Local level application of the dynamic land use model METRONAMICA

Assessment and modelling – a case study on the Dutch municipality Weert

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LOCAL LEVEL APPLICATION OF THE DYNAMIC LAND USE MODEL METRONAMICA

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I am glad to present this thesis report about modelling urban development in the municipality Weert. It was my second report and again a period of hard work. The time I spend in Maastricht has been full of opposites. Now, being finally finished with all my studies, I am curiously looking forward to a new step in life.

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Abstract

Policy makers, who are faced with decision making about spatial activities in urban areas, can be guided by means of computer based decision support systems. An example of such support systems are land use models, offering important benefits and assistance. The land use model METRONAMICA is such a decision support system. Its allocation methodology is based on a cellular automaton. The model is interactive and user-friendly, facilitates learning and employs complex and weakly-structured decision contexts.

For the thesis at hand a study area in the Netherlands, the municipality Weert, was chosen. Here, several major changes and redevelopments are planned but different opinions considering future growth perspectives exist. METRONAMICA could be used for developing them. The question is, if the model provides accurate results and usable support when being applied at a high resolution and local level.

In the course of the study METRONAMICA’s possible application is tested and evaluated. First METRONAMICA is compared to a selection of other spatial models (CLUE, LandUseScanner, UrbanSim and SLEUTH). Keeping in mind the local scale of application, the availability of suitable data then is assessed, input datasets are created and suitable variables are chosen while carrying out the model calibration. For assessing the quality of calibration, two measurements are applied: Kappa statistics and Zipf’s law. Special attention is paid to the applied cell size (25 x 25 m) and the size of the neighbourhood the cellular automaton takes into consideration (8 cell and 16 cell radius neighbourhood). In order to evaluate METRONAMICA's possibilities for local planning support, several development scenarios are created and simulated until the year 2040.

The results show, that a local application seems to be possible, but more detailed data should be inserted into the modelling environment to be able to model more detailed land use functions (e.g. splitting up the urban land uses). Then, also much more detailed transition rules could be implemented, accounting for dynamics within the urban environment. The simulation results obtained show a remarkable difference between the 8- and 16-cell neighbourhoods. The model was calibrated with an 8-cell neighbourhood, and then the neighbourhood extended to 16 cells, resulting in very blobby simulation result. The model should hence fully be calibrated again. Changing the neighbourhood while expecting to achieve better simulation results, seems only possible when adapting also the transition rules.

Keywords: spatial modelling, cellular automaton (CA) calibration, neighbourhood extent, local level application, urban development, SEA (strategic environmental assessment)
Zusammenfassung


Stichwörter: räumliche Modellierung, Zellulärer Automat, Kalibration, Größe der Nachbarschaft, lokale Maßstabs Ebene, urbane Entwicklung, SUP (Strategische Umweltprüfung)
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## Abbreviations

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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>BBG</td>
<td>NL: Bestand BodemGebruik, UK: inventory of current land use in the Netherlands</td>
</tr>
<tr>
<td>CA</td>
<td>Cellular automata</td>
</tr>
<tr>
<td>COROP</td>
<td>UK: Coordination Commission Regional Research Programme. NL: Coördinatie Commissie Regionaal Onderzoek Programma,</td>
</tr>
<tr>
<td>DSS</td>
<td>Decision support system</td>
</tr>
<tr>
<td>EIA</td>
<td>UK: Environmental impact assessment. DE: UVP - Umwelverträglichkeits Prüfung, NL: m.e.r. – milieueffectrapportage.</td>
</tr>
<tr>
<td>GIS</td>
<td>UK: Geo-Information System, DE: Geo-Informationssysteme</td>
</tr>
<tr>
<td>LGN</td>
<td>NL: Landelijk Grondgebruiksbestand Nederland, UK: National Land Cover Database of the Netherlands.</td>
</tr>
<tr>
<td>LOV</td>
<td>NL: LeefOmgevingVerkenner, UK: Environment Explorer</td>
</tr>
<tr>
<td>MCK</td>
<td>Map Comparison Kit</td>
</tr>
<tr>
<td>NUTS</td>
<td>Nomenclature of Territorial Units for Statistics</td>
</tr>
<tr>
<td>RCM</td>
<td>Random constrained match map</td>
</tr>
<tr>
<td>RUR</td>
<td>Rural-urban-region</td>
</tr>
<tr>
<td>SDSS</td>
<td>Spatial decision support system</td>
</tr>
<tr>
<td>SEA</td>
<td>Strategic Environmental Assessment. DE: Strategische Umwelprüfung (SUP), NL: plan-milieueffectrapportage (plan-m.e.r.)</td>
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1 Introduction and Rationale

1.1 Context and Background

Urban areas and cities are supporting the social and economic functions of our society. They can be regarded as information-rich systems, consisting of many abstract interactions and connections and are indeed one of the most successful creations of human society (White and Engeelen 1993). In 2008 a momentous milestone will be reached: for the first time in history, more than half of the human population (3.3 billion people), will be living in urban areas. By 2030, this is even expected to swell to almost 5 billion people (UNFPA 2007). Consequently, much research has been carried out on surveying and governing the urban development. The complexity we see in cities seems to express chaos or noise, which is however also an essential quality. Each type of region in a city interacts with every other type and a continual growth, change, decline, and restructuring takes place at the same time (White and Engeelen 1993). When trying to understand these systems, and aiming at transforming the apparent ‘noise’ into information, cities should first be understood in terms of their local properties (Batty and Xie 1994, 33).

Policy makers, who have to decide about spatial activities and developments in urban areas, nowadays can make use of computer based decision support systems (DSS). These systems can be used for guiding policy makers when trying to find optimal strategies for future development (Van Delden et al. 2007). They add value to strategic planning processes, but do not replace important phases of the decision-making process (Van Delden 2006). Applications of DSS in urban regions have been carried out amongst others in Santa Barbara, USA (Herold et al. 2003), Nanjing, China (Sheng et al. 2008), the Puget Sound region (Waddell et al. 2002) and the island la Réunion (LaJoie and Hagen-Zanker 2007).

Land use models, that are part of such support systems, facilitate these notions. Especially for planning purposes their spatial detail represents actual local features that for example people living in a city experience and planners must deal with (White and Engeelen 1997). Advantages are their interactivity, the visualization and quantification of potential outcomes, their linkage to geo-information systems (GIS), and the easy incorporation of raster-based spatial data derived from remote sensing platforms into the modelling environment (Jantz et al. 2004, 252). When modelling land-use dynamics, cellular automata (CA) (see Annex I.1) can offer important benefits and assistance. While being inherently spatial, with cellular automata dynamics can be modelled on a very high resolution (White and Engeelen 2000). Batty and Xie (1994, 33) illustrated the power of CA when applied for urban simulations. They are moreover able of simulating different types of urban forms (Yeh and Li
2001), investigating the evolution of urban spatial structure over time (White and Engeelen 2000) and projecting urban land-use (White et al. 1997). The land use model METRONAMICA is a decision support system that makes use of cellular automata. It is interactive and user-friendly, facilitates learning and employs complex and weakly-structured decision contexts (Van Delden 2006).

1.2 Problem Definition and Purpose of the Study

As urbanization occurs, the amount of unsealed land decreases and is replaced by surfaces such as pavement and concrete. This procedure may have different effects, such as altering the hydrological regime, destroying natural habitats and influencing the local climate, depending on where and how the land-use change has occurred. When aiming at projecting such future developments and their possible impacts, one must include projecting changing patterns of land-use (Jantz et al. 2004, 252).

A relatively new development is modelling the future with the help of cellular automata (CA) models (see Annex I.1), who were first related to planning in the 1980s. A new challenge in their application is the investigation of how global models reflect local characteristics and how increased spatial resolution improves sensitivity of local factors (Silva and Clarke 2002, 527). This study aims at using a cellular automaton on a local scale. For doing so, a study area in the Netherlands was chosen: the municipality Weert located in Limburg, in the south of the Netherlands. Here several major changes, redevelopments and new buildings are planned. However different opinions exist considering desired future growth perspectives and the optimal development strategy for the entire municipality. The spatial model METRONAMICA, which consists of a cellular automaton, could be used to assist the municipality and residents in developing future perspectives about the city.

METRONAMICA has been applied to a wide range of cities, regions and countries worldwide. The spatial resolution of these applications normally varies between 50 m and 1000 m. The question is, if METRONAMICA also shows a realistic behaviour when being applied on a local scale at a very detailed resolution. According to White et al. (1997) the success of any application depends on two conditions: the ability of the model to replicate reliable the actual evolution of the urban form, and on the capacity of the model to yield consistent results in spite of the inherent stochasticity of both the model and the city. Since METRONAMICA has only once before been applied on such a detailed level (Phyn 2008), its possible application must be tested and evaluated. To answer the question posed above. For this reason, as part of the study, special attention will be paid on the applied cell size (25 x 25 m) within the model and the neighbourhood size that the cellular automaton takes into consideration.
Cell transitions are based on the quality of a cell’s neighbourhood. Each cell within a neighbourhood is weighted differently depending on its type of land use. New land uses will change the neighbourhoods attractiveness for activities already present and others searching for space. Small cell sizes are representing neighbourhood properties different than do larger ones, which is shown in Figure 1.

Here, two different situations are shown: map subset A representing a village and subset B the urban fringe. Each subset is shown once with a 25 m (A1 and B1), and once with a 50 m cell size (A2 and B2). The central cell and its neighbourhood are indicated by a thick black line. When looking first only at the neighbourhood properties from both subsets with a small cell size (A1 and B1), within the neighbourhood no differences are visible: in both 65 cells are urban (red) and 78 cells agriculture (yellow). From the neighbourhood itself it is not possible to differentiate between a village and a city. When having larger cells however, a differentiation becomes possible. As shown by the arrow in subset A2 stretches the neighbourhood out beyond the village. In subset B2 is more urban area included. Hence, both neighbourhoods have different properties. The application of METRONAMICA has a much rounder and also larger neighbourhood, but its main attributes are represented usually by the subsets A1 and B1. When extending the neighbourhood, it would be possible to represent also the subsets A2 and B2.

Figure 1: Cell sizes influencing neighbourhood properties.

1 It has to be mentioned that the neighbourhood of the scenarios A2 and B2 is not shown in its full extend.
1.3 Research Questions

The following research carried out aims at answering a set of questions. One overall research question was defined and four sub-questions.

Overall research question:
Can METRONAMICA provide accurate results and usable support when being applied at the local level with a high spatial resolution?

Sub-research questions:
1) In what ways does METRONAMICA differ from other existing land use models?
2) What are the variables and datasets that have to be considered as inputs for METRONAMICA?
3) Does the accuracy of the results calculated by METRONAMICA change when the model is applied with a different neighbourhood configuration?
4) Can METRONAMICA provide support to local urban design and planning?

1.4 Methodology of the thesis

The research’s methodology is based on the above defined research questions.

Considering sub-research question 1:

In order to justify METRONAMICA’s usability for the following application, it is first compared to a selection of spatial models. This theoretical chapter of the report also aims at describing basic parts and functions of METRONAMICA itself, a required knowledge for the reader to fully understand the following research carried out.

Considering sub-research question 2:

Keeping in mind the local scale of application, in a first step the availability of suitable data will be assessed. Then, input datasets are created and finally suitable variables will be chosen while carrying out the model calibration. Special focus is paid to the calibration and validation, that are seen as major challenges for an application of a dynamic land use model (STRAATMAN et al. 2004). The quality of the results from cellular automata applications depends on the adequacy of the transition rules, which contain parameters that must be calibrated (STRAATMAN et al. 2004). In principle every cell in the model represents at the least one state variable. Thus, the model consist of tens of thousands, if not millions of dynamic equations (VAN DELDEN et al. 2005, 6). In practice, the model consists of only a few types of equations applied to thousands of spatial units. Hence an extremely rich behaviour can result from running the model. Within the calibration process, the task is precisely to ensure that the
model behaves in a realistic manner and is able of generating existing spatial patterns (VAN DELDEN et al. 2005, 6).

Considering sub-research question 3:

Special attention will be paid to models neighbourhood. The modelling will once be carried out with an 8-cell neighbourhood and once with a 16-cell neighbourhood.

Considering sub-research question 4:

In order to assess METRONAMICA’s possibilities for local planning support, first future scenarios for the municipality Weert are developed. These are then implemented into the modelling environment and the application will be run with the different scenarios and a final evaluation elaborates on the overall research question.

1.5 Organization of the thesis

The thesis is divided into five chapters. Chapter 1 focuses on the introduction and introduces research questions. The theoretical framework and literature study can then be found in chapter 2. Here, several spatial models are introduced and the study area Weert including its future development scenarios is described. The methodological part of setting up a new application, calibration and validation is contained in chapter 3. Simulation results are shown in chapter 4 and final conclusions are drawn in chapter 5. Figure 2 presents an overview of the thesis.
2 Theoretical framework

Chapter 2 comprises the thesis’ theoretical framework and literature study. First, different spatial models are presented and compared to each other. Then an introduction into the study area Weert with its current development is given. Finally, future development scenarios are described for Weert that will be modelled subsequently in the course of the study.

2.1 Spatial models

The following chapter comprises a functional description of several spatial land use models. The review includes the models CLUE, LandUseScanner, UrbanSim, SLEUTH, and concludes with a description of METRONAMICA, the land use model incorporated within this study. The review aims at justifying why METRONAMICA was chosen by analyzing its advantages over other spatial models. Each of the following models was designed to model spatial development. However, each one consists of a different approach. Interest to this study was to evaluate differences and find similarities. First each model will be described individually, next a summary follows comparing the different approaches.

2.1.1 CLUE

The CLUE modelling framework (Conversion of Land Use and its Effects) was originally developed to simulate land-use change using empirically quantified relations between land use and its driving forces in combination with dynamic modelling (VELDKAMP and FRESCO 1996). It is a land-use change model that accounts for the entire system of complex interactions between historic and present land use, socio-economic conditions and biophysical constraints. Its first application was carried out on Costa Rica and worldwide applications (Ecuador, China, Philippines, Malaysia) followed (VERBURG et al. 1999b).

Input data

Input datasets are biophysical data (e.g. soil maps, elevation, climate) and socio-economic conditions taken from census data (VERBURG et al. 1999b). The spatial data consist of raster cells with its cell sizes changing according to the chosen application (ibid). In every application two spatial resolutions with different cell sizes are implemented, as described in the paragraph “allocation mechanism”. In contrast to other cell-based approaches, where land use is determined by the most dominant type, it is here characterized by the relative cover of each land use type in each grid cell. For example, a grid cell can contain 30 % cultivated land, 40 % grassland and 30 % forest (VERBURG et al. 1999a).
Drivers for land use change

Cell transition only takes place within CLUE as it corresponds with the direction of the change in demand at the national level (a top-down driven land-use system). To account also for bottom-up interactions, autonomous developments are implemented for changes exclusively based on the local biophysical and demographic conditions, independent from the national demand. These autonomous developments cause the system to be much more dynamic with both top-down and bottom-up interactions (VERBURG et al. 1999b). Bottom-up effects become visible when areas are unsuitable for certain land-use types, e.g. the establishment of a nature reserve. Because the national demands must be fulfilled, the decrease of cover in a certain area due to unsuitability will affect land use in other parts of the country.

Allocation mechanism

CLUE allocates land use demands externally provided by other models based on a regular spaced grid. It consists of three main modules (see Figure 3). The demand module calculates at the national level changes in demand for different land use types. Calculations can be based upon changes in demand for agricultural products taking into account population growth, changes in diet, and import/export. The population module calculates changes in the population and associated demographic characteristics based upon projections and historic growth rates. The allocation module is the central part of CLUE which calculates for all cells land use change on a yearly basis. For the allocation, a cell-based system containing land use, socioeconomic and biophysical variables is used. In addition to the national scale, on which demands are calculated takes the allocation place on two spatial scales: a coarser and a finer scale (VERBURG et al. 1999b) (Figure 4). This multi-scale approach artificially grids the data at multiple resolutions. At each resolution, the relations between land use and driving forces are then statistically determined.

