Modelling land use changes according to transportation scenarios using raster based GIS indicators

Morten Fuglsang
Bernd Münier
Henning Sten Hansen

Follow this and additional works at: https://scholarsarchive.byu.edu/iemssconference
Modelling land use changes according to transportation scenarios using raster based GIS indicators.

Morten Fuglsang¹,², Bernd Münier¹, Henning Sten Hansen²

¹ Department of Environmental Science, Aarhus University, Frederiksbergvej 399
4000 Roskilde, Denmark
{mofu, bem}@dmu.dk

² Aalborg University Copenhagen, Lautrupvang 2B
2750 Ballerup, Denmark
{mofu, hsh}@plan.aau.dk

Abstract: The modelling of land use change is a way to analyse future scenarios by modelling different future pathways. This study demonstrates the potential to explore and test the understanding of land use change relations by applying spatial data of different scales, coupled with socio-economic data. In the EU-FP7 research project PASHMINA (Paradigm Shift modelling and innovative approaches), three storylines of future transportation paradigm shifts towards 2050 are created. These storylines are translated into spatial planning strategies and their implication on land use changes were modelled via the cellular automata model LUCIA. An Eastern Danish case area was selected, comprising the Copenhagen metropolitan area and its hinterland.

The different scenarios are described using a range of different GIS datasets. These include mapping of accessibility based on public and private transportation, urban density and structure, and distribution of jobs and population. These indicators are then incorporated in the model calculations as factors determining urban development and localization of urban sprawl, reflecting the scenario outlines.

The results calculated from the scenarios reveal the great difference in urban distribution that different spatial planning strategies may initiate, and thus change the shape of the urban landscape. The scenarios outline different planning strategies, leading to a more homogenous urban structure, targeted at a reduction of transportation work and thus energy consumption. This will lead to less impact on climate from transportation based on a more optimal localization and transport infrastructure strategy.

Keywords: Spatial indicators, Raster GIS modelling, Cellular automata, future scenarios

1 INTRODUCTION

The modelling of land use change is a way to analyse future scenarios by modelling different future pathways. Carried out using spatial data of different scales coupled with relevant socio-economic data, it is possible to explore and test the understanding of land use change relation by modelling the often complex local and regional relations in the land use systems.
Cellular automata (CA) models, implemented in GIS (Geographical Information Systems), have been increasingly used to simulate such complex urban systems. Empirical data can be used to calibrate CA models so that observed spatial development of urban areas can be incorporated and reflected by the model (Liu et al. 2008). The model is capable of measuring the sensitivity of key variables in terms of the land change patterns that it may influence (Veldkamp & Lambin 2001), determining the impact of changed planning legislation and habits of people. Through interpretation of scenarios, the models become able to predict the direct influence of spatial explicit planning (Oana, P. L et al 2011).

For this study, a series of four qualitative scenarios of future development was created, describing pathways of development in societal structure, economic development and growth until 2050 (ISIS 2010).

This paper will be focusing on a Danish case-study, where the qualitative scenarios developed during PASHMINA were turned into land use predictions. These were used as starting point for land use change modelling in LUCIA (Land Use Change Impact Analysis) Cellular Automata tool developed by Hansen (2010). The focus of the paper will be on the translation of the scenario narrative into spatial data, by creating spatial indicator dataset, which will allow for detailed modelling of the narrative. A list of the most commonly used factors in Cellular Automata models has been published by Santé et al. (2011). This supported selection of a series of different datasets, created from the best available geographical- and registry data from Denmark. A range of different GIS techniques has been drawn upon in this process, ranging from network based vector analysis to raster based density and distance mapping.

The paper is divided into three parts. In the methodology section, four selected spatial indicators are presented, with focus on the GIS approach taken to create them. In the result section, results from the scenarios will be presented, showing how the indicators are used to create the predictions from the scenarios. Finally in the discussion the work conducted will be evaluated, and future work with the modelling will be outlined.

