)	0,667	0,682	0,978	0,735	1,611 / 1,573
Mixed land uses (S)	0,432	0,437	0,989	0,604	1,715 / 1,727
Regional scale retail services (KV)	0,109	0,231	0,473	0,172	1,872 / 1,451

The goodness-of-fit measures presented here reveal many interesting details about simulation model performance, and can be useful for further development of the simulation model.

In the case of family houses (BI) and recreation houses (RI), there is a very strong fit between simulated and observed land uses. The low values of κ in the case of multi-family houses (BH) are mainly due to differences between the number of simulated and observed land-use changes documented by low values of κ_{hist}. κ_{loc}, however, indicates a good co-location fit between observed and simulated values.

The low κ_{hist} in the case of regional scale retail services (KV) indicates differences in the number of simulated and observed frequencies of land use changes in this category. Wrong assumptions on retail floor area per capita are the most probable reason for the misfit.

κ_{fuzzy} indicates the relative success of the simulation model in locating family houses (BI), recreation houses (RI) and mixed-land uses (S). Mainly in the case of mixed-land uses (S) κ_{fuzzy} indicates a radical improvement in comparison with kappa κ proving that the simulation model locates mixed-land uses in the right localities, but with a small displacement from the observed locations. However, κ_{fuzzy} confirmed poor performance of the simulation model already indicated by kappa κ, for regional scale retail services (KV).

The observed and simulated family houses land-use patterns (BI) have a similar fractal dimension $\mathbb{D}$, which confirms the ability of the land-use model to reproduce the shape complexity of their land uses. Differences are apparent in the case of regional-scale retail services (KV) and recreation houses (RI). In this case, the observed land uses form more fragmented clusters than the simulated clusters. However, the simulated pattern of multi-family houses is more fragmented than the observed pattern, as the land-use model does not anticipate the emergence of concentrated and compact planned housing estate development in the 1980s.

The land-use model can also be validated by comparison with the random model, which randomly allocates the same amount of land uses. The random model is generated using the Map Comparison Kit (Jasper 2006, RIKS 2005). The Random Constrained Match method is used to randomly allocate the land uses in the same amount as is allocated in the outputs of the tested simulation model. The random model represents the situation of zero knowledge on causes of land-use changes, and the overall number of land-use changes is the only available information.

The land-use changes between 1981 and 2008 are simulated by both models, and are then compared with the observed land-use changes in the same period. The results show that the simulation model outperforms the random model for all types of land use changes measured by κ_{fuzzy}.

Table 7. The fit between simulated and observed land use changes of the Tábor model for simulation and random model results, measured by κ_{fuzzy}.

Land use transformation	Simulated	Random
from non-built to family housing (NB → BI)	0,145	0,012
from non-built to apartment housing (NB → BH)	0,073	0,002
from non-built to individual recreation (NB → RI)	0,038	0,012
from non-built to mixed use (BI→ S and BH → S)	0,043	0,013
from non-built to regional scale retail (NB → KV)	0,006	0,003

Testing the model behaviour with the use of alternative scenarios

The usual way to test the behaviour of simulation models is to perform sensitivity tests by varying the model input parameters and observing the resulting behaviour of the model.

To test the sensitivity of the model, three additional model scenarios are added to scenario 1 used in the validation process. Each alternative scenario is proposed with different assumptions for the future development of the territory. The following alternative scenarios are proposed for testing the performance of the model:

- Scenario 1: approximation of past trends with exogenous land-use limits implemented
- Scenario 2: approximation of past trends without exogenous land-use limits
- Scenario 3: high preference for living in family houses with exogenous land-use limits implemented
- Scenario 4: high preference for living in family houses in existing housing stock that is accompanied by a decreasing vacancy rate and with exogenous land-use limits implemented

The comparison of scenario 1 and scenario 2 presented in figure 8 mainly demonstrates how strongly location preferences are constrained by exogenous land-use limits. A comparison of the two scenarios also shows localities, in which the strongest pressures for relaxation of land-use limits can be expected. A comparison of the two scenarios clearly indicates that family houses that are forced to locate inside or at least in proximity with built-up areas, while being constrained by land-use limits, have a tendency to scatter across the simulated territory when the constraints are removed.