Figure 3: Structure of the main components of the CLUE modelling framework (VERBURG et al. 1999a, 49)
On the coarse scale general patterns of land use are calculated. The cell size can be several kilometres, for example 36 x 36 km for an application in Ecuador (VERBURG et al. 1999b). The output represents the average cover of the different land-uses, based on biophysical and socio-economic conditions. Several regression models (for further information see Annex I.2) then determine which areas of the country have the potential for an increase in a certain land use type. The actual change is determined by an iteration procedure which adapts the fraction of the difference between actual- and the regression cover (VERBURG et al. 1999a).

On the fine scale variability within regions and landscapes can be revealed, based on results of the coarse scale. Cells on this scale have sizes of few kilometres, for example 9 x 9 km for an application in Ecuador (VERBURG et al. 1999b). The level is created by aggregating nine grid cells using a focal function (VERBURG et al. 1999a). Actually, the allocation procedure similar to the coarse level is once more repeated, but fractions allocated on this scale are then modified by the calculated relative land use change at the coarse scale. Areas with very large or relatively small changes are identified by comparing changes of individual grid cells with the average change of all grid cells.

The fine allocation scale creates a balance between the top-down influence of regional land-use change and bottom-up effects of land-use change due to the possibility of implementing local conditions (VERBURG et al. 1999b). For example local unsuitability for certain land-uses causes that change is not allocated on a certain grid cell, even though the area seems suitable on the coarse scale.

Model implementation

CLUE has a user interface through which parameters and land use demands can be entered or changed, but no possibilities to visualize the output maps. The user has to export them and import them in a geo-information system. A demonstration version of the model can be downloaded from the internet (http://www.cluemodel.nl).

For calibration purposes two aspects need to be taken into consideration: The relative magnitude of autonomous developments and parameters influencing the multi-scale approach.
Autonomous developments are defined as local land use change taking place opposite to the national trend. They can be defined by analyzing historic maps. Considering the multi-scale approach, one has to keep in mind that if grid cells of a certain land-use type from the coarse level increase more than the national increase, the model will increase the change of grid cells at the finer scale. To define appropriate interaction between the two allocation scales, historic data is needed (VERBURG et al. 1999b).

**Special features**

For a regional application of the model, the CLUE-S model (Conversion of Land Use and its Effects at the Small regional extend) was developed. This model is designed for input datasets with a high spatial resolution and to be applied on land use in small regions (e.g. watershed or province) (VERBURG et al. 2002). Similar to CLUE consists also CLUE-S of a non-spatial demand module that calculates area change for all land-use types at an aggregated level. The demand module varies between different applications and its results are also direct input into the allocation module.

The spatial allocation module within CLUE-S translates the demands into changes at different locations within the study area. Also here the user can specify rules that restrict cell conversions on certain areas (e.g. for nature protected areas). The allocation is then carried out in an iterative procedure, regarding probability maps, decision rules, the actual land-use map and the overall demand. For each specific land-use conversion elasticity is given to each land use type. This elasticity causes some land-use types to be more reluctant to change (e.g. permanent crops) whereas others shift location (VERBURG et al. 2006). There is a constant interaction between macro-scale demands and local land-use suitability, determined by regression equations (ibid). In contrast to CLUE, CLUE-S also takes neighbourhoods into consideration, by implementing driving forces that do not only act locally, but operate over a certain distance (ibid).

### 2.1.2 LandUseScanner

The LandUseScanner (NL: Ruimte-Scanner) is a decision support system, simulating future land use in the Netherlands. It was developed in the late 1990s by a consortium of several Dutch research institutes (the National Institute for Public Health and the Environment (RIVM), the Free University (VU), the National Spatial Planning Agency (RPD) and the Agricultural Economics Research Institute (LEI)). The model represents spatial patterns of land use processes such as population growth, production and natural conservation.
Input data

It is a grid based model with usual cell sizes of 500 x 500 m, but the size can be adjusted if necessary (BORSBOOM-VAN BEURDEN et al. 2002, 3). The model’s input datasets consist of regional demands and local suitability. Regional demands are based on future assumptions on the regional and global level, such as demographic growth, agricultural production and infrastructure (HILFERINK and RIETVELD 1999). They are calculated within different sectoral models. It depends on the type of data and application, which spatial division (global, regional) will be chosen. For the Netherlands projections for urban land have for example been generated at the COROP level (total of 40 in the Netherlands, size between provinces and municipalities) (ibid). It is however possible for the same application to choose multiple different regional divisions (to use for example municipalities and NUTS² level simultaneously).

Local suitability consists of different input datasets, all based on grid cells. The following datasets are example inputs, which can be extended or diminished, depending on the type of application: Current land use maps (e.g. residential, industrial, agricultural, natural areas and water) are the starting point for simulating future developments on the regional as well as on the local scale (KOMEN et al. 2008, 5).

Physical suitability maps are a crucial variable for the allocation of land use change in a specific grid cell. They are created for each land use type by combining for example soil quality, land use and the amount of similar land use in the neighbourhood (HILFERINK and RIETVELD 1999). The suitability ranges from -10 to 10. The higher the suitability value for a certain land use type is, the higher the probability that the cell will be occupied by this type. Locations with already fixed construction plans could be assigned a value of 10, and search locations formulated in policy documents a value of 5 (ibid). The suitability of a cell is not constant and can alter as a result of changes in land use.

Policy maps are needed when future land use changes are known, such as building permits or preservation of natural areas (HILFERINK and RIETVELD 1999). The model assumes that the reserved areas are completely filled in with the new land use type (BORSBOOM-VAN BEURDEN et al. 2002, 4).

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² The Nomenclature of Territorial Units for Statistics (NUTS) was developed by the European Union. It is a geocode standard for referencing the administrative divisions of member countries for statistical purposes. The NUTS division does not necessarily correspond to administrative divisions within the country EC (Council of the European Union), 2003. "Regulation (EC) No 1059/2003 of the European Parliament and of the Council of 26 May 2003 on the establishment of a common classification of territorial units for statistics (NUTS)". .
Distance relation maps are needed because the proximity to certain land use types influences the suitability for other land use types (people like to live close by but not near the highway) (Kuhlman et al. 2005). Distance relation maps contain attractiveness values, which are calculated by determining the distance to current types of land use or features with the help of distance decay functions (Borsboom-Van Beurden et al. 2002, 4).

Drivers for land use change

For each time step of 10 years the LandUseScanner models a new land-use map. Regional and global claims are allocated to individual grid-cells based on their suitability. The user can specify minimum and maximum values of cells with a certain land use that must be allocated (for example maximum hectare of industry). Also the neighbourhood of cells is included, enabling to model spatial relations (Hilferink and Rietveld 1999). Having for most applications a circular format, the neighbourhood also can have an oval form when modelling drainage or wind directions.

Allocation mechanism

For the allocation of future land use data is entered into the allocation module (see Figure 5). The allocation is based on an economical mechanism, in which land use changes occur according to bid prices.

![Diagram](Figure 5: Design of the LandUseScanner model: regional demand and local suitability form the input into the allocation module, where future land use is been allocated (Koomen et al. 2008, 5).)

In the allocation module equal units of land (cells) are allocated to those land-use types for which they have the highest suitability. This is also taking the regional and global land-use claims into consideration. The procedure is based on the bid-rent theory, which states that parcels of land are allocated to the use in which they generate the highest economic value. It
means that the allocation is considered as being optimal, when the sum of all suitability values corresponding to the allocated land use is maximal. The LandUseScanner approximates the economic value, or bid price of grid cells for various land use types by a suitability score (Eppink et al. 2008, 564). As the suitability of a grid cell to a land allocation type increases relative to other types, the likelihood of allocating the grid cell to the land allocation type also increases (ibid, 565). The allocation is subject to the following constraints:

- The amount of land allocated to a cell cannot be negative
- The amount of land allocated to a land-use type in a region should be between the minimum and maximum claim for that region (Koomen et al. 2008, 6).

It is possible to specify overlapping regions for the claims (although the regions of claims for the same land-use type must be disjoint) and to apply distinct minimum and maximum claims (Koomen et al. 2008, 7). In the final result land use probabilities are then translated into hectares and when visualizing these, always the dominant land use function of each cell is presented (Hilferink and Rietveld 1999). The LandUseScanner includes no stochastic (random) effect, so that only one solution for a given initial situation is modelled.

Model implementation

In order to implement the model, an information system was developed in the C++ language, called the Data and Model Server (Kuhlmán et al. 2005, 6). The system manages several sets of tables, some related to grid cells, others to regions containing attributes on regional claims. The resulting maps in grid format can be exported as ASCII files and thus used in standard GIS applications. The final LandUseScanner output is spatially explicit and shows patterns of land use that correspond with an economic equilibrium in the (future) land market (Eppink et al. 2008). The model software can be downloaded from: http://www.lumos.info/landusescanner.htm.

Special features

The LandUseScanner enables integrating governmental interventions by adding constraints and changing suitability of grid cells. The user can modify expressions related to the land use types and thus influence and change attractiveness factors, hence modelling different scenarios and dependencies (Hilferink and Rietveld 1999).

2.1.3 UrbanSim

UrbanSim was developed by the Centre for Urban Simulation and Policy Analysis at the University of Washington. The project began in the late 1990's, and a first version was released as Open Source software in 1998 (WaddeLL et al. (Forthcoming), 2). Originally created for Honolulu, several applications in metropolitan areas within the United States
followed and later also applications in Europe have been developed. The model is designed specifically to address policy analysis requirements of metropolitan growth management and interactions between land use, transportation and public policy are incorporated (WADDELL 2002, 2).

**Input data**

Input data consists of grid cells, whose usual cell size of 150 x 150 m can be changed. Running the model requires the following datasets (WADDELL et al. (Forthcoming), 18):

- Population and employment data in (unemployment database, business establishments).
- Household data from census sources to estimate household characteristics.
- Parcel database with acreage, land use, housing units, year built, value, city and county.
- GIS overlays of environmental features or other sensitive or regulated lands.
- Transportation system plans (travel access indicators from external transportation models)
- Land use plans
- Travel model outputs
- Development costs (land costs, construction costs)
- A location grid.

**Drivers for land use change**

UrbanSim represents specific agents (developers) interacting with other agents (households, jobs, and governments) within a simulation environment (WADDELL and ULFARSSON 2004, 24). Current land use however, is represented by cells and their probability to change is influenced by the state of neighbouring cells. Interactions are thus modelled both at the model component level and at an individual agent level (ibid). The time step modelled is one year.

**Allocation mechanism**

UrbanSim is not one single model, but actually an urban simulation system, consisting of several different models (see Figure 6). All models and input datasets are combined in the data store that represents each household as an individual object, with relevant modelling characteristics (household income, size, children, number of workers) (WADDELL 2002, 13).

*Transition models (non spatial):* The demographic transition model simulates how many households of each type must be added or removed from the database. It is based on external information from macroeconomic models that project the total population and additional information such as household size and income distributions. The economic transition model models job creation and loss, similar to the demographic transition model. The model
assumptions will then be consistent with external assumptions about economic growth or decline in different economic sectors.

Relocation models (representing agents making decisions): The household relocation model projects the probability that a household will move. Movement probabilities are based on historical data. Once a household has chosen to move, it is placed in limbo to indicate it has no current location, and the space it formerly occupied is made available. The employment relocation model determines which jobs in a given sector will move from their current locations during a particular year.

Location choice models: The household location choice model chooses a location for each household that currently has no location. For each household a set of possible locations is randomly selected. Each alternative is evaluated for its desirability to the household, through a logit model (for more information see Annex I.3: logit models). The household is then assigned to its most desired location. The variables used include attributes of housing in the grid cell (price, density, and age), neighbourhood characteristics (land use mix, density, average property values) and regional accessibility to jobs.

The employment location choice model determines a location for each job that has no location. Allocation is carried out similar to the household location choice model. Variables include real estate characteristics in the grid cell (price, type of space, density, age), neighbourhood characteristics (average land values, land use mix, employment), and regional accessibility to population.

Real estate developer model: This model simulates developer choices about which construction to undertake where, including both new development and redevelopment. The model iterates over all grid cells and creates a list of possible transition alternatives. The probability to change is then calculated in a logit model. Variables include characteristics of the
grid cell (current development, policy constraints and improvement value), characteristics of
the site location (proximity to highways, existing and recent development) and regional
accessibility to population.

Land price model: This model uses location and real estate characteristics to simulate
land prices of each grid cell as the characteristics of locations change over time. These
influence then the location choices of households, firms, and developers. The model is based
on urban economic theory, which states that the value of location is capitalized into the price
of land. It also allows incorporating effects of short-term fluctuations in local and regional
vacancy rates on overall land prices.

Transportation data: An additional accessibility model is responsible for maintaining
accessibility values for occupants within each traffic analysis zone. Accessibility values from the
travel model influence decisions of developers, employers, and residents. They may raise travel
demands, which then feed back into the travel model. UrbanSim also incorporates local
accessibility measures, corresponding to the activities that can be reached by walking, over a
distance of 600 meters, using spatial queries of the grid cells in the data store. All model

Model implementation

The UrbanSim software is distributed as Open Source software and can be
downloaded from the internet at no cost (http://www.urbansim.org). The Open Source
approach is meant to make the model open to scrutiny and to further extension and adaption
to emerging requirements for modelling (WADDELL 2002, 4).

- For the actual operation of the model, a created baseline scenario contains
  assumptions against which other scenarios will then be compared (WADDELL and
  ULFARSSON 2004, 32). The data export process gathers, aggregates and exports data from
  the data store to external files for subsequent analysis and graphical display. The user can
  choose different output files and specific simulation years. Outputs are then created at the
  grid cell level, and summarized by traffic zone and for the region as a whole. The output
data is written in a standard format and possible to use in common GIS programmes
  (WADDELL 2002, 13). Output information includes (WADDELL et al. (Forthcoming), 2):

  - Households by income, age, size, and presence of children
  - Businesses and employment by industry
  - Acreage by land use
  - Dwelling units by type
  - Square feet of non-residential space by type
  - Land values per acre by land use
  - Improvement values per unit or square feet by land use
UrbanSim is calibrated with data from three time periods. The simulation runs from the first period to the second, and simulated results are compared with the existing real data. Also the validation uses separate data that was not used yet for calibration. Thus, data is needed from one time period to serve as initial condition, from a later period to serve as a comparison with model projections and from a third time period for the model validation (WADDELL and ULFARSSON 2004, 30).

**Special features**

The system allows interactive testing of how different policy strategies influence a particular vision or set of community objectives. By creating input files that represent these policy interpretations, such scenarios can be imported into UrbanSim.

### 2.1.4 SLEUTH

SLEUTH is an acronym for the input layers that the model uses in gridded maps: Slope, Land-use, Exclusion, Urban extent, Transportation and Hill shade. It was developed by Keith C. Clarke at the University of California, Santa Barbara. First applications were carried out in North American cities, but world wide applications, also in Europe, followed. SLEUTH consists of a cellular automaton, within which predefined growth rules are applied spatially to raster maps. Its design is meant to be both scaleable and universally applicable (SILVA and CLARKE 2002, 525).

**Input data**

The following input datasets are required (SILVA and CLARKE 2002, 525):

- Topographic slope layer
- Land use
- Areas excluded from urbanization (one layer, areas unavailable for development)
- Urban extents (for statistical purposes at least four layers from different years)
- Road transportation layer (two layers of different years, a road hierarchy can be defined)
- Graphic hillshade layer (one layer, use as a background only with graphical model version).

**Drivers for land use change**

A simulation is a series of growth cycles that begins at a start date and completes at a stop date. The model is thus applied in a set of nested loops: an outer loop executes each growth history and retains statistical data, while an inner loop executes the cellular automaton that allocates cell transitions for each single year. The “seed year” that the model takes is generally the earliest year, against which the model runs and compares the modelled data with the available real urban data (CLARKE *et al.* 1997).
Allocation mechanism

The model consists of multiple modular parts, from which one is a cellular automaton on a two-dimensional grid, driven by growth rules to determine cell transitions, including an investigation of spatial properties from neighbouring cells (CLARKE et al. 1997) (for further information see Annex I.1: cellular automata). The basic growth cycle is shown in Figure 7.