2 METHODOLOGY

Based upon a study of scenarios from a range of other projects, and a Delphi survey amongst experts and scientists, three scenarios of future development have been suggested by Sessa et al. for further use in PASHMINA.

The scenarios address the main long-term evolutions of key economic, social, technological and environmental indicators, showing up possible future states of the system in the year 2050. These include impacts of different paradigm shifts that may result by a number of unfolding demographic economic, social and cultural trends, global environmental changes and breakthrough discontinuities, as for instance the emergence of new technologies and applications (Sessa et. al 2011).

The scenario overview can be seen in figure 1. The Pashmina project operates with three suggested shifts, represented by the arrows in figure 1. The objective is to transition from a “Do it fast and alone” society, to a “Do it together” and “Do it slow” society. The three shift scenarios imply different levels of shifts. The apple scenario representing the green shift is focused on the “Do it together” transition, the potato scenario is focused on “Do it Slow”, and the orange scenario is a balance between the two others. For a more detailed description of the scenarios, and the background study see (Sessa et al. 2011).
Based on the scenarios and the narratives describing them, elements related to spatial planning practice and societal structure was selected for the modelling of land use change. For our modelling purpose we discard the potato scenario, and instead model the pear scenario future instead, to be able to create a baseline scenario. The key scenario setup as it was created, based on the narrative that is illustrated in figure 2. The interpretations made to address the conceptual drivers, was based on Danish planning practice, to match the context of the scenarios with Danish planning implementation. The modelling period is from 1990 to 2040, based on the population prediction statistics, which currently only is calculated to 2040 from the Danish statistical office.

The CA model applied for the modelling of the PASHMINA scenarios, is the Land Use Change Impact Analysis model (LUCIA) developed by Hansen (2010), which is a raster based GIS application. The model uses data aggregated into grid cells, and processed as binary arrays. In our case we use a spatial resolution of 100 meter, in order to be able to reflect even minor changes in land use and urban development. The grid used for the calculations are equivalent to the standardized Danish grid network and the resolution of Corine Land Cover maps that form the basis for present land use maps at EU-level.

The model simulates future patterns of land use change based on two levels, being macro and micro level driving forces (Hansen 2010). The modelling basics can be seen in figure 3. The model uses the macro level drivers such as population growth predictions to determine the demand for new urban areas. Based on these data, the model then assesses the transition potential of each cell, based on multicriteria
analysis techniques (MCA). Here each of the micro level factors is assigned a weight to which it is multiplied. Then all factors are summarized into one cell value. Based on these values, the cells with the best scores are most suitable for transition of a type of land use, and are then converted into new urban areas.

![LUCIA model approach](image)

Each cell’s transition potential is calculated from a set of factors such as suitability, accessibility and proximity, and a set of defined constraints containing zoning and protection status not available for urban expansion. (Hansen 2010). The model is calibrated against observed data, to assess the uncertainty of the results. The calibration period is from 1990 to 2002.

To assess land use changes according to the scenarios, maps reflecting these factors have been created and applied in the modelling. The LUCIA model generates statistically based indicators such as spatial autocorrelation based proximity that in our case favours new urban cells to be located adjacent to cells of equal land use. Other factors must be created by combining auxiliary map layers through GIS modelling before entered into the LUCIA model. The following paragraphs will explain the work conducted, creating some of the central factors for the modelling, making it possible to implement the scenarios in the CA model.

The pear scenario is considered the ‘business as usual’ scenario in relation to forecasting of development and land use change in Denmark. The patterns in urban development observed in recent decades in Denmark are dominated by a sprawl like pattern, with very disperse development. From the storyline of the pear scenario we adopt the car dependency and the scattered urban pattern into the modelling, by making the car and motorway accessibility to be the main location factor alongside value of property. Finally, for planning zones, we create some much expanded planning zones, making development possible in a large variety of locations.