Scenario 2 is unconstrained by land-use limits. In line with general expectations, scenario 2 produces more extensive growth of the urbanized area than the constrained scenario 1: there are 539 newly urbanized cells compared to 478, related to residential land use (BI and BH). The imposition of exogenous land-use limits in scenario 1 leads to the concentration of new population in the existing housing stock, which has a high vacancy rate. By contrast, the absence of land-use limits in scenario 2 leads to the population being located in localities with no pre-existing housing stock. The built-up areas are therefore extended. A comparison of the two scenarios leads to the conclusion that land-use limits contribute significantly to more efficient utilization of the housing stock.

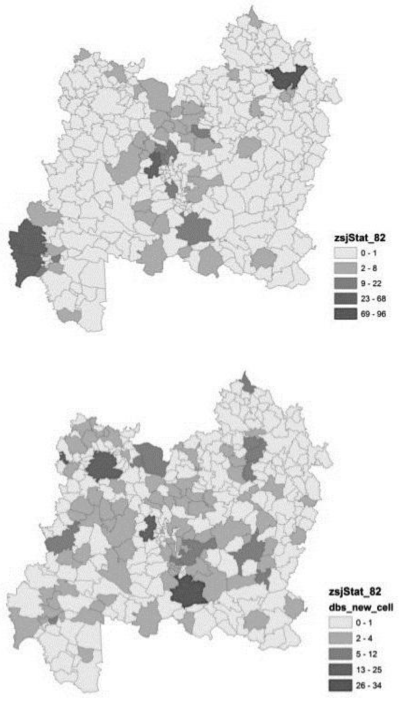

Fig. 8. The number of newly-urbanized cells in scenario 1 and 2 of the Tábor model.

Scenario 3 tests the impact of increased preferences for low-density family houses (BI) at the expense of multi-family houses (BH). Increased demand for family houses translates into the emergence of clusters of family houses land use. Higher preference for family houses has a negative impact, increasing the built-up areas from 478 urbanized cells in scenario 1 to 509 cells in scenario 3.

Scenario 4 has the same parameters as scenario 3, except for the lower expected vacancy thresholds. Scenario 4 explores the assumption that the existing housing stock will be more intensively used for allocation of new households. The visual comparison of scenarios 3 and 4 in figure 9 reveals a similar land-use pattern in both scenarios. The decrease in the vacancy rate from 21,23% in 1981 to 10% in 2008 in scenario 4 leads to a reduction from 509 urbanized cells in scenario 3 to 447 newly urbanized cells in scenario 4.

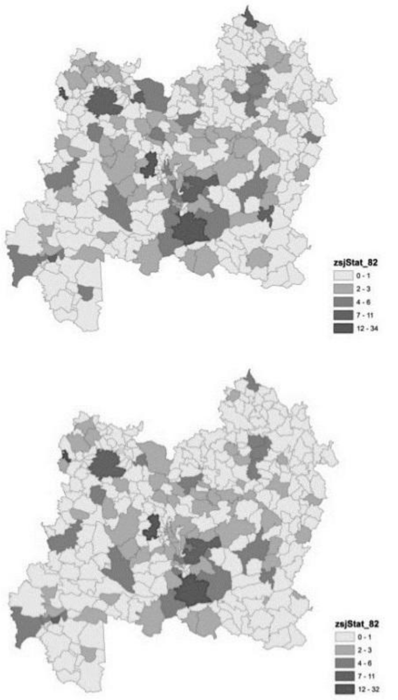

Fig. 9. The number of newly urbanized cells in scenarios 3 and 4 of the Tábor model.

Conclusions

The experimental application of a land-use simulation model has helped to identify the limits of land use simulation models based exclusively on the physical and spatial characteristics of the territory and observed land-use changes. Our project implies that land-use modelling should not be focused exclusively on physical land-use changes, but should include a representation of other processes underlying changes in land use. The following section discusses the weaknesses of the approach used here, and proposes some corrections in the data that has been used, and also in the land-use modelling methodology.