Five coefficients control the behaviour of the cellular automaton: diffusion (overall scatter of the growth), breed (likelihood of new settlements being generated), spread (growth outward and inward from existing spreading centres), slope resistance (flat ground is preferred) and road gravity (attraction of urbanization to roads and diffusion of urbanization along roads). All coefficients range from 0 to 100.

Next to these coefficients, four types of growth behaviour simulate urban land-use: spontaneous, diffusive, organic and road-influenced growth (JANTZ et al. 2004, 254). They are sequentially applied during each growth cycle (one year) and in conjunction with above mentioned excluded layer probabilities, they determine the probability of any location of becoming urbanized.

Figure 7: Basic simulation of SLEUTH (USGS 2008)

Spontaneous neighbourhood growth: simulates the random urbanization of single pixels. The probability that a non-urbanized cell will become urbanized is determined by a dispersion coefficient (JANTZ et al. 2004). New spreading centre growth: models the emergence of new urbanizing centres by generating up to two neighbouring urban cells around areas that have been urbanized through spontaneous growth. Edge growth: simulates outward growth from the edge of new and existing urban centres. It is controlled by the spread coefficient, which influences the probability that a non urban cell with at least three urban neighbours will also become urbanized. Road-influenced growth: the final growth step simulates the influence of the transportation network on growth patterns by generating spreading centres adjacent to roads.

Newly urbanized cells are randomly selected. If roads are found in the neighbourhood, a temporary urban cell is placed at the closest location adjacent to a road. This temporary cell then searches along the road for a permanent location. The permanent location becomes a new spreading centre. Up to three cells along a road can be urbanized this way (JANTZ et al. 2004).
Model implementation

The program code is written in the C programming language, and supports three different modes: test, calibration, and projection modes. A free version of the model can be downloaded on the internet (http://www.ncgia.ucsb.edu/projects/gig/project_gig.htm).

Implementation occurs also first by calibrating the model and then projecting. The calibration process, known as “brute force calibration” has been automated by allowing the model to “learn” its local setting over time (SILVA and CLARKE 2002). The model code actually tries many combinations and permutations of the control parameters and performs multiple runs from the seed year to the present. Results are sorted, and parameters of the highest scoring model runs are used to begin the next, more refined sequences or permutations over the parameter space. Between the calibration phases the user can extract values that best match the five growth coefficients. Calibration relies on maximizing spatial statistics between the model behaviour and the known data at specific calibration data years (SILVA and CLARKE 2002). After the calibration, historic patterns of growth are projected into the future (JANTZ et al. 2004, 254). Self-modification of the growth rules (diffusion, breed, spread, slope and road coefficients) change the control parameters, so that the model’s behaviour includes feedback. The self-modification is equivalent to adaptation or evolution.

Special features

Besides the above described initial growth rules, a second level of behaviour rules is defined: each time the model records rapid, little or no growth, the model adapts itself to the new conditions. This functionality, termed ‘self-modification’, is intended to simulate more realistically the different rates of growth that occur in an urban system over time. Without self-modification, SLEUTH would simulate a linear growth rate (JANTZ et al. 2004, 254). One important feature is the model’s conduciveness to interactive and animated computer graphics, allowing point-and-click access to the parameters and immediate visualizations of the outcomes (CLARKE et al. 1997).

2.1.5 METRONAMICA

METRONAMICA was developed in 1992 by the Research Institute for Knowledge Systems (RIKS) in collaboration with Roger White from Memorial University in St. John’s, Canada. It comprises a dynamic land use model applied to the full territory of the area to be modelled. Besides exploring the effects of policy options on the quality of the socio-economic and physical environment, its aims at stimulating and facilitating awareness building, learning, and discussion prior to decision making processes (RIKS BV 2005). Main feature is its modularity, meaning that METRONAMICA comprises of several independent blocks. It does
not seek to find one optimal solution for only the economic, ecological or social dimensions. The model rather tries to maximise the whole by requiring input datasets from all three dimensions. The benefit of this approach is the strong integrative and interactive nature of the resulting system, in which highly dynamic, autonomous processes play a key role (ibid).

**Input data**

Land use maps represent the entire area modelled by a mosaic of raster cells. Their cell size is most often between 100 x 100 m and 1 x 1 km, but can technically be downscaled to any desired size. Small cell size applications are however conceptually questionable and only one research was carried out with cell sizes of 25 x 25 m (PHYN 2008). The land use map consists of as many land use types as required for one specific application (see also chapter 3.1.5). All land use types are then grouped into three categories: Land use functions are those types driven by external factors and that change actively (e.g. forest, urban, industry, and retail). Vacant land uses are those that can be taken over by land use functions if they grow and require more space (e.g. bare soil, nature). Land use features are those that affect the transition potential of other cells, but stay constant during the modelling process (e.g. water, roads). They can only be changed manually. Besides the land use map additional data is included (see Figure 8).

Suitability maps determine the degree to which a cell is capable to support or maintain a certain land use function. It is a composite measure, prepared on the basis of factor maps and determines the physical, ecological and environmental appropriateness of a cell. Suitability is often “a fact of life” and represents an intrinsic quality of an area (RIKS bv 2005, 10). It comprises facts that can hardly be changed, such as elevation, soil or pollution and is presented by one map for each land use function (VAN DELDEN et al. 2005). Each cell has then a value ranging from zero to one. Zero when the cell is absolutely unsuitable for a specific function, one when it is extremely suitable.

Zoning maps are man made instruments for imposing constraints or stimulating particular trends (RIKS bv 2005, 10). Zoning, like suitability, is also implemented by one map for each land use function, based on master plans or other planning material. As a composite measure it includes protected areas or buffer areas and determines which cells are allowed to be taken over by a certain land use function. It is possible for the user to integrate here also a temporal aspect by including up to three time periods. By doing so, a defined area is prohibited to be taken over by a function only for a defined period of time, for example no residential development in a forest area from 2010-2015. After that period, for example from 2016-2020 the function may be allowed. Each cell has a zoning value either of zero, one, two or three. According to a yes/no relationship are cells with a value of zero allowed to be taken over by the land use function from the beginning of modelling. Cells with a one are allowed to be
taken over from time step 1 one and with a two from time step 2, respectively. Cells with a 3 however, are never allowed to be taken over.

**Accessibility maps** take the infrastructure (roads, railroad and waterways) into consideration. They display the need of transportation for certain activities or land use functions, and also allow for the importance and quality of infrastructure elements (road vs. highway) for a particular activity or land use function. Agriculture needs for example access to smaller roads, whereas industry may need a railroad connection. A maximum of 16 infrastructure elements is supported. Also here, each cell has a value ranging from zero to one. The precise accessibility value depends on the type of the infrastructural element in the neighbourhood (each type of street can be assigned with a different value) and their distance to the cell (the distance decay, meaning the further away a street is, the less important it becomes).

![Figure 8: Input datasets in METRONAMICA (Picture taken from the Environmental Explorer for the Netherlands, resolution is 25ha for each cell) (RIKS BV 2005, 11).](image)

**Drivers for land use change**

METRONAMICA typically runs for a 30-year period into the future, whereas also shorter intervals are possible. Results of much longer modelling periods (e.g. 50 years) are questionable, due to increasing uncertainty in the future, but technically possible to implement. Results are always calculated on a yearly basis. The model consists of three modelling levels, described in more detail in the following (Figure 9).

**Global level:** The global level consists of the entire modelled area. Global trend lines such as main economic activities, demographic growth and natural land use categories are calculated, taken from planning agencies or stakeholder groups. Main economic activities are typically concentrated to 3 to 10 sectors, such as farming, mining, industry, commercial activities and recreation. The population is represented in 1 to 4 categories, where categories can be divided based on densities, income or other features selected by the user (RIKS BV 2005, 8). At this level constraints are calculated for the regional and local level.
Regional level: At the regional level population, employment and productivity are calculated. This level consists of several administrative regions. A dynamic gravity based model accounts for regional inequalities, based on the fact that some parts of a country are more attractive to economic and demographic developments than other parts. This phenomenon usually results in an uneven spread of growth. The national socio-economic growth as well as the migration of residents and activities is allocated according to the following principles: each region competes with all other regions considering people and economic activities. The attractiveness of a region is calculated from factors such as employment level, activities already present and the transportation system. If a region has no space left for a certain activity anymore, it will lose attraction and growth is diverted to other regions.

Local level: The output of the regional level is converted to single cell-state requirements on the local level. The cell-state can change directly, for example cells along the shore would change from beach to water if the sea level rises (White and Engeelen 1997, 240). However, most cell demands are generated by economic and demographic requirements on the regional level and implemented on the local one. For example the demand of an increasing population requires more cells of residential land use on the local level (RIKS BV 2005). The local level determines the detailed allocation of people, jobs and land use. Summarized cellular measurements obtained from the local level influence in turn the regions’ attractiveness regarding people and economic growth, influencing regional attractiveness (RIKS BV 2005, 12).

Allocation mechanism

Allocation takes place on the local level, based on a constrained cellular automaton (for further information see Annex I.1). The entire area modelled is represented by a mosaic of raster cells, each cell having one known state. All cells are simultaneously evaluated and updated according to their internal states and values of their neighbour cells.

A set of rules, called ‘transition rules’, determines whether or not a cell changes when it is evaluated. It depends on the quality of its neighbourhood that consists of a defined radius of
up to 8 cells and also includes the cell itself (thus a maximum of 196 cells) (VAN DELDEN et al. 2005). The strength of the attraction and repulsion is defined by a function of distance for every occurring land use. It means that each cell within the neighbourhood is weighted differently depending on its state and distance from the reference cell. This accounts for the effect that frequently a cells’ effect will be stronger the closer it is, and may change sign as the distance increases (WHITE and ENGELEN 1997, 239). The weight may also be positive, representing an attractive effect, or negative if two states are incompatible. So attracts a new park for example housing, which is in contrast repelled by industry.

Cells will finally always change to that land use function, for which they have the highest transition potential, until regional demands are satisfied. After that point is reached, no more cells are converted to that state. Thus before any cells are converted all cells must be ranked by the value of their highest potential, and conversions proceed starting with the cell with the highest potential.

Besides the neighbourhood effect that causes cells to change from one type of land use to another, METRONAMICA also accounts for local constraints, implemented via the above described zoning, suitability and accessibility (RIKS BV 2005, 10). In addition also a factor of randomness is taken into consideration. Through this is the modelling of spontaneous growth possible and also unpredictable developments. For each cell in the model the transition potential is calculated simultaneously and the cell changes to the land use with the highest potential. The final transition potential \( P_k \) for each cell is calculated by:

\[
P_k = r(\alpha) \times N_k \times S_k \times A_k \times Z_k
\]

Where for land use \( k \):
- \( r(\alpha) \) is a random perturbation factor with magnitude controlled by the parameter \( \alpha \)
- \( N_k \) is Neighbourhood effect
- \( S_k \) is Suitability
- \( A_k \) is Accessibility
- \( Z_k \) is Zoning

**Model implementation**

METRONAMICA is a “template SDSS” which means that no programming is required to set up an application. A graphical user interface provides access to all variables, parameters and maps used at every level of detail. Manual calibration and validation is required, similar to the procedure as mentioned in the UrbanSim model description. Outputs are a new land use map for each time step and information about the policy or strategies tried out with the model in the form of time charts, animations and numeric outputs. The model cannot be downloaded from the internet, but may be available for research purposes after contacting RIKS (www.riks.nl).
**Special features**

METRONAMICA can be characterized by its high level of completeness, flexibility and interactivity (Van Delden and Engelen 2006, 7). It integrates socio-economic and physical processes and provides an integrated view of a modelled region at a very detailed level (Van Delden et al. 2005, 8). Policy variants and spatial scenarios can be entered interactively by using an alternative set of numbers and maps (Engelen et al. 2003, 97).

### 2.1.6 Summary and comparison

The successful application of a model in one particular area does not necessarily imply its successful application in another. Local characteristics, territorial constraints and other properties are differing between two areas. One of the major criticisms of the first generation of computer-based urban models was their specificity to the cities to which they were applied (Lee 1973). Urban and environmental models need to be adapted to or able to “learn” characteristics of the particular area that they explain and project (Silva and Clarke 2002, 526). The following paragraphs discuss the possibility to apply the above described models for the specific urban context in the study area Weert. The models are compared to each other considering different important aspects for a local application based on high resolution datasets. The comparison criteria were chosen according to required needs for the current application. A final overview is given in Table 1.

**Data: what type of input data is required to set up a new application?** Several data formats should be supported, the data should be easy available and if necessary manually producible. The LandUseScanner is able to integrate detailed databases and sectoral models from different backgrounds. It is able use widely varying input data and also generates different kinds of outputs (Borsboom-Van Beurden et al. 2002, 8). Both CLUE and UrbanSIM require spatial- as well as non-spatial input data. No information was however found which data formats are supported. UrbanSIM requires a large amount of input datasets that could be difficult to receive. SLEUTH and METRONAMICA require to a large extend a similar set of input data. But SLEUTH is lacking flexibility, because it is only possible to use two land use functions (urban and non-urban). For all models high quality data is needed (e.g. current land use maps from at least two different years) which is not easy to receive. However some input datasets (e.g. zoning and suitability) can manually be created by the user, for which not always maps in digital format are essential.

**Spatial resolution: can the cell size be changed for a local application?** For the research at hand it is aimed at modelling at a cell size of $25 \times 25$ m. CLUE is based on a multi-scale approach, gridding data artificially at multiple resolutions. The cell size can be adapted to different scales. Downscaling should thus be possible, only a large-scale application could be crucial. The LandUseScanner was designed for the Netherlands with a grid cell size of 500 m. Cell sizes can
be changed, making a local application possible. UrbanSim usually uses grid cells of 150 x 150 m, but whose size can also be modified. The grid cell sizes of the SLEUTH model can be changed and the model adapted to local characteristics through calibration (SILVA and CLARKE 2002, 530). It proved to apply equally as well to European cities as to the North American cities for which it was designed, representing in detail local characteristics of each metropolitan area (CLARKE et al. 1997). METRONAMICA was applied on many different spatial resolutions, one first time also at a 25 x 25 m scale (PHYN 2008). However, this application was conducted by leaving open questions and unsolved problems which should be tackled in a second approach.

**Dynamic evolution: which time step is integrated in the model? Is the modelled result used as basis for calculating the new modelling step as required when aiming at a dynamic modelling approach?** UrbanSim, SLEUTH and METRONAMICA calculate the land use on a yearly basis while making use of the land use of the previous year. This way spatial pattern can emerge from local dynamics. The LandUseScanner models land use in time steps of 10 years. It uses the simulated land use map as basis for further simulation, which can be regarded as dynamic evolution. However the dynamic of a 10 year time step is questionable. CLUE does not integrate dynamic evolution, but accounts for bottom-up as well as top-down interactions.

**Neighbourhood effect: are neighbouring cells taken into account when modelling future land use? Also a distance decay effect should be possible to implement.** Within CLUE-S (not CLUE itself) and the LandUseScanner a distance rule for urban land use is used to calculate the impact of current urban centres on future urban centres. The LandUseScanner carries out this calculation on the initial land use map, while CLUE-S has the ability to calculate it for more years in the simulation. SLEUTH includes neighbouring cells when allocating new spreading centre growth and road influenced growth. UrbanSim considers in the household and employment location choice model neighbourhood characteristics. And also METRONAMICA takes neighbouring cells (all within a radius of eight cells) into consideration. For these neighbours, even different spatial interaction rules can be defined.