The apple scenario can be considered as the planning scenario that current planners ideally aim at, when conducting the long term plans. Here the narrative dictates stricter planning zones, and less car dependency. Therefore we model planning zones in relation to the Danish planning concept ‘The fingerplan’, and the ‘closeness to stations’ principle. These dictate urban development in fingers leading in to Copenhagen, with green areas in between the fingers. The closeness to stations dictates that urban development must be placed close to stations, thereby facilitating use of urban transportation. Furthermore the dependency of cars must be lowered, so instead of focusing on car accessibility, the main accessibility driver is by public transportation.

Finally the orange scenario in the narrative is described as a complete rethinking of planning practice. The goal is a large degree of urban densification, as well as a much less transportation dependent systems. The interpretation that was created,
focus on societal changes to occur, where for instance the use of teleworking will become more used. This will reduce the influence of travel to work, making the travel to recreational opportunities etc. more important in the overall transportation need. Therefore the focus of placement of development is on a recreational distance indicator, urban density indicators, as well as job distance. Figure 2 gives an overview of the chosen scenario drivers.

2.1 Acceptable commuting time

In the most common CA models, accessibility is a key factor, describing the access and connectivity to the road network (Santé et al. 2011). For the modelling of the scenarios, the goal also was to calculate accessibility that express accessibility in terms of connectivity to services through the network, not just the network itself. In order to make an indicator describing accessibility to jobs through the road network, an analysis of the ‘acceptable commuting time’ that people are willing to travel by car was conducted. Study’s by Andersen (2010) and other publications point out, that the size of a city determines how far people was willing to commute to get there. A large centre with many different jobs and services attracts people from a larger area than smaller cities with fewer services. Therefore, a classification was made to determine the potential attraction of 275 cities within the case area, giving them an acceptable time to commute to get to them.

The Road network created by the Danish National Survey and Cadastre has been used to create a vector based road network inside ArcGIS Network analyst (ESRI). For each road segment, the mean travel-speed was used to calculate the drive-time for each section (Winther 1999). This vector network was then used to calculate the service area of all cities one by one, based on the potential attraction that each city was assigned. Finally the results were converted to a raster layer and combined into one measure of city centre accessibility by car. The results of the model can be seen in figure 4. For each raster cell in the map, it can be determined how many centres you can reach, meaning that a higher value corresponds to many centres in range.

For the CA modelling by LUCIA, this indicator is used to optimize the location of new urban areas, namely in the automobile dependent pear scenario. Here, a main location preferences is the ability to reach jobs by car. For an in depth description of this method, see (Fuglsang 2012)
### 2.2 Distance to recreational opportunities

In the orange scenario a larger change in transportation habits is anticipated to occur and we needed to be able to address the accessibility to recreational opportunities as well. If for instance an increased focus is put on teleworking, then peoples overall transportation need shifts as well. If individuals commute by car five days a week, then that is their primary transportation need, and all others are secondary. A shift into teleworking three days a week this reduces the need for transportation to working places and other preferences like accessibility to recreation become more important when choosing a place to reside and settle. Therefore, an indicator of recreational accessibility was created for the orange scenario. The indicator was created using multi criteria evaluation (MCE) combining and prioritising a number of factors, a technique often used to assess suitability. Recent examples that demonstrate the techniques are (Hossain, M. 2007) and (Kallali 2007).

The datasets that where integrated into the analysis were: distance to marine areas, forest, lakes, and urban centres. In the MCE analysis the distance to lakes and forest were weighted higher than those to the sea. Furthermore, urban centres obtained the highest weight in the analysis as it is show by Andersen (2010) that the majority of the citizens preferred to use the recreation and leisure opportunities provided by cities, as main recreational attractor. The result of the MCA modelling can be seen in figure 6.

### 2.3 Property value

Through the analysis of the observed changes in the 1990 to 2002 calibration period of the model, a pattern regarding new urban development and land property values has been observed. The pear scenario reflects business as usual and it is anticipated that property values play an important role. This indicator was created by combining three large Danish registries about housing and the cadastral maps. In the Building registry (BBR) data about the size of properties and buildings are stored, which can be combined with the Sales and Taxation registry (SVUR) containing sales prices and assessment of property values by the taxation authorities. These data can then be combined with the Danish Cadastral map provided by The Danish National Survey and Cadastre. The value pr. square meter can be calculated for each parcel by merging these three sources. The resulting map is then rasterized, and holes from lakes, roads etc. are filled by surrounding values. The final resulting indicator can be seen in figure 6.