Unsuitable level of detail of the land-use data

In Czech Republic there is a lack of consistent time series of land-use data at a detailed scale. Digitization of cadastral maps has not yet been completed, and the Fundamental Base of Geographic Data (ZABAGED) (ČÚZK 2012), another source of land-use data, documents land use at a level of detail that is not adequate for the purposes of land-use modelling (the scale is 1:10 000). Geo-referenced data on buildings, which was used in this exercise, is the only available digital source of data organized in consistent time series. However, it is not trivial task to translate this data to land uses.

Simulation of non-standard development events

The success of land-use change modelling depends on the frequency of land-use change observations, and on the degree of independence with which the particular land-use change occurs with regard to other changes in land use.

When the degree of independence and the frequencies are high, as in the case of family houses land-use changes (NB → BI), replication of land-use changes by the land-use model is quite successful. However, the high degree of spatial correlation of land-use changes manifested by the multi-family housing estates constructed in the period from 1981-1991 on the basis of comprehensive planning schemes, leads to high covariance of location factors, which makes the use of statistical regression models difficult. The same is true for the clusters of large-scale retail premises that have emerged in the last two decades.

One possible solution to that problem would be to increase the number of observations of spatially constructed events. This could be accomplished by extending the study area.

Generally, however, it is becoming more and more obvious that the employment of statistical models is not appropriate in the situation of infrequent arbitrary decisions on the placement of large-scale, concentrated developments, i.e. housing estates, industry and public facilities. This corresponds to the approach of many other land-use models, which treat the arbitrary location of big, spatially concentrated development projects as exogenous variables (Waddell 2002).

Length of the calibration period

The low frequency of some types of land-use transformations makes it necessary to use a long calibration period, in this case over 40 years, from 1961 to 2008. During such a long period, the impact of land-use change factors is not constant. It can be expected that the location factors before 1989 differ significantly from the factors in the subsequent period of liberalization. This discontinuity decreases the validity of the model. A possible solution is to extend the area of analysis to increase the frequencies of the observed land-use changes, and then to reduce the calibration period to the last 20 years.

Differentiation of the demand and supply side of land-use change

Geolocalized data on buildings is the only detailed data representing physical residential activities at a local scale. Although it primarily represents the supply of housing stock, the data is utilized as a proxy for the location preferences of households. As a result, the demand side of residential land-use change is not properly represented, and this probably leads to distortion of the population distribution at regional level (measured at the level of municipalities). The land-use model underestimates the suburbanization process in municipalities that are adjacent to the regional centre, Tábor, and overestimates the increase in population in the peripheral localities. The attractiveness of Tábor is also underestimated. The demand side should therefore be simulated independently from the supply side.

Explicit representation of socio-economic processes

Land-use change is the result of a complex interplay of diverse economic, environmental and social processes. In order to explain changes in land use satisfactorily, it is necessary to represent the processes explicitly. This applies particularly to the residential choice of households, the demography of households, the location of jobs and possibly the firmography.

When considering the socio-economic processes, it is important to take into consideration the characteristics of individuals and their impact on their individual decision-making processes. All important actors assumed to influence the land-use change should be considered, e.g. individual inhabitants, households and companies (Waddell et al 2010, Benenson, 2004). Micro-simulation and agent-based approaches to land-use modelling follow these arguments, and become the standard for future land-use modelling (Waddell 2002).

In Czech Republic data on the behaviour of individuals (micro-data) are only partially accessible for research purposes. Micro-data on households and companies needs to be completed before any micro-simulation model application.

Recommendations

On the basis of our conclusions the following general recommendations can be made: a) move to more comprehensive land-use simulation models that explicitly represent the main processes that underlie land-use changes, b) derive the land uses from the location of activities in the territory, c) include the characteristics of individuals, households and businesses in their decision-making.

Our project will focus on developing a more explicit representation of the demand and supply sides of residential land-use changes. The demand side of the model will be represented by a micro-simulation migration model. Micro-data on population migration and census micro-data available in the near future will be used for this purpose. The households will first be distributed to municipalities on the basis of observed residential moves in history. Their residential choices will then induce the demand for housing in each municipality. The degree to which the demand for housing in each municipality translates into the supply of new houses will depend on the vacancy rate and on the availability of land convertible for residential land use in each municipality. The households allocated to municipalities will be then further allocated to particular cells in the municipality on the basis of their attractiveness, in the same way as in the existing model.

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