**Multi-scale approach: does the model analyze land use at multiple scales, to account for the hierarchical organization of land-use systems?** CLUE incorporates three scales into the model: the national scale (modelling one area), a coarser and a finer allocation scale. Also LandUseScanner and METRONAMICA include three scales, a global or national, regional and local scale. Within the LandUseScanner multiple different regional scales can be integrated, and within METRONAMICA this regional scale can also be left out. UrbanSim has a cellular scale, a traffic zone scale and a regional scale on which outputs can be created. SLEUTH does not include multiple scales, only several consecutive growth cycles.
Ranking of functions: are variables and/or input factors ranked for allocation purposes to take for example stricter policies or highly suitable areas into consideration? In the LandUseScanner functions are ranked according to their relation between bid-prices and occurring values in the suitability map. Functions with a higher rank receive higher bid-prices. SLEUTH consists of 5 growth coefficients that range independently from 0 to 100. METRONAMICA incorporates ranking via local interaction rules. The higher the value of a distance decay function, the higher the rank of the function. This ranking can also be negative, when functions repel each other. The CLUE model takes biophysical and socio-economic conditions into consideration that both have similar weights, no ranking is incorporated into this model. Also in UrbanSim combines the data store several models, but does not rank certain variables higher than other.

Suitability - includes the model (physical) suitability maps, e.g. elevation, soil quality and erosion? This factor may be important when modelling an area with many different characteristics. CLUE includes local suitability for certain land-uses that prevents land-use change on a certain grid cell, even though the area seems suitable on the coarser allocation scale. Within the LandUseScanner, for each land use type physical suitability maps are created. The suitability maps consist here of physical aspects, policy maps and distance relationships added to the current land use map. UrbanSIM, SLEUTH and METRONAMICA all include input layers with suitability aspects concerning only physical conditions, such as a topographic slope layer or other environmental features, e.g. wetlands and flood ways.

Policy intervention - does the model enable policy interventions, e.g. zoning or nature protected areas? Besides natural factors especially policies are important, influencing to a high degree land use change. All models take policy interventions into consideration. The CLUE-S model can assign a certain land use to a cell imposing policies thus as hard measures in the model. The LandUseScanner includes policy maps such as building permits for residential and industrial land use or preservation and development of natural areas. These maps are added onto other maps, as described above. UrbanSim considers within the real estate development choice model grid cell characteristics that include the current development and also policy constraints. SLEUTH incorporates different levels of protection for different areas (Jantz et al. 2004, 254) and METRONAMICA integrates input layers containing areas excluded from urbanization or from any other user defined land-use class.

Accessibility - is a transportation network included, showing main roads, waterways and railroad? Each land use may have different requirements considering infrastructural elements. UrbanSim includes local accessibility measures and can effectively represent pedestrian and bicycle scales of travel. It is the first model available that achieved this scale of analysis (WadDEll 2002, 13). Also SLEUTH and METRONAMICA, include both a road transportation layer. The LandUseScanner includes distance relation maps that determine the distance to current types
of land use or features (railway station and a highway access points) with the help of distance decay functions. Only CLUE takes no transportation data into consideration.

**Policy support** - aims the model at supporting policy makers and was it already in practical use? Used as a SDSS, should the modelled output data be possible to use within policy processes. UrbanSim has successfully been applied worldwide in projects together with policy makers. SLEUTH has however no adequate mechanism to simulate the potential impacts of incentive policies. It was nonetheless seen as a useful tool for assessing the impacts of alternative policy scenarios (Jantz et al. 2004, 254). METRONAMICA allows an easy generation and assessment of future policies and development alternatives as well as past spatial policies with the aim to support decisions of planners and policy-makers (Van Delden et al. 2005, 8). The LandUseScanner was developed for being an important communication tool during planning processes, and was applied in the Netherlands only. CLUE is designed for scientists and policy makers to help understanding the adverse effects of land-use changes. However no information was found on a practical application that included interaction with policy makers.

**Algorithm - which allocation algorithms are used in the models?** The UrbanSIM model is based on an agent based approach. The allocation within CLUE is based on regression models. The LandUseScanner makes use of a bid price methodology, and optimized land use, whereas SLEUTH and METRONAMICA both are based on a constrained cellular automaton and thus simulate land use.

Table 1 highlights differences between the models, considering an application for answering the research questions as stated in chapter 1.3. A check mark (✓) symbolizes suitability of the model, a cross (✗) unsuitability.

Table 1: Differences and similarities between the five land use models CLUE, LandUseScanner, UrbanSim, SLEUTH and METRONAMICA.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application possible with available data sets</td>
<td>✓</td>
</tr>
<tr>
<td>High spatial resolution</td>
<td>✓</td>
</tr>
<tr>
<td>Yearly, dynamic evolution</td>
<td>✓</td>
</tr>
<tr>
<td>Neighbourhood effect</td>
<td>✓ (CLUE-S)</td>
</tr>
<tr>
<td>Multi-scale approach</td>
<td>✓</td>
</tr>
<tr>
<td>Ranking of functions</td>
<td>×</td>
</tr>
<tr>
<td>Suitability</td>
<td>✓</td>
</tr>
<tr>
<td>Policy interventions</td>
<td>✓ (CLUE-S)</td>
</tr>
<tr>
<td>Dynamic accessibility</td>
<td>✓</td>
</tr>
<tr>
<td>Policy support</td>
<td>×</td>
</tr>
</tbody>
</table>
2.2 Study area municipality Weert

The municipality Weert, study area for this thesis, is situated in Limburg in the south of the Netherlands (see Figure 10). For the research the entire area of the municipality will be taken into consideration, the urban, peri-urban and rural regions including. Weert belongs to the “moderate urban” municipalities, an intermediate between rural and urban (CBS 2008).

The size of the municipality is about 104 km² (CBS 2005, 18). A total of 13 % is build-up, 23 % are nature areas or forest, 3 % area for recreational purposes and 56 % used for agriculture (Table 2). Main villages are: Altweerterheide, Laar, Stramproy, Swartbroek, Tungelroy, and the city of Weert, being also the municipalities’ centre. The cities’ location can be seen on the city map Weert (see map in Annex IV.1 and in digital format on the data CD). The following paragraphs describe the current as well as expected and future developments of Weert. They are divided into the topics of demographical, residential, economical, employment, agricultural, transportation network, recreational and educational developments.

![Figure 10: Location of the study area in the Netherlands and the region Limburg (PROVINCIE LIMBURG 2007b).](image)

<table>
<thead>
<tr>
<th>Category</th>
<th>Streets and Rail tracks</th>
<th>Build up area</th>
<th>Semi-build up area</th>
<th>Recreation area</th>
<th>Agricultural area</th>
<th>Forest and nature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area [km²]</td>
<td>4</td>
<td>14</td>
<td>1,5</td>
<td>3</td>
<td>61</td>
<td>25</td>
</tr>
<tr>
<td>Amount [%]</td>
<td>4</td>
<td>13</td>
<td>1</td>
<td>3</td>
<td>56</td>
<td>23</td>
</tr>
</tbody>
</table>

2.2.1 Demographical developments

In the past 13 years the population in Weert increased from 46,769 inhabitants in 1995 to 48,335 inhabitants in 2008 (CBS 2008) (Table 3). For the future, population shrinkage is expected and three possible scenarios were developed by ETL (2008) (Table 4). Within the low scenario strong population shrinkage will take place to 41398 residents in 2040. The middle scenario assumes a slightly less shrinkage to 43999 residents in 2040 and the high scenario assumes a population growth until 2021, which is then followed by shrinkage to 46760 residents in 2040.
Table 3: Population development from 1995 until 2008 (CBS 2008)

<table>
<thead>
<tr>
<th>Year</th>
<th>No. inhabitants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>46769</td>
</tr>
<tr>
<td>1996</td>
<td>47107</td>
</tr>
<tr>
<td>1997</td>
<td>47415</td>
</tr>
<tr>
<td>1998</td>
<td>47590</td>
</tr>
<tr>
<td>1999</td>
<td>47711</td>
</tr>
<tr>
<td>2000</td>
<td>47959</td>
</tr>
<tr>
<td>2001</td>
<td>48151</td>
</tr>
<tr>
<td>2002</td>
<td>48479</td>
</tr>
<tr>
<td>2003</td>
<td>48785</td>
</tr>
<tr>
<td>2004</td>
<td>48724</td>
</tr>
<tr>
<td>2005</td>
<td>48707</td>
</tr>
<tr>
<td>2006</td>
<td>48575</td>
</tr>
<tr>
<td>2007</td>
<td>48484</td>
</tr>
<tr>
<td>2008</td>
<td>48335</td>
</tr>
</tbody>
</table>

Table 4: Population prognosis for Weert, showing expected inhabitants per year for three different scenarios: low, middle and high (Etil BV 2008).

<table>
<thead>
<tr>
<th>Year</th>
<th>Low scenario</th>
<th>Middle scenario</th>
<th>High scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>48199</td>
<td>48218</td>
<td>48238</td>
</tr>
<tr>
<td>2010</td>
<td>48099</td>
<td>48169</td>
<td>48238</td>
</tr>
<tr>
<td>2011</td>
<td>48000</td>
<td>48146</td>
<td>48294</td>
</tr>
<tr>
<td>2012</td>
<td>47900</td>
<td>48139</td>
<td>48379</td>
</tr>
<tr>
<td>2013</td>
<td>47781</td>
<td>48115</td>
<td>48451</td>
</tr>
<tr>
<td>2014</td>
<td>47663</td>
<td>48092</td>
<td>48525</td>
</tr>
<tr>
<td>2015</td>
<td>47529</td>
<td>48054</td>
<td>48583</td>
</tr>
<tr>
<td>2016</td>
<td>47370</td>
<td>47988</td>
<td>48614</td>
</tr>
<tr>
<td>2017</td>
<td>47212</td>
<td>47924</td>
<td>48646</td>
</tr>
<tr>
<td>2018</td>
<td>47057</td>
<td>47841</td>
<td>48659</td>
</tr>
<tr>
<td>2019</td>
<td>46865</td>
<td>47762</td>
<td>48675</td>
</tr>
<tr>
<td>2020</td>
<td>46688</td>
<td>47677</td>
<td>48686</td>
</tr>
<tr>
<td>2021</td>
<td>46506</td>
<td>47586</td>
<td>48690</td>
</tr>
<tr>
<td>2022</td>
<td>46316</td>
<td>47486</td>
<td>48685</td>
</tr>
<tr>
<td>2023</td>
<td>46127</td>
<td>47387</td>
<td>48680</td>
</tr>
<tr>
<td>2024</td>
<td>45943</td>
<td>47292</td>
<td>48680</td>
</tr>
<tr>
<td>2025</td>
<td>45741</td>
<td>47179</td>
<td>48661</td>
</tr>
<tr>
<td>2026</td>
<td>45540</td>
<td>47065</td>
<td>48640</td>
</tr>
<tr>
<td>2027</td>
<td>45322</td>
<td>46933</td>
<td>48601</td>
</tr>
<tr>
<td>2028</td>
<td>45097</td>
<td>46794</td>
<td>48554</td>
</tr>
<tr>
<td>2029</td>
<td>44862</td>
<td>46643</td>
<td>48493</td>
</tr>
<tr>
<td>2030</td>
<td>44605</td>
<td>46469</td>
<td>48409</td>
</tr>
<tr>
<td>2031</td>
<td>44338</td>
<td>46283</td>
<td>48312</td>
</tr>
<tr>
<td>2032</td>
<td>44058</td>
<td>46083</td>
<td>48199</td>
</tr>
<tr>
<td>2033</td>
<td>43767</td>
<td>45870</td>
<td>48072</td>
</tr>
<tr>
<td>2034</td>
<td>43466</td>
<td>45645</td>
<td>47932</td>
</tr>
<tr>
<td>2035</td>
<td>43147</td>
<td>45401</td>
<td>47771</td>
</tr>
<tr>
<td>2036</td>
<td>42813</td>
<td>45139</td>
<td>47591</td>
</tr>
<tr>
<td>2037</td>
<td>42470</td>
<td>44868</td>
<td>47399</td>
</tr>
<tr>
<td>2038</td>
<td>42122</td>
<td>44589</td>
<td>47198</td>
</tr>
<tr>
<td>2039</td>
<td>41764</td>
<td>44299</td>
<td>46985</td>
</tr>
<tr>
<td>2040</td>
<td>41398</td>
<td>43999</td>
<td>46760</td>
</tr>
</tbody>
</table>

For an application of METRONAMICA only input values considering future urban development are required, no statistical demographical values. However, the demand for urban space is influenced by the total number of residents. Considering a population of 47415 people and 935 ha urban area in 1997 (see Table 14, chapter 3.1.2), an average of 50.7 people per
hectare urban area can be calculated. In 2004, 48724 residents lived on 964 ha urban space, resulting in an average of 50.5 people per hectare. Based on these values, for the future a value of 50 people is assumed to live on one hectare urban space. These 50 ha take into account past space requirements and also future residential developments, as described in the following.

### 2.2.2 Residential developments

From the years 1980 to 2000 residential land use in the Netherlands has increased by a total of 14 % (Koomen and Groen 2004). Due to increasing prosperity demanding for bigger and second homes this growth is expected to continue in the future. The household size is expected to decrease to an average size of 2.3 people in 2010 (Gemeente Weert 2005). At the same time the amount of single- and 2-person households increases from now 34 % of all households, to 39 % in 2020 (see Table 5).

<table>
<thead>
<tr>
<th>Year</th>
<th>Total number of households</th>
<th>Average household size [no. of people]</th>
<th>Amount households with children [%]</th>
<th>Amount single households [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>20 170</td>
<td>2.4</td>
<td>39</td>
<td>27</td>
</tr>
<tr>
<td>2004</td>
<td>20 250</td>
<td>2.4</td>
<td>39</td>
<td>28</td>
</tr>
<tr>
<td>2005</td>
<td>20 300</td>
<td>2.4</td>
<td>38</td>
<td>28</td>
</tr>
<tr>
<td>2006</td>
<td>20 380</td>
<td>2.4</td>
<td>38</td>
<td>29</td>
</tr>
<tr>
<td>2007</td>
<td>20 510</td>
<td>2.3</td>
<td>37</td>
<td>31</td>
</tr>
<tr>
<td>2008</td>
<td>No data</td>
<td>2.3</td>
<td>37</td>
<td>34</td>
</tr>
</tbody>
</table>

Table 6: Planned new building projects in the municipality Weert, taken from Gemeente Weert (2007) and SatijnPlus Architects (2007)

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Amount</th>
<th>Time frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beekpoort</td>
<td>New apartments on a former industrial area</td>
<td>400 apartments</td>
<td>Building begin in 2009</td>
</tr>
<tr>
<td>Hornehoof Oudenakerstraat</td>
<td>New apartments, pharmacy and medical practice rooms</td>
<td>22 apartments</td>
<td>Building plan expected to be finished in 2008</td>
</tr>
<tr>
<td>Laarveld</td>
<td>Development of new residential area</td>
<td>250 apartments, 85ha</td>
<td>General planning approval in 2001, construction begins in 2008</td>
</tr>
<tr>
<td>Lambroek – Stamproy</td>
<td>New apartments and houses</td>
<td>9 apartments and 17 parcels for new houses</td>
<td>Planning approval in 2008</td>
</tr>
<tr>
<td>Stamproy – Walestraat</td>
<td>New apartments and houses</td>
<td>53 apartments and 7 parcels for new houses</td>
<td>Construction begins in 2007</td>
</tr>
<tr>
<td>Vrouwenhof</td>
<td>Building of new apartments</td>
<td>320 apartments</td>
<td>General planning approval in 2006, construction begins in 2008</td>
</tr>
<tr>
<td>Weert-Noord</td>
<td>Nursing and residential care home.</td>
<td>80 residential and 30 nursing apartments</td>
<td>Planning approval in 2007</td>
</tr>
<tr>
<td>Weert-Oost</td>
<td>Nursing and residential care home.</td>
<td>80 residential and 30 nursing apartments</td>
<td>Conceptual design in 2007</td>
</tr>
<tr>
<td>Weert-Zuid</td>
<td>Residential care home.</td>
<td>57 residential apartments and 5 living communities</td>
<td>Conceptual design not finished yet</td>
</tr>
</tbody>
</table>

In the future the current trend to choose for living in suburban areas will continue. Only singles that are working or studying prefer an urban environment (Gemeente Weert 2005). The residential developments will result in a slight rise of urban land-use, even though the population shrinks. The living space required by these developments is supplied by the
transformation of farm-land (pasture and agriculture) and abandoned stables remaining from
the zero-grazing sector (Koomen and Groen 2004).