As mentioned, this indicator is used in the pear scenario to bind together the model runs with the cost/demand for property, which has been observed. This means that by using this factor, we can replicate the situation, where the property with the highest prices are the most attractive lots, and thereby more likely to be urbanized first.

### 2.4 Public transportation accessibility

In order to express a changing focus on transportation and choice of commuting, the commonly used measure of accessibility to roads (Santé et al. 2011) had to be refined. Therefore, next to the road accessibility and centre accessibility, a measure for public transportation accessibility was created. The methodology was based on work by Blecic et al. (2011) and Fuglsang et al. (2011), where a map layer reflecting constrained accessibility are suggested.

For all public transportation modes, train lines, stations, bus routes and stops were collected from existing maps and databases and converted into raster data, with the travel-speed information appended to the line segments (Winther 1999).

When modelling accessibility by car, as described in section 2.1, it is anticipated that the road network can be entered and exited at all locations. However, when
travelling by public transportation, individuals are limited to enter and exit the network at stations and bus stops. Therefore, constraints were added along railway lines and bus routes and finally stations and stops were used to provide accessibility at these points.

The resulting surface was then calculated using the ‘Cell-crossing-time’ presented by Juliao, R. P (1999), which were used as the final input for modelling accessibility according to public transportation. The model iterates through all centres with a population larger than 2000 inhabitants, using a distance decay function to assess the number of jobs accessible over distance. The results of all cities are then joined into one final result layer, which describe the job accessibility by public transportation network, as can be seen on figure 7.

This indicator is used in the apple scenario where the focus is shifted from private to public transportation. Here the locational preferences of individuals are to be determined more, by the service-level of public transportation and the possibility to reach jobs within reasonable time through the services.

3 RESULTS

Based on the indicators presented here, and a list of other datasets, the CA modelling of the scenario storylines was conducted in LUCIA. The model configuration of the scenarios where dependent on the interpretation of the storyline content. This makes the modelling runs quite different, since the inputs are quite distinct. Datasets and weights that was applied to the modelling can be seen in table 1.
When conducting the CA modelling, focus must be put on the calibration and validation of the model results, to ensure that the results is viable and that the model is capable of describing the future in a sound way. (Yeh and Li 2006). In the LUCAI model, 12 years of detailed land use maps based on Corine are used as validation and calibration period. By using the Danish building and housing registry, the 1990 and 2000 Corine products are turned into yearly land use maps, by using detailed information about building construction.

For validation of the results, the observed land use map was compared to the modelled 2002 map using the Map Comparison Kit. This tool is capable of making detailed map comparison and statistics about the land use maps, conduction amongst others Kappa statistics on the mapping results. Table 2 shows the calibration of the pear scenario, which is the baseline scenario in our modelling. The calculation of the Kappa statistics is based on the entire image pixel count, evaluating only the precision of the changes within the expanding urban classes.

Based on the calibration of the model and the interpretations of the Pashmina scenarios, the modelling was conducted towards 2040. In figure 7 and 8, results of the modelling in two selected municipalities in 2040 are shown. It is evident that the changes in planning practice that are suggested through the scenarios has a large impact on how the urban landscape is going to evolve and develop. It is clear that even in relatively small municipalities, hotspots of development can change quite drastically, indicating that the planning implementation effectively can modify the landscape to ensure that climate strategies are met.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Accessibility</th>
<th>Hapaxity</th>
<th>Property value</th>
<th>Main road accessibility</th>
<th>Centre accessibility</th>
<th>Urban density</th>
<th>Public transportation accessibility</th>
<th>Job density</th>
<th>Distance to recreation</th>
<th>Specialized planning zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pear scenario</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
</tr>
<tr>
<td>Apple scenario</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
</tr>
<tr>
<td>Orange scenario</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
<td>★</td>
</tr>
</tbody>
</table>