Table 6 gives an overview of planned building projects within Weert. The projects are
sorted according to their status of realization from conceptual design to building begin. The
largest new residential living area is the Laarveld, an area of about 85 ha. Start of construction
is in 2008. Besides the Laarveld only smaller projects at the outskirts of urban areas are
planned. The municipality concentrates on redevelopment within the city centre. Outside
urban areas, defined as “red contours”, no further growth (residential and industrial) is allowed
(Province Limburg 2006). Exceptions are given only to developments that adapt to the
landscape and compensate their interference by realizing high quality nature and landscape
projects in the area.

2.2.3 Economical developments

With the publication of the latest spatial planning report in 2004, the Fifth Report on
Physical Planning (Vijfde Nota over de Ruimtelijke Ordening), the Dutch government offers
now more freedom to local municipalities to govern their rural areas. The report leads to more
opportunities for the creation of residential and commercial areas in regions where this was
formerly discouraged (Koomen and Groen 2004, 7). Also in Weert became the realization of
the new business park Kampershoek only possible due to the new planning report. For more
information on the Dutch planning system see also Annex II.

Weert’s economy is based mainly on the sectors agriculture and industry. Although
having a growing service sector industry is still the largest employer (Gemeente Weert
2002). Commercial land use (industry and retail) is expected to grow between 14 and 34 %
until 2020 (Koomen and Groen 2004, 7). Important locational preferences of businesses
include the accessibility to a sizable workforce and the proximity to highways (ibid). Weert’s
current inner city centre consists of many small shops and is functioning well. It is of
importance to the municipality that these existing shops are not endangered in the future.

Business park Kampershoek-North:

The municipality Weert is developing in the north-east a new business park, the
Kampershoek-North. The area is easy to reach by car, since it is situated close to an exit of the
national expressway A2. The entire area is in property of the project developers. At the
moment the area is still used as pasture, but construction is expected to begin by the end of
2008. Two possible perspectives exist considering future development on this area: the
Kampershoek-North will either be developed as a mix of light industry and retail or only
consist of modern mixed industry. In total about 50ha sales area is planned, with the smallest
shop size being about 1.000m² (Satijn Plus Architecten bv 2007). The final decision
depends also on future developments concerning the Moesdijk business park (see below). Expectations of the new retail are additional employment possibilities and close by shopping facilities, but especially shops owners in the city centre fear additional concurrence.

Business park Moesdijk-Roermondsestreet:

In the south of Weert, the business park Moesdijk-Roermondsestreet is located. The area consists now of a mix of light industry and retail, such as two hardware stores (Gamma and Praxis), a gas station, a car sale (Blankers), a horseback riding store (Hipoweert), a store for mechanical engineering (Numac), and a wholesale for food (Sligro). Also several vacant buildings and residential housing can be found. Most owners possess the land their enterprise is located on (SATIJNPLUS ARCHITECTEN BV 2007). The area is supposed to be redeveloped, either for retail or for industry. It is not possible for the municipality to develop two retail areas. A decision has to be made whether retail will move to the Kampershoek or to the Roermondsestreet. The final decision depends also on regional plans from Limburg considering the street network within the municipality (see chapter 2.2.6). Besides the Kampershoek also other new investments are planned, mainly redevelopment. Table 7 gives an overview of main economical developments.

Table 7: Planned projects regarding working and industry in the municipality Weert, taken from: GEMEENTE WEERT (2007) and SATIJNPLUS ARCHITECTEN (2007)

<table>
<thead>
<tr>
<th>Working and Industry</th>
<th>Location</th>
<th>Description</th>
<th>Amount</th>
<th>Time frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working and Industry</td>
<td>Location</td>
<td>Description</td>
<td>Amount</td>
<td>Time frame</td>
</tr>
<tr>
<td>Centrum Noord</td>
<td>Construction of new office buildings</td>
<td>12ha</td>
<td>Construction completed in 2015</td>
<td></td>
</tr>
<tr>
<td>Kampershoek-Noord</td>
<td>Development of the area for modern mixed industry, eventual also retail (choice will be made in 2008)</td>
<td>30ha</td>
<td>Construction completed between 2009 and 2015</td>
<td></td>
</tr>
<tr>
<td>Moesdijk</td>
<td>Redevelopment of the industrial area for retail or modern industry (choice will be made in 2008)</td>
<td>30ha</td>
<td>Redevelopment starting after 2008</td>
<td></td>
</tr>
<tr>
<td>De Kempen</td>
<td>Expansion of the area for mixed and modern industry</td>
<td>additional 20.5ha</td>
<td>Completed between 2009 and 2012</td>
<td></td>
</tr>
<tr>
<td>Leuken-Noord</td>
<td>Expansion of the area for mixed and modern industry</td>
<td>additional 4.3ha</td>
<td>Completed between 2009 and 2012</td>
<td></td>
</tr>
<tr>
<td>Kanaalzone I</td>
<td>redevelopment of the area, from which 15% will be made up of leisure and office buildings</td>
<td>40ha</td>
<td>Plan approval between 2008 and 2015</td>
<td></td>
</tr>
<tr>
<td>Savelveld</td>
<td>redevelopment of industrial area</td>
<td>25ha</td>
<td>Plan approval between 2008 and 2012</td>
<td></td>
</tr>
</tbody>
</table>

2.2.4 Employment developments

The total potential working population (20-64 years old) shrinks from 27,500 people today to 25,500 people in 2015 and finally to 22,500 people in 2030 (GEMEENTE WEERT 2005, 24). In the future a higher employment rate is expected within smaller companies in the service sector, and a decrease within the agricultural and industrial sector (ibid). The past employment development in Weert (from 1994 until 2006) is shown in Table 8. Until the year 2004 the employment rate rises; it starts to decrease in 2005.
Table 8: Employment in Weert. Number of employed people within agricultural, industrial, commercial and non-commercial sector (CBS 2008).

<table>
<thead>
<tr>
<th>Year</th>
<th>Agriculture</th>
<th>Industry</th>
<th>Commercial</th>
<th>Non-commercial</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>120</td>
<td>6930</td>
<td>6380</td>
<td>4200</td>
<td>18660</td>
</tr>
<tr>
<td>1995</td>
<td>100</td>
<td>6940</td>
<td>7290</td>
<td>3800</td>
<td>19250</td>
</tr>
<tr>
<td>1996</td>
<td>110</td>
<td>7290</td>
<td>7650</td>
<td>4810</td>
<td>21020</td>
</tr>
<tr>
<td>1997</td>
<td>190</td>
<td>7740</td>
<td>8060</td>
<td>5160</td>
<td>21150</td>
</tr>
<tr>
<td>1998</td>
<td>200</td>
<td>7800</td>
<td>9160</td>
<td>5380</td>
<td>22540</td>
</tr>
<tr>
<td>1999</td>
<td>210</td>
<td>8030</td>
<td>9310</td>
<td>5600</td>
<td>23150</td>
</tr>
<tr>
<td>2000</td>
<td>250</td>
<td>8390</td>
<td>9330</td>
<td>5260</td>
<td>23230</td>
</tr>
<tr>
<td>2001</td>
<td>210</td>
<td>8590</td>
<td>9820</td>
<td>6360</td>
<td>24980</td>
</tr>
<tr>
<td>2002</td>
<td>200</td>
<td>8420</td>
<td>9690</td>
<td>6820</td>
<td>25130</td>
</tr>
<tr>
<td>2003</td>
<td>210</td>
<td>7670</td>
<td>9210</td>
<td>6110</td>
<td>23200</td>
</tr>
<tr>
<td>2004</td>
<td>190</td>
<td>7590</td>
<td>9780</td>
<td>6060</td>
<td>23620</td>
</tr>
<tr>
<td>2005</td>
<td>200</td>
<td>7240</td>
<td>9910</td>
<td>6220</td>
<td>23570</td>
</tr>
</tbody>
</table>

2.2.5 Agricultural developments

Agriculture is the most dominant land use type in the Netherlands. In Weert it makes up 58% of the total area (61 km² from a total of 104 km²). Nonetheless a decrease of agricultural land in the Netherlands can be observed the past 10 years. It supplies space that is demanded by other functions, especially greenhouses, urban areas, water and nature (DE WIT 2003, 3). More than 50% of all land use changes in the Netherlands take place from agricultural area into urban. Additionally an increasing number of farmers started to provide land for wild plants and animals in exchange for financial compensation (KOOMEN and GROEN 2004) that caused another 15-20% change from agricultural land into nature and woodland (HAEU 2006, 4). At the same time that agricultural land decreases in size, its production increases through intensification possible by technological developments. These new inventions lead to more space efficient forms of agriculture and made space available for other uses (KOOMEN and GROEN 2004).

2.2.6 Transportation network developments

Through the municipality runs the national expressway A2 from Amsterdam via Eindhoven and Maastricht to Belgium, and two provincial roads: the N280 connecting to Germany and the N292 connecting to Belgium. In addition a train connects northwards to Eindhoven and eastwards to Roermond, and the IJzeren Rijn (railway tracks form 1839 that connected Antwerpen to Germany) connects to Belgium. Considering waterways is the Zuider-Willemsvaart channel a connection to the river Maas.

The total length of all streets is 603 km, from which municipal and water board roads make up 563 km, provincial streets 21 km and national ways 19 km (CBS 2005, 17). Figure 11 gives an overview of the amount of cars per day on Weert’s major streets.
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For the future an increasing use of the Roermondsestreet (N280) is expected, especially used by trucks as a shortcut to Germany instead of taking the national expressway A2. The regional municipality of Limburg decided to implement major changes on the N280 (PROVINCIE LIMBURG 2007a), see Figure 12. The N280’s section through the city of Weert currently leads along the business park Moesdijk. The street is however supposed to be redirected and leading south around the business park to counter steer raising traffic in the city centre (PROVINCIE LIMBURG 2007a). Shop owners of the Moesdijk that favour a redevelopment of the business park fear additional difficulties when this major access ceases to exist. The relocated N280 will touch nature protected areas and cross a residential living area.

Omitting a relocation of the N280, would lead however to a better entry into the city Weert. Besides the relocation of the N280, a solution would also be possible by increasing only the street’s safety. Proposed plans are the implementation of two new roundabouts, a tunnel under the railway tracks and a speed limit of 50 km/h.

![Figure 11: Main roads in Weert and load of traffic per day (PROVINCIE LIMBURG 2007a, 44)](image1)

![Figure 12: Relocation of the Roermondsestreet (N280) (PROVINCIE LIMBURG 2007a, 56)](image2)

2.2.7 Developments in recreation and natural and protected areas

The countryside is characterized by wind- and watermills, churches and old brick stone farmhouses. Mentionable is the protected Dutch-Belgian landscape Kempen-Broek, comprised
of marshland, swamps, brooks and streams. Due to an increasing prosperity the demand for recreational space in Weert will increase, similar to observed/expected developments in the rest of the Netherlands (Koomen and Groen 2004, 5). At this moment within the municipality 3 km² is available for recreational purposes, and another 25 km² for nature areas and forest (CBS 2005, 18). The municipality plans to increase the recreational areas by developing hiking and biking routes near the village Tungelroy.

2.2.8 Educational developments

Considering the residential development, especial families with children are potential new inhabitants for the municipality. Thus, schools (especially ground schools) are seen as important attractions for new residents. At the moment, 22 ground schools are located within the municipality. No major higher schools or universities are available, except the Bisschoppelijk College, the Koninklijke Militaire School and the Philips van Horne School. The first two schools plan to extend their campus.

2.3 Development scenarios

The following chapter comprises a short introduction into the topic of scenarios, followed by the presentation of different future development scenarios created for the municipality Weert. With the use of scenarios future states can be visualized and the decision making process be supported. The technique of creating scenarios was first developed in the 1960’s by H. Kahn and A. Wiener (Kahn and Wiener 1968). Scenarios can be divided into projective scenarios assessing current trends and processes, exploratory scenarios assessing alternative plausible futures, and normative scenarios assessing a desired future (Rounsevell and Henrichs 2008). One should point out that they are no predictions, forecasts or speculations, but help to understand and assess possible future situations. Their degree of uncertainty and complexity is moderate, compared for example to simple facts that are much lower in both complexity and uncertainty (Figure 13). Speculations in contrast, are much higher in complexity but also have a higher uncertainty.

![Figure 13: Complexity and uncertainty of facts, figures, projections, scenarios expectations and speculations compared to each other (Rounsevell and Henrichs 2008).](image)
Scenarios should be used within (landscape) planning when the consequences of different goals are unclear or the consequences of future developments should be visualized, e.g. when policy makers have difficulties to imagine future developments (Haaren 2004). Before developing scenarios, the status quo must be well known and described (as done in chapter 2.2). Then relevant influencing factors and alternative development possibilities must be defined. Finally, future projections can be described (ibid).

Scenarios should always be plausible, internal consistent and comprehensive. When developing them one has to cope with the major characteristics and challenges of credibility, saliency and legitimacy. Credibility aims at reducing uncertainty, meaning that the stakeholder's subjectivity must be addressed as well as, their biases and prejudice. The aspect of saliency is based on the participatory approach. Scenarios must be presented and communicated to stakeholders in an accessible manner. They should capture imagination while staying goal directed at the same time. Legitimacy should be ensured by designing transparent scenarios that are useful to stakeholders and policy makers (Roundell and Henrichs 2008).

Before presenting different scenarios for the municipality Weert, in the following driving development forces on land-use are presented: In general, population can be regarded as the major force for land consumption. In the future more people will be living in smaller households, demanding for more space for living and recreation (Tötzier 2008). Other influencing sectors are agriculture, forestry, tourism and energy. Policies affect these sectors and they also interact with each other (Jansson et al. 2008). Private land-use decisions, direct actions by governments and bio-physical conditions have less influence, but should also not be neglected.

### 2.3.1 Future development scenarios for Weert

Based on future expected developments for Weert (see chapter 2.2) the following paragraphs describe development scenarios for the municipality Weert. Because only land use functions can actively be modelled within Metronamica (see chapter 2.1.5), numbers and figures concentrate on these and leave out land use features and vacant states. The modelled functions include: grass in build up area, sparse natural vegetation, agriculture, forest, urban, peri-urban, industry and retail (more information in chapter 3.1.5). Three main scenarios are developed: a shrinkage scenario, a level-off scenario and a low grow scenario. Each scenario is divided into variants, one taking into consideration the Roermondsstreet (N280) in its state as today, and one in its modified version (see network map in Annex IV.6 and on the CD enclosed). Considering the grow scenario, two more variants are modelled including constraints regarding the development of retail and industry (see Table 9).
Table 9: Overview of the created development scenarios for the municipality Weert

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrinkage scenario</td>
<td>“Competition variant” with “N280 as is” and “N280 potential”</td>
</tr>
<tr>
<td>Low grow scenario</td>
<td>“Competition variant” with “N280 as is” and “N280 potential”</td>
</tr>
<tr>
<td></td>
<td>“Moesdijk retail” with “N280 as is”</td>
</tr>
<tr>
<td></td>
<td>“Kampershoek retail” with “N280 potential”</td>
</tr>
</tbody>
</table>

**Shrinkage scenario**

The shrinkage scenario will be modelled in the “competition variant”. A zoning map for industry and retail is introduced, allowing equal growth for both categories (see Annex IV.5 and digital on the CD). From 2008 on, new growth is permitted on the Kampershoek-north area, and after 2015 in the entire area of the municipality, except for protected natural areas. The competition variant will be modelled in version a) “N280 as is” and version b) “N280 potential”. The population growth as shown in Table 4 (low scenario) is used for calculating future urban development (see chapter 2.2.1), keeping in mind the expected residential developments in Weert and low-density housing, it is assumed that on average 50 people require 1 ha of urban space. All eight land use functions modelled within METRONAMICA and their spatial development from 2004 until 2040 are shown in Table 10. Main growth aspects are described in the following.

Table 10: Amount of hectare per land use function modelled within the shrinkage scenario.

<table>
<thead>
<tr>
<th>Land use functions</th>
<th>2004</th>
<th>2015</th>
<th>2030</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. cells</td>
<td>hectare</td>
<td>No. cells</td>
<td>hectare</td>
</tr>
<tr>
<td>Grass in build up area</td>
<td>9460</td>
<td>591</td>
<td>9280</td>
<td>580</td>
</tr>
<tr>
<td>Sparse natural vegetation</td>
<td>4207</td>
<td>263</td>
<td>4688</td>
<td>293</td>
</tr>
<tr>
<td>Agriculture</td>
<td>85059</td>
<td>5317</td>
<td>82480</td>
<td>5155</td>
</tr>
<tr>
<td>Forest</td>
<td>30872</td>
<td>1930</td>
<td>31056</td>
<td>1941</td>
</tr>
<tr>
<td>Urban</td>
<td>15433</td>
<td>964</td>
<td>16784</td>
<td>1049</td>
</tr>
<tr>
<td>Peri-urban</td>
<td>6411</td>
<td>401</td>
<td>6320</td>
<td>395</td>
</tr>
<tr>
<td>Industrial</td>
<td>4758</td>
<td>297</td>
<td>5552</td>
<td>347</td>
</tr>
<tr>
<td>Retail</td>
<td>145</td>
<td>9</td>
<td>192</td>
<td>12</td>
</tr>
</tbody>
</table>

- **Urban**: until 2015 the new-building project Laarveld is realized, making an additional 85 ha of residential urban area available in Weert. Afterwards the impact of population shrinkage becomes noticeable. According to the low population growth and based on the assumption of 50 people per ha, the urban area will shrink to 828 ha until 2040.
- **Peri-urban**: is first affected by a slight shrinkage of 0.5 ha per year until 2015, due to population decline and abandonment of farm buildings. Afterwards, the demand of peri-urban living rises, and in the period 2015-2030 an additional 5 ha emerge. But due to population decrease this demand lowers again by 11 ha until the year 2040.
- **Industry**: After 2008 the new industrial area of Kampershoek-North and extension of De Kempen take place, resulting in an additional 50 ha of industrial area. Afterwards the
municipality will stimulate slightly further industrial development in this area. Until 2030 additional 7 ha and until 2040 additional 5 ha are available for industrial development.

- **Retail**: With the realization of the Kampershoek, 3 ha of retail are realized between 2008 and 2015. Afterwards new development is possible, but no large-scale new projects will be planned. Until 2030 additional 1.5 ha and until 2040 one additional hectare retail develop.

- **Agriculture**: Based on land abandonment and intensification land used for agriculture shrinks continuously by 10 % until 2015 and then further 4 ha per year

- **Sparse natural vegetation**: Increasing abandonment of agricultural and residential land causes sparse natural vegetation to increase by 30 ha until 2015, then an additional 20 ha until 2030 and 10 ha until 2040.

- **Grass in build up**: Due to abandoned urban as well as peri-urban areas and infill development, grass in build up area will generally increase. Only until 2015 a decrease by 15 ha takes place, due to the new living area Laarveld. Increase takes then place after 2015 by 60 ha, as a result of urban shrinkage. Also between 2030 and 2040 an increase takes place, but with less intensity, resulting in an extra 15 ha.

- **Forest**: grows until 2015 slowly by 11 ha. In total this category grows by 300 ha from 2005 until 2040, developing on sparse natural vegetation or being planted on agricultural land.

**Level-off scenario**

Also the level-off scenario will be modelled in the “competition variant”. Again, urban development is based on population growth as shown in Table 4 (middle scenario). All eight land use functions modelled and their spatial development from 2004 until 2040 within the level-off scenario are shown in Table 11. Main growth aspects are described in the following.

- **Urban**: Also here the Laarveld project is realized until 2015, making an additional 85 ha of residential area available. Afterwards also here the impact of population shrinkage will be noticeable and the demand shrinks to 880 ha in 2040 (50 people on one hectare urban).

- **Peri-urban**: Even though the population declines and farm buildings will be abandoned, many people favour living in the urban fringe and pressure on peri-urban land is high. This land use class grows slightly by 1 % until 2040.

- **Industry**: The industrial area of Kampershoek-North and extension of De Kempen take place, resulting in an additional 50 ha of industrial area until 2015. Afterwards the municipality concentrates on infill development, but also new projects will be realized. New economical investments in the area will require 10 ha until 2030 and 7 ha until 2040.

- **Retail**: 3 ha of retail are realized until 2015. Then a growth of 3.5 ha until 2040 takes place.

- **Agriculture**: will shrink continuously. First by 8 % until 2015, then 3 ha per year based on land abandonment and intensification.
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- **Sparse natural vegetation**: will increase by 10 ha until 2015 and again 18 ha until 2040, based on abandoned agricultural and residential land.

- **Grass in build up**: increases mainly due to abandoned of former urban areas. Similar to the shrinkage scenario first this category decreases by 20 ha until 2015, and then increases by 45 ha until 2030 and additionally by 15 ha until 2040.

- **Forest**: Based on land abandonment forest grows about 150 ha until 2040.

### Table 11: Amount of hectare per land use function modelled within the level-off scenario.

<table>
<thead>
<tr>
<th>Land use functions</th>
<th>2004</th>
<th>2015</th>
<th>2030</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. cells</td>
<td>hectare</td>
<td>No. cells</td>
<td>hectare</td>
</tr>
<tr>
<td>Grass in build up area</td>
<td>9460</td>
<td>591</td>
<td>9136</td>
<td>571</td>
</tr>
<tr>
<td>Sparse natural vegetation</td>
<td>4207</td>
<td>263</td>
<td>4368</td>
<td>273</td>
</tr>
<tr>
<td>Agriculture</td>
<td>85099</td>
<td>5317</td>
<td>82992</td>
<td>5187</td>
</tr>
<tr>
<td>Forest</td>
<td>30872</td>
<td>1930</td>
<td>30960</td>
<td>1935</td>
</tr>
<tr>
<td>Urban</td>
<td>15433</td>
<td>964</td>
<td>16784</td>
<td>1049</td>
</tr>
<tr>
<td>Peri-urban</td>
<td>6411</td>
<td>401</td>
<td>6384</td>
<td>399</td>
</tr>
<tr>
<td>Industrial</td>
<td>4758</td>
<td>297</td>
<td>5552</td>
<td>347</td>
</tr>
<tr>
<td>Retail</td>
<td>145</td>
<td>9</td>
<td>192</td>
<td>12</td>
</tr>
</tbody>
</table>

**Low grow scenario**

The low grow scenario will be modelled for three variants. Once more the “competition variant” will be modelled, and in addition the variants “Moesdijk retail” and “Kampershoek retail”. Each variant will be introduced via zoning maps, allowing in case of the “Moesdijk retail” variant no growth of retail on the Kampershoek and respectively in the “Kampershoek retail” variant no growth of retail on the Moesdijk. All zoning maps can be seen in Annex IV.5 and in digital format on the CD enclosed. Urban development is based on the population growth as shown in Table 4 (high scenario), the eight land use functions and their spatial development until 2040 are shown in Table 12. Main aspects of the low growth scenario are described in the following.

- **Urban**: Again the Laarveld project (additional 85ha available urban land) is realized in 2015. The urban demand shrinks then to 880ha in 2040, based on demographical developments.

- **Peri-urban**: As a result of high pressure on peri-urban living, this category increases by 2%.

- **Industry**: The industrial area Kampershoek-North and extension of De Kempen take place, resulting in an additional 50 ha of industrial area until 2015. Afterwards the municipality concentrates on new projects. A total of 25 ha industrial area is available until 2040.

- **Retail**: Also 3 ha of retail are realized until 2015, and similar to industry a growth takes place by an additional 6 ha until 2040.

- **Grass on build up**: Within this scenario new industrial growth takes place, influencing grass on build up area. First shrinkage of 60 ha takes place. Then this category grows by 20 ha until 2030 and stays constant until 2040.

- **Sparse natural vegetation**: stays constant until 2015 and increases eventually by 7 ha until 2040 resulting from abandoned agricultural and residential land.
- **Agriculture**: shrinks due to intensification and abandonment by 8% until 2040. In this scenario the abandonment is highest, due to better jobs in the industrial sector and retail.

- **Forest**: also this category stays constant until 2015 and grows eventually by 100 ha until 2040. This scenario has the lowest growth rate, because available land will be taken over by industry and retail.

Table 12: Amount of hectare per land use function modelled within the low grow scenario.

<table>
<thead>
<tr>
<th>Land use functions</th>
<th>2004</th>
<th>2015</th>
<th>2030</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. cells</td>
<td>hectares</td>
<td>No. cells</td>
<td>hectares</td>
<td>No. cells</td>
</tr>
<tr>
<td>Grass in build up area</td>
<td>9460</td>
<td>591</td>
<td>8496</td>
<td>531</td>
</tr>
<tr>
<td>Sparse natural vegetation</td>
<td>4207</td>
<td>263</td>
<td>4208</td>
<td>263</td>
</tr>
<tr>
<td>Agriculture</td>
<td>85069</td>
<td>5317</td>
<td>82992</td>
<td>5187</td>
</tr>
<tr>
<td>Forest</td>
<td>30872</td>
<td>1930</td>
<td>30880</td>
<td>1930</td>
</tr>
<tr>
<td>Urban</td>
<td>15433</td>
<td>964</td>
<td>16784</td>
<td>1049</td>
</tr>
<tr>
<td>Peri-urban</td>
<td>6411</td>
<td>401</td>
<td>6456</td>
<td>403.5</td>
</tr>
<tr>
<td>Industrial</td>
<td>4758</td>
<td>297</td>
<td>6384</td>
<td>399</td>
</tr>
<tr>
<td>Retail</td>
<td>145</td>
<td>9</td>
<td>192</td>
<td>12</td>
</tr>
</tbody>
</table>

2.3.2 **Summary**

An overview of all scenarios and their variants can be taken from Table 9, a comparison of growth or decline per land use function is shown in Table 13. The final amount of hectare per land use function in the final simulation year 2040 is shown in Figure 14.

Table 13: Development of each land use function modelled per scenario.

<table>
<thead>
<tr>
<th>Land use function</th>
<th>Shrinkage scenario</th>
<th>Level-off scenario</th>
<th>Low grow scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass in build up area [%]</td>
<td>+11%</td>
<td>+7%</td>
<td>-7%</td>
</tr>
<tr>
<td>Sparse natural vegetation [%]</td>
<td>+29%</td>
<td>+11%</td>
<td>+3%</td>
</tr>
<tr>
<td>Agriculture [%]</td>
<td>-6%</td>
<td>-4%</td>
<td>-3%</td>
</tr>
<tr>
<td>Forest [%]</td>
<td>+14%</td>
<td>+8%</td>
<td>+5%</td>
</tr>
<tr>
<td>Urban [%]</td>
<td>-15%</td>
<td>-9%</td>
<td>-3%</td>
</tr>
<tr>
<td>Peri-urban [%]</td>
<td>-3%</td>
<td>+1%</td>
<td>+2%</td>
</tr>
<tr>
<td>Industrial [%]</td>
<td>+21%</td>
<td>+22%</td>
<td>+43%</td>
</tr>
<tr>
<td>Retail [%]</td>
<td>+54%</td>
<td>+71%</td>
<td>+99%</td>
</tr>
</tbody>
</table>

Figure 14: Comparison of the final amount of cells per scenario.
3 Methodology

3.1 Setting up a new application

The METRONAMICA framework requires a considerable amount of data when setting up a new model application. The following chapter introduces all input datasets and variables, as well as their constraints needed to set up the application for Weert. The datasets include: land use maps for the start- and end year of the calibration period, base maps for creating zoning and suitability and a transportation network.

3.1.1 Temporal extend

The modelling is carried out from the year 2004 on up to the year 2040, according to available statistical data for the municipality Weert (demographic and economic developments). Each modelling step represents one year.

3.1.2 Spatial scale

In cellular automata, the spatial scale is defined by three components: spatial extent, cell size, and neighbourhood configuration. All three aspects are described in the following.

Spatial extent

The spatial extent refers to the dimension of the area that is modelled. For the study at hand, a so called single layer mode was chosen. From a total of three possible modelling levels only two are taken into consideration: the global and the local level. The global level consists of one area: the municipality Weert. The local level consists of a constrained cellular automaton. Because the modelling area is quite small and homogeneous without having significant regional inequalities, no regional level was included. Due to the single layer mode only spatial data forms essential input (see chapter 2.1.5), but statistical data is also helpful.

Cell size

The cell size specifies what area of the landscape each cell is going to cover. Cell sizes vary from 100 x 100 m or less to almost 1 km x 1 km. The cell size used in this application is 25 x 25 m. Most other applications of METRONAMICA use a cell resolution of at least 100 x 100 m as a compromise between computing speed and having cell sizes similar to natural land use units (RIKS bv 2007). An application at a 25 m resolution may face unknown hindrances, but it is also interesting to see what results will be obtained and how the model behaves. A more detailed discussion of the cell size can be found in chapter 5.
Neighbourhood

The neighbourhood configuration determines the distribution and number of neighbours that will have an impact on the evolution of each cell. Neighbourhood configurations are mainly circular approximations and range in size from the Moore neighbourhood (one-cell radius, see Annex I.1) to a 196-cell neighbourhood (eight-cell radius) (MÉNARD and MARCEAU 2005). Li et al. (1990) found that, when more neighbours are involved in updating each cell, cell values become increasingly sensitive to cells at larger distances and this increased interdependence among cells makes random dynamics more likely. The current tendency in cellular automata is clearly leaning towards extended neighbourhoods. The justification behind these larger neighbourhoods lies in the geographic influence of land-use states and local actors (MÉNARD and MARCEAU 2005).

Hence, two types of neighbourhood are applied within this study: The 8-cell neighbourhood is based on a radius of 8 cells, also including the cell itself. It consists thus of 196 cells. As the cell size used for this application will be 25 m, it means that the maximum neighbourhood distance is 200 m. This neighbourhood is integrated into the standard version of METRONAMICA. The 16-cell neighbourhood is based on a radius of 16 cells, again including the cell itself; with its maximum neighbourhood distance of 400 m. This neighbourhood is not integrated into the standard application. The program had to be changed for this application.

3.1.3 Region map

By making use of the region map, METRONAMICA differentiates between the boundaries of the modelled and the un-modelled area. Important to know is that the licence file is coupled to the region map. For METRONAMICA most licences are sold per region, making it impossible for the user to model any other arbitrary area. The region map is a categorical map in ASCII file format. The modelled area (municipality of Weert) is represented by the value 1, the un-modelled area by the value 0. When having an application with multiple regions, for example a country divided into four regions, each region receives a value from 1 to 4 and the out of modelling area the value 0. In this case the region map is also used within the regional model of METRONAMICA.

3.1.4 Land use

Basis of the land use maps applied in this application of METRONAMICA is the Dutch “National Land Cover Database” LGN (Landelijk Grondgebruiksbestand Nederland, see Annex III.1 and a map in Annex IV.2, as well as in digital format on the data CD). The dataset is delivered in raster format with cell sizes of 25 x 25 m. For calibration purposes two versions of the LGN were used: the LGN3 from 1997 and the LGN5 from 2004. Because the
dataset does not include industrial areas, it was joined with the “Land Use Base of Statistics Netherlands” - BBG (Bestand Bodem Gebruik) from the year 2000 (see Annex III.2 and a map in Annex IV.3, as well as in digital format on the data CD). The BBG is delivered in shapefile format and was transformed into raster data. The dataset does not differentiate between differences in industrial areas and retail. The category “retail” had to be digitized manually, based on expert knowledge from SATIJNplus Architecten and the municipality Weert.