Table 1: Scenario driver overview

<table>
<thead>
<tr>
<th>Kappa statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed 2002 / Modelled 2002</td>
</tr>
<tr>
<td>Kappa</td>
</tr>
<tr>
<td>K</td>
</tr>
<tr>
<td>K</td>
</tr>
</tbody>
</table>

Table 2: Kappa statistics
4 DISCUSSION AND CONCLUSION

The modelling that has been conducted in this research, is as stated in the introduction based on interpretations of scenarios and storylines. The interpretations that were created have focused on creating some interpretations that are boundary pushing in terms of their consequences. This should highlight the results of different plausible paradigm shifts and potential development paths. We have shown how to rethink traditional factors for CA modelling, by conducting various GIS analysis, creating new indicators and factors to include as drivers. In this way, the CA model has become equipped to model some land use transactions that are different from most CA implementations (Santé 2011).

Computation of indicator-maps includes many different spatial and registry data, so that drivers for the model that can make up a realistic storyline for adaptation approaches. Without the detailed input with spatial data, it would not have been possible to create the detailed indicators that we have calculated in 100 m resolution. The indicators are a result of an iterative process where the standard approach to CA modelling has been challenged, by adding a long list of new possible drivers to the scenarios. A problem based approach has been chosen to analyse how we could include the parameters needed into CA modelling. The creation of the individual indicators is a result of this process, guided by the availability of data.

We use the different GIS indicators as factors that express proximity and suitability as input map layers for the model. In this way, the model becomes capable of analysing and visualizing the thoughts and ideas expressed in the storylines in a way that is plausible for a broader audience. Interpretation and translation into Danish context is an important and necessary step herein. The scenario outputs show clear distinction between the three different pathways of possible urban development and sprawl, which has been one of the targets in implementing the scenarios in a land use model. In figure 8 and 9, selected land use changes of the scenarios can be seen.

In relation to the uncertainty introduced to the CA modelling by adding these new indicators, the quality of data and methods must be assessed. Firstly, since all data are generalised into raster representation, the spatial resolution is limited by the grid size chosen, here 100x100m. Furthermore the calculation and algorithm is the primary shaper of the output, determining the quality of the result. The two indicators for property value and centre accessibility by car are used in the pear scenario that has been used for calibration. This means that the uncertainties in these indicators are to be considered alongside the modelling uncertainty, when calibrating the model of the baseline scenario. By achieving high Kappa scores, the uncertainty introduced to the model by the new indicators can be considered insignificant to the overall modelling task. The other calculation based indicators are used in the predictive scenarios, and thus uncertainty can be considered less important, since the primary element in the use of these, is prediction of planning patterns.

Future work for the remaining period of the on-going PASHMINA project will focus on consolidating the scenario modelling, and to evaluate the consequence of the suggested planning scenarios in depth. Focus will be on analysing the urban patterns for consequences for sustainability, by analysing the traffic impacts of the scenarios in terms of trip generation, length and other related factors.

Acknowledgement

Funding for this study was provided by the European Union, Seventh Framework Program, Theme 8, Small or medium-scale focused research project, Grant agreement no.: 244766 - PASHMINA (PAradigm SHifts Modeling and INnovative Approaches).
5. REFERENCES

Andersen, H. S. Når teltpælene rykkes op - Geografisk mobilitet i Danmark og dens årsager, Center for Bolig og Velfærd. [IN DANISH] 2010


Fuglsang, M., Münier, B Visualizing implications of acceptable commuting time using network based GIS analysis for the Zealand region of Denmark. Submitted to *Computers and Geoscience*. 2012


Winther, M. Analyse af emissioner fra vejtrafikken: Sammenligning af emissionsfaktorer og beregningsmetoder i forskellige modeler”, Faglig rapport fra DMU, no. 265, Danmarks Miljøundersøgelser, Aarhus Universitet. 1999 [IN DANISH]