The land use maps for 1997 and 2004 were created in ArcGIS, saved as ASCII raster files and inserted into METRONAMICA (both land use maps are shown in Annex IV.4 and in digital format on the CD enclosed). Each raster cell is assigned one known value between 0 and 11. The model uses these values to differentiate between the 12 different land use classes. For the application at hand values were assigned as shown in Table 14: bare soil = 0, nature = 1, grass in build up area = 2 etc. When setting up a new simulation, the user decides which land use categories are vacant states (can be taken over by land use functions or becomes available when the total amount taken in by land use functions declines), land use functions (changing actively) or land use features (staying constant). For the application at hand, two vacant states, eight functions and two features were introduced (see chapter 2.1.5). Each land use category was then defined with reference to HAEZU (2005):

0. **Bare soil**: bare soil in built-up area, consisting mostly of mining areas, extraction sites and construction pits.
1. **Nature**: heathland, shifting sands and nature areas with little or no vegetation cover.
2. **Agriculture**: agricultural crops (maize, potatoes, sugar beet, cereals) including greenhouses, orchards, horticulture, tree nurseries and flower bulb cultivation, and grasslands within the stratum agriculture used for agricultural production.
3. **Grass in built-up area**: grass-cover areas within the built-up or urban areas: parks, sport facilities, recreational areas, etc.
4. **Sparse natural vegetation**: open nature areas consisting mostly of natural grasslands.
5. **Forest**: coniferous and deciduous forest, as well as forest within built-up areas such as parks and recreation areas, and strips of forest along roads and highways.
6. **Urban**: continues urban area including minor roads, narrow canals and small parks.
7. **Peri-urban**: buildings outside the urban areas, but with no agricultural function, such as sewage treatment plants, buildings in recreation areas, power stations. Furthermore, also forest with dense buildings (areas that cannot be discriminated from a forest on the basis of the satellite imagery, but which had a large number of interspersed buildings and thus had to be classified as an urban class) and buildings in agricultural areas.
8. **Industrial**: industrial areas and business parks.
9. **Retail**: selling of goods or merchandise (see “GDV” in Annex II).
10. **Roads**: main roads and railways.

11. **Water**: fresh water.

Table 14: Included land use classes, organized according to their type of being vacant, function or feature, and their amount in 1997 compared to 2004.

<table>
<thead>
<tr>
<th>Land use category</th>
<th>Value</th>
<th>Land use 1997</th>
<th>Land use 2004</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vacant land uses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bare soil</td>
<td>0</td>
<td>271</td>
<td>330</td>
<td>+ 3.96 ha (59 cells)</td>
</tr>
<tr>
<td>Nature</td>
<td>1</td>
<td>4487</td>
<td>4099</td>
<td>- 24.31 ha (388 cells)</td>
</tr>
<tr>
<td><strong>Land use functions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass in build up area</td>
<td>2</td>
<td>8925</td>
<td>9459</td>
<td>+ 53.38 ha (534 cells)</td>
</tr>
<tr>
<td>Sparse natural vegetation</td>
<td>3</td>
<td>2684</td>
<td>4207</td>
<td>+ 15.23 ha (1523 cells)</td>
</tr>
<tr>
<td>Agriculture</td>
<td>4</td>
<td>88278</td>
<td>95059</td>
<td>- 201.19 ha (3219 cells)</td>
</tr>
<tr>
<td>Forest</td>
<td>5</td>
<td>30909</td>
<td>30872</td>
<td>+48.87 ha (782 cells)</td>
</tr>
<tr>
<td>Urban</td>
<td>6</td>
<td>14967</td>
<td>15433</td>
<td>+ 46.66 ha (466 cells)</td>
</tr>
<tr>
<td>Peri-urban</td>
<td>7</td>
<td>6239</td>
<td>6411</td>
<td>+ 17.82 ha (172 cells)</td>
</tr>
<tr>
<td>Industry</td>
<td>8</td>
<td>4350</td>
<td>4758</td>
<td>+ 25.88 ha (408 cells)</td>
</tr>
<tr>
<td>Retail</td>
<td>9</td>
<td>145</td>
<td>145</td>
<td>+/-. 0 ha (0 cells)</td>
</tr>
<tr>
<td><strong>Land use features</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>10</td>
<td>1866</td>
<td>1974</td>
<td>+ 6.75 ha (108 cells)</td>
</tr>
<tr>
<td>Roads</td>
<td>11</td>
<td>6054</td>
<td>5606</td>
<td>- 2.88 ha (448 cells)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>168353</td>
<td>168353</td>
<td>+/-. 0 ha (0 cells)</td>
</tr>
</tbody>
</table>

### 3.1.5 Zoning

For the land use functions urban, peri-urban, industry and retail one zoning map was created, based on planning documents available from the municipality Weert and public authorities in Limburg. The zoning includes ecologically valuable areas (natural habitats and of wild fauna and flora), redevelopment areas and extension areas for industry and living.

All zoning maps were created in ArcGIS and again introduced as ASCII raster files into METRONAMICA. The ASCII file contains the values 0, 1, 2 and 3, allowing this way to include also a temporary aspect. On raster cells assigned with a 0, growth is permitted from 2004 on (begin year of modelling period). On cells with the value 1 growth is permitted only from 2008 on, with a value 2 from 2020 on and on cells with a value 3 no growth is allowed (protected areas). Zoning maps for industry and urban can be found in Annex IV.5. For each scenario variant as described in chapter 2.3, a new zoning map for the land use features industry and retail was introduced. For the land use functions grass in build up area, sparse natural vegetation, agriculture and forest no zoning is introduced. The first two categories do not underlie any zoning, they emerge anywhere under low human influence and land abandonment. Agriculture will decrease in the future, and unwanted growth in the future can be assumed to be irrelevant. No planning documents prohibiting agriculture in certain areas exist. Also forest will grow slightly, but again no areas in Weert are known where the growth of forest is explicitly unwanted.
3.1.6 Suitability

Within the modelling environment of METRONAMICA suitability can be implemented for each land use functions. Because no significant elevation, wet ground or other hindrances are known in this area, it is assumed that all land use functions are able to emerge or can be realized by humans with the use of techniques at any place in the modelling area.

3.1.7 Accessibility

The accessibility (transportation network) is based on the land use base of Statistics Netherlands, BBG from 2000 and the city map of Weert. Streets and railroads were copied from the BBG. They were however only available as polygons and lacked any differentiation between their feature type (railroad, highway, provincial way etc.). The streets first had to be selected from the BBG dataset, were then changed into line features and finally manually edited. The procedure was quite time consuming, but no other transportation dataset was available. Also the point features (highway exit, station and schools) were manually digitized, based on the city map of Weert (FALKPLAN BV 2005). Schools, that are actually not part of the transportation network as usually known, are also included. Reason for this decision is that all accessibility features attract certain land use types. For urban and peri-urban development schools are seen as important factors in the future attracting new residents. All transportation network features used within this application are shown in Table 15. METRONAMICA requires the transportation network to be in shapefile format, with a numerical attribute field “AccType”, containing the values 0, 1, 2 until 6. Each accessibility type is assigned one value, which METRONAMICA uses to differentiate between the types of transportation. A map of the applied network can be seen Annex IV.6.

Table 15: Transportation network types (line and point features) used within the application.

<table>
<thead>
<tr>
<th>Accessibility type (line)</th>
<th>Name (if applicable)</th>
<th>Speed [km/h] (if applicable)</th>
<th>AccType</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal road</td>
<td></td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Provincial street</td>
<td>N280, N292</td>
<td>50</td>
<td>1</td>
</tr>
<tr>
<td>National expressway</td>
<td>A2</td>
<td>120</td>
<td>2</td>
</tr>
<tr>
<td>Railroad</td>
<td>Spoorlijn Eindhoven-Roermond and IJzeren Rijn</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Accessibility type (point)</td>
<td>Name (if applicable)</td>
<td>Amount occurring</td>
<td></td>
</tr>
<tr>
<td>Exit expressway</td>
<td>Weert Noord, Nederweert, Kelpen</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Railway station</td>
<td>Station Weert</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Schools</td>
<td>Ground schools</td>
<td>22</td>
<td>6</td>
</tr>
</tbody>
</table>
3.2 Model calibration

The key component of any modelling process is the one of calibration, referring to the process by which numerical values are assigned to model parameters in such a way that the model accurately reproduces patterns similar to those in reality (Silva and Clarke 2002, 529). The calibration period of the model was a period of seven years starting from 1997 until 2004. The model was calibrated to receive as much resemblance as possible between the actual land use map of 2004 and the simulated map for 2004. First the model is run with initial conditions given by the land use map from 1997. The simulated model output for the year 2004 is then compared with the land use map from 2004. The heart of the calibration is then to find such a set of parameters, that each cell changes similar as it would in reality (Straatman et al. 2004, 154). On the basis of differences between the two maps, parameters are adjusted to improve the match of the simulated and the real map for 2004 (White 2006). These parameters are found by means of an iterative converging approach. After successful simulation of the historic land use change, the model is run into the future.

3.2.1 External model drivers

The macro model determines the demand for land use and consists of a set of trend lines, one for each land use function. Each trend line represents the demand for one land use function over time, represented by the function's total number of cells. As vacant land use states are passive, they have no demand and are left out. Also land use features do not change during the simulation and also hence have no demand or transition potential.

![Example trend lines for the land use functions agriculture and pasture, peri-urban and rural, industry, and retail, taken from the shrinkage scenario.](image)

Figure 15: Example trend lines for the land use functions agriculture and pasture, peri-urban and rural, industry, and retail, taken from the shrinkage scenario.
Four example trend lines are shown in Figure 15. The number of cells from one land use function (for example industry) must mandatory be entered once at the simulation begin year and once at the simulation end year. The fist value depends on the occurring cells per land use function in the land use map from the begin year (in this case 2004). The last value has then to be entered depending on estimated future development. It is possible to enter as many intermediate steps as needed. This allows for example also the insertion of growth in the beginning of the simulation period and shrinkage in the later years. The simulation is forced to match the inserted cell numbers, implementing these constraints into the cellular automaton.

In order to model scenarios with METRONAMICA the trend lines where changed according to the development scenarios as described in chapter 2.3.1. The values presented in Table 10, Table 11 and Table 12 were first transformed into the correct amount of cells (1 ha = 16 cells) and then entered into the macro model.

### 3.2.2 Neighbourhood transition rules

For each land use function a set of neighbourhood rules (implemented by means of linear splines) had to be calibrated. Each spline determines the degree to which a function is attracted to or repelled by other vacant states, functions or features. The spline is actually a sum of weights, which are calculated by a function of distance relative to all other land use functions, features and vacant states. If the attractiveness is high enough, the function will occupy a certain cell. If the attractiveness is too low, the function will look for more attractive cells to occupy. Each spline is defined by a set of points having the following properties:

- An inertia value is always given on the x-axis at value 0. The inertia is then set by a value on the y-axis. It determines the strength of a land use to remain at a certain location once it is allocated and also its strength to take over another land use. If set negative, it accounts for the repulsion of a function to other land uses.
- The second point must be located at distance 1 on the x-axis. It determines how strong a function takes over neighbouring land uses. If set negative, the land use is repelled.

An arbitrary amount of points can be set between the second and the last point. Again, points can be negative or positive, according to attraction or repulsion. The spline can also be in the beginning attractive and later repulsive or the other way around (retail for example clusters, but is repelled by other retail in the distance, being this concurrence) (RIKS bv 2007).

When calibrating METRONAMICA, WHITE and ENGELEN (2003) recommend as a first step the qualitative calibration of these neighbourhood rules, starting with the basic generic forms of rules as shown in Table 16.

The calibration process involves editing the different splines for land use functions aiming to arrive at a calibration that simulates the real large scale land use patterns correctly.
While calibrating the neighbourhood rules it is also important to keep the “truth of the rule” in mind. This means that if no interaction can be found between two land uses, also no rule should be introduced. In order to investigate interactions between land uses, the two land use maps from 1997 and 2004 have to be numerically and visually compared to each other.

At this point, no suitability, accessibility and zoning should be included. Instead a value of 1 is used creating a homogenous cell space, as these components are calibrated later. Because it is important that all rules represent real development, one should be able to phrase them out. All neighbourhood rules are written out and can be found with images of their implemented splines in Annex V.

### 3.2.3 Accessibility parameters

Considering the accessibility, several parameters had to be calibrated for each land use function. A screenshot of the input mask is shown in Figure 16. Implicit accessibility refers to
the fact that certain land use functions consist of transportation features which are not included in the network map. For example urban areas consist of many small streets that are not found in the network dataset. The implicit accessibility ranges from $0 = \text{no accessibility}$ to $1 = \text{full accessibility}$. It is subdivide for build-up and non build-up area. In Figure 16 an example is shown for peri-urban areas. So is for build up areas a value of 1 inserted, assuming that peri-urban areas are always connected to a road. For non-build up areas a value of 0.5 is entered, assuming that most likely new build peri-urban areas will have a road connection. Explicit accessibility can be chosen if the land use is impassable, for example glacial areas or water. This parameter was not needed within the application at hand.

Accessibility to links and nodes is subdivided into relative importance and distance decay. Relative importance ranks all existing transportation features on a scale of $0 = \text{unimportant}$ to $1 = \text{important}$. In the example were municipal roads seen as important (value 1) and provincial roads as fairly important (value 0.8). Railway stations are unimportant (value 0), assuming that people living in peri-urban areas do not require a station to be close by. People tend to move close to schools, that makes them fairly important (value 0.5).

The distance decay determines how fast the importance lessens. Expressway exits attract also people living distant to them and their influence of 1 is divided into half only after 100 cells. Municipal roads in contrast lose their influence fast. Their importance is dived into half already after 10 cells, assuming that people require municipal roads to be close by and won’t likely move to areas without connection. The distance decay can also be negative, for example for expressways and railway tracks. Negative values in the example assume that people do not want to live close by a noisy road or rail track. The accessibility parameters were defined for every land use feature. For graphical purposes, the parameters can also be
visualized by means of accessibility background maps. Two more examples of accessibility parameters with their computed accessibility backgrounds can be found in Annex IV.6 and in digital format on the data CD.

3.2.4 Random parameter α

Calibration of METRONAMICA also involves finding suitable values for the parameter $\alpha$, which controls the magnitude of the random perturbation factor (see chapter 2.1.5.). This parameter accounts for random developments that may also occur in reality. With the neighbourhood rules it is for example possible to simulate repulsion of urban to industry. However there may always exist people that actually do start building houses nearby industrial areas. Hence, this factor allocates land uses randomly over the modelling area. It also influences the “blobbyness” of the simulated land use map. The factor varies from $0 = \text{no randomness}$, blobby simulation result, to $1 = \text{high randomness}$, no blobby results. For this application of METRONAMICA a value $\alpha$ of 0.6 was calibrated for achieving best results.

3.3 Model validation

In the case of validation, the process is similar to calibration the simulated map from 2004 should match the real land use map from 2004 as close as possible. Calibration refers to the process of creating a model such that it is consistent with the data used to create the model (VERBURG et al. 2006, 130). But within validation, the comparison of the two maps is done with the aim of discovering to what degree and in what ways the model captures the processes that shape the actual landscape (WHITE 2006). It is therefore the process of measuring the model prediction and independent data. Usually, the data available should be split into two subsets, the calibration data and the validation data. In many model applications validation is lacking due to lack of good datasets and appropriate validation techniques (VERBURG et al. 2006, 131). Similar, was this application of METRONAMICA lacking sufficient datasets. It was not possible to split the data into two parts. Hence, actually a goodness-of-fit of calibration was carried out instead of a goodness-of-fit validation. Two measures are applied in the following, keeping in mind the aspects of “goodness of fit” (how similar two maps are) and “simulated patterns” (how realistic the modelled outcome is, even though cell clusters may be different). For an assessment of the results the Map Comparison Kit (MCK) was used (HAGEN-ZANKER et al. 2006). This tool visualizes differences between two maps and calculates statistics.
3.3.1 Cellular level validation

On the cellular level only the 'goodness of fit' will be assessed, because cellular patterns are not visible when carrying out a single cell-by-cell comparison. For this validation the Kappa index will be consulted, calculated with the MCK. Kappa expresses the level of agreement between two maps in one single number, ranging from -1 (not identical) to 1 (identical), and 0 is what is expected by chance.

Kappa, however, confounds similarity in quantity with similarity of location. To overcome this problem, two additional types of similarity are calculated: the one of location and the one of quantity. 'Location' in this sense depends to the spatial distribution of the different categories on the map and is expressed as $K_{Loc}$. 'Quantity' depends on the total number of cells taken in by each category found in the legend (in other words: the histogram). It is expressed by the value $K_{Hist}$. (HAGEN-ZANKER et al. 2006). As a rule is: $K_{Hist} \times K_{Loc} = Kappa$. Besides, also a categorical Kappa is independently calculated for each land use category. For this categorical Kappa the two input maps (1997 and 2004) are first transformed to one map consisting of only two categories. The first category is the category for which the individual kappa statistic is derived. The second category is the combination of all other categories (HAGEN 2002b). Then the Kappa is calculated for the first category, resulting in an indication for each land use class.

Random Constrained Match map (RCM)

When having calculated the Kappa, the challenge remains in interpreting the obtained values. For instance a Kappa value of 0.81 might be found, but the question remains what that value of 0.81 signifies. As a solution to this problem, an additional map is created with the Random Constraint Match tool (RCM) available in the MCK. The random constraint match model finds locations of change randomly and evolves towards a 'speckled' map of small clusters (HAGEN-ZANKER and LAJOIE 2008). In other words, it creates a new map by minimally adjusting the original map from 1997, giving it the same frequency distribution of the categories as occurring in the map from 2004. The cells of the 2004 map that are modified are selected randomly. First decreasing land use is identified, then removed and randomly filled with increasing land use. Thus, it interprets the frequency distribution of the 2004 map as constraints and imposes these constraints by randomly modifying the 1997 map, but only as little as strictly necessary (HAGEN-ZANKER and LAJOIE 2008). The RCM map is then compared to the real known land-use map from 2004. If the Kappa “RCM map – land use map 2004” is lower than the Kappa “simulated map 2004 – land use map 2004”, this part of the calibration is successfully, since it shows that the model is able to perform well on a cellular level.
3.3.2 Global level validation

For measuring polygons on the global level, Zipf’s law will be made use of. It describes a relation between the size of urban cell-clusters and their rank (amount of appearance). The law is based on the theory that the most frequent value (the smallest urban cell cluster) will occur approximately twice as often as the second most frequent value, which occurs twice as often as the fourth most frequent value, etc. In other words, the frequency of urban cell cluster of a certain size is logarithmic proportional to their rank (number of cells belonging to the cluster). Zipf’s law is true for northern European landscapes. Few large clusters can be found (larger cities), some medium sized, but most clusters occurring are small (towns). When plotting this relationship, a graph as shown in Figure 17 should be created.

For the application at hand, three graphs are created: one for the land use map 1997 and one for the land use map 2004. Then, the simulation will be run from the land use map 1997 a total of 50 years into the future, resulting into a simulation map for the year 2047. The graph for calculated for the year 2047 is used as reference graph. After 50 years it becomes possible to evaluate if the transition rules are set in such way that the simulation captures urban dynamics in the area. For the creation of the graph, all three maps are reclassified into the two categories urban and other, allowing then to extract only urban clusters. With the help of the Map Comparison Kit are the amount and size of all urban clusters extracted. The cluster sizes are then be plotted against the rank on a logarithmic scale. If the graph resembles the one as shown in Figure 17, the calibration can be seen as successful (WHITE 2006).

Figure 17: Zipf’s law and examples of cell cluster sizes. Only few large cell clusters, but many small clusters (consisting of one cell) exist.
4 Results

The following chapter present results obtained during the modelling process. First, distinctions between the land use maps are shown, followed calibration results, and simulation results for each scenario developed. Also results considering the differences between the 8-cell and 16-cell neighbourhood are shown.

4.1 Distinctions between the land use maps 1997 and 2004

When comparing the two land use maps from 1997 and 2004 it could be seen that agriculture is the land use function that decreased most (-3219 cells) and sparse natural vegetation the function that increased most (+1523 cells) (see Table 14 in chapter 3.1.4). No changes were occurring within retail, based on the fact that the same amount of cells was manually added on both maps. Changes within water and roads are result from differences in the LGN map making procedure (see Annex III.1).

Because it is not possible to deviate from this comparison to which new class the land uses were changing, a contingency table was consulted\(^3\) (Table 17). In both maps belong 84349 cells to agriculture and 14935 cells to urban. A total of 1107 cells that were agriculture in 1997 changed to sparse natural vegetation in 2004 and another 1469 cells changed into forest. The increase of 346 cells from road to agriculture results from differences in the map making procedure. Forest mainly increased on agriculture and urban cells. Grass in build up area changed to urban in 2004. Also peri-urban cells emerged on land previously occupied by agriculture: 361 agricultural cells from 1997 changed into peri-urban, but also the other way around – 135 cells that were peri-urban in 1997 became agriculture in 2004. Probably these deviations are based on classification mistakes too. Industry and retail were digitized manually and hence no variances are shown. For the visual comparison the MCK was made use of. Only the four land use functions peri-urban, urban, forest and agriculture are shown in this example (see Figure 18). Based on the visual comparison was it now also possible to locate the changes and to investigate certain patterns or connections. Each picture shows the municipality Weert and areas in four colours: green areas show the presence of one land use category in both years, red only in 1997 and blue only in 2004.

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\(^3\) A contingency table (or confusion matrix) is used to record and analyse the relationship between two or more variables, in this case two land use maps from different years. It details how the distribution of land use categories in map A (1997) relates to that of map B (2004). Each cell in the table contains a value which is the number of the cells in the particular map. The fraction is taken in the 1997-map by the category specified in the matrix row, and in the 2004-map by the category specified in the matrix column (HAGEN, 2002b). On the diagonal (highlighted in dark grey) the number of cells belonging in 1997 and 2004 to the same land use function can be seen.
Chapter 4 - Results

Legend:
- in none of the maps
- in both maps
- only in map 1, not in map 2
- only in map 2, not in map 1

a) Peri-urban:
If surrounded or adjacent to urban, does peri-urban change to urban (red spots in the north).
New cells emerge on agriculture adjacent to existing peri-urban cells. Generally only very few changes.

b) Urban:
Mainly activation of empty housing units, only few sprawl (blue spots in inner city).
New cells emerge on the categories "grass in build up area" and "agriculture".
Partly taken over by industry (red spots in city centre).

c) Agriculture:
Increase of cells based mainly on differences in classification procedure, entire express way is classified different within the LGNS5 (blue strip in the north).
Decrease of cells mainly due to changes into forest or sparse natural, smaller areas also into nature (red spots)
At the outskirts of the city Weert changes agriculture into grass in build up area.

d) Forest
New cells emerge mainly on agriculture, and grass in build up area, adjacent or close to existing forest cells (blue areas).
One exception is the decrease of forest, indicated by a large, square-shaped spot in the west (red square). Here were trees cut down for a new mining area.

Figure 18: Visual comparison of the functions peri-urban, urban, agriculture and forest with the MCK.
Table 17: Contingency table from the land use maps 1997 and 2004

<table>
<thead>
<tr>
<th>Eventual</th>
<th>Bare soil</th>
<th>Nature</th>
<th>Sparse natural vegetation</th>
<th>Grass in build up area</th>
<th>Agriculture</th>
<th>Forest</th>
<th>Urban</th>
<th>Peri-urban</th>
<th>Industry</th>
<th>Retail</th>
<th>Water</th>
<th>Roads</th>
<th>Total 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>Bare soil</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>Nature</td>
<td>4038</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sparse nat. veg.</td>
<td>432</td>
<td>2666</td>
<td>0</td>
<td>1107</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4207</td>
</tr>
<tr>
<td></td>
<td>Grass build up</td>
<td>201</td>
<td>0</td>
<td>8299</td>
<td>784</td>
<td>93</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>81</td>
<td>9460</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agriculture</td>
<td>0</td>
<td>0</td>
<td>84349</td>
<td>229</td>
<td>0</td>
<td>135</td>
<td>0</td>
<td>0</td>
<td>346</td>
<td>85059</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Forest</td>
<td>1</td>
<td>0</td>
<td>1469</td>
<td>29334</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>36</td>
<td>29</td>
<td>30872</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>10</td>
<td>0</td>
<td>349</td>
<td>37</td>
<td>2</td>
<td>14935</td>
<td>98</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>15433</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peri-urban</td>
<td>1</td>
<td>11</td>
<td>17</td>
<td>5999</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>26</td>
<td>6414</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Industry</td>
<td>0</td>
<td>12</td>
<td>69</td>
<td>88</td>
<td>2</td>
<td>4288</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4759</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Retail</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>141</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>141</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>136</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1826</td>
<td>0</td>
<td>1974</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roads</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3572</td>
<td>5606</td>
<td></td>
</tr>
<tr>
<td>Total 1997</td>
<td>271</td>
<td>4487</td>
<td>2684</td>
<td>8926</td>
<td>88278</td>
<td>50090</td>
<td>15023</td>
<td>6259</td>
<td>4294</td>
<td>141</td>
<td>1866</td>
<td>6054</td>
<td></td>
</tr>
</tbody>
</table>

4.2 Calibration results

In the following, calibration results concerning the cellular and global level are presented. As mentioned in chapter 3.3 the Kappa index and Zipf’s law were consulted.

4.2.1 Cellular level validation results

First the Kappa was calculated for the land use map 2004 compared to the random constrained match map (RCM) (see chapter 3.3.1). The obtained value was 0.909 (Figure 19). The categorical KHisto value (see Table 18) is in this case always 1, based on the fact that during the procedure of generating the RCM map, the exact same amount of cells has been allocated for each land use class. The lowest categorical Kappa obtained in this case was 0.177 for the class ‘bare soil’, the highest 0.64 for ‘urban’. The KLoc value is always identical to the categorical Kappa, because when generating the RCM map the cell’s spatial distribution remains the same.

In a second step, the land use map 2004 was compared to the simulated map 2004. The transition rules for the simulation were changed and adapted, until the Kappa obtained here was higher than the one compared to the RCM map. Then, the calibration was considered as being successful. Finally a Kappa of 0.915 was achieved (Figure 20). Also almost all categorical Kappa values are higher (Table 19). The values for bare soil and nature are still
lower, which is however of less relevance due to their status as being vacant land uses. Only for urban and peri-urban it was not possible to achieve a higher categorical kappa. Again the KHisto value is 1 for all land use functions, because these were forced within the macro model to the same amount of cells as occur on the land use map of 2004. The vacant states and land use features do not have a KHisto value of 1, because their amount of cells is not defined within METRONAMICA (Table 19).

**Table 18: Categorical Kappa for the land use map 2004 and the RCM map**

<table>
<thead>
<tr>
<th>Land use function</th>
<th>Kappa</th>
<th>KLoc</th>
<th>KHisto</th>
</tr>
</thead>
<tbody>
<tr>
<td>bare soil</td>
<td>0.177</td>
<td>0.899</td>
<td>1</td>
</tr>
<tr>
<td>nature</td>
<td>0.899</td>
<td>0.871</td>
<td>1</td>
</tr>
<tr>
<td>sparse nat. veg.</td>
<td>0.632</td>
<td>0.910</td>
<td>1</td>
</tr>
<tr>
<td>grass in build up</td>
<td>0.910</td>
<td>0.939</td>
<td>1</td>
</tr>
<tr>
<td>agriculture</td>
<td>0.964</td>
<td>0.933</td>
<td>1</td>
</tr>
<tr>
<td>forest</td>
<td>0.910</td>
<td>0.952</td>
<td>1</td>
</tr>
<tr>
<td>urban</td>
<td>0.924</td>
<td>0.924</td>
<td>1</td>
</tr>
<tr>
<td>peri-urban</td>
<td>0.917</td>
<td>0.917</td>
<td>1</td>
</tr>
<tr>
<td>industry</td>
<td>0.972</td>
<td>0.960</td>
<td></td>
</tr>
<tr>
<td>retail</td>
<td>0.972</td>
<td>0.960</td>
<td></td>
</tr>
<tr>
<td>water</td>
<td>0.972</td>
<td>0.960</td>
<td></td>
</tr>
<tr>
<td>roads</td>
<td>0.972</td>
<td>0.960</td>
<td></td>
</tr>
</tbody>
</table>

**Table 19: Categorical Kappa for the land use map 2004 and the simulated map 2004**

<table>
<thead>
<tr>
<th>Land use function</th>
<th>Kappa</th>
<th>KLoc</th>
<th>KHisto</th>
</tr>
</thead>
<tbody>
<tr>
<td>bare soil</td>
<td>0.005</td>
<td>0.864</td>
<td>1</td>
</tr>
<tr>
<td>nature</td>
<td>0.888</td>
<td>0.644</td>
<td>1</td>
</tr>
<tr>
<td>sparse nat. veg.</td>
<td>0.919</td>
<td>0.940</td>
<td>1</td>
</tr>
<tr>
<td>grass in build up</td>
<td>0.940</td>
<td>0.957</td>
<td>1</td>
</tr>
<tr>
<td>agriculture</td>
<td>0.932</td>
<td>0.920</td>
<td>1</td>
</tr>
<tr>
<td>forest</td>
<td>0.957</td>
<td>0.932</td>
<td>1</td>
</tr>
<tr>
<td>urban</td>
<td>0.957</td>
<td>0.932</td>
<td>1</td>
</tr>
<tr>
<td>peri-urban</td>
<td>0.957</td>
<td>0.932</td>
<td>1</td>
</tr>
<tr>
<td>industry</td>
<td>0.954</td>
<td>0.950</td>
<td>1</td>
</tr>
<tr>
<td>retail</td>
<td>0.950</td>
<td>0.954</td>
<td>1</td>
</tr>
<tr>
<td>water</td>
<td>0.954</td>
<td>0.950</td>
<td>1</td>
</tr>
<tr>
<td>roads</td>
<td>0.954</td>
<td>0.950</td>
<td>1</td>
</tr>
</tbody>
</table>
4.2.2 Global level calibration results

Finally, three graphs were created, as described in chapter 3.3, considering Zipf’s law. The distribution was plotted on a logarithmic scale and a trend line added. Each graph shows the distribution of urban clusters in 1997, 2004 and 2047. As already mentioned earlier, is the graph for the year 2047 is used for reference purposes. After a period of 50 years it is possible to evaluate if the transition rules are set in such way that they capture urban dynamics in the area. The result shows similarities between all three graphs (see Figure 21).

The results also show that a distribution equally to the one in Figure 17 was not achieved. There are many small one-cell clusters and a few unique large clusters occurring. Especially between the cell sizes of 100 and 10,000 is each cluster occurring only once.

When overlaying the trend lines from 2004 and 2047, the line for 2047 is slightly lower and a bent into horizontal direction than the one for 2004 (Figure 21). This should capture in theory the trend of growing cities. People are abandoning small towns and move into the urban fringe. But when looking at the data labels, in 2047 a total of 849 single cells occur, whereas in 2004 only 236 single cells occur. So actually an increase of small clusters takes place. But also medium-large clusters increase in the simulation for 2047. Compared to 2004 are here much more clusters to be found between sizes of 10 and 100 cells.

![Image of graphs showing urban clusters in 1997, 2004, and simulation 2047](image)

Figure 21: Dispersal of urban clusters in 1997, 2004 and simulation 2047 (cluster size (amount of cells) plotted against count (number of clusters) on a logarithmic scale).
4.3 Scenario simulation results

For the research at hand, a total of three scenarios were developed. The scenarios were simulated in four different variants, resulting in eight simulations (see Table 9 for an overview). In the following paragraphs, each simulation result is described and a map for the final simulation year 2040 is shown. On the data CD enclosed, animations for each scenario and final simulated land use maps for each scenario can be found.

Generally, not many significant changes take place. Main differences are occurring in industrial growth and urban shrinkage. Urban shrinkage is replaced mainly by the land use category grass in build up and new industrial areas replace agricultural cells. New developing cells of the land use classes nature and forest emerge always along already existing natural and forested areas. Comparing then each scenario regarding differences between “N280 as is” and “N280 changed”, it becomes obvious that a relocation of the street influences especially urban land use. The map comparison visualizes this by indicating a red spot for urban land use (see Figure 22c). Here, urban shrinkage takes place especially at the area north of the Moesdijk when the infrastructure is missing. This development is especially visible in the shrinkage scenario, where a relocation of 284 cells takes place (Figure 22c). The higher the growth in urban land use, the less cells are relocated, resulting in 188 cells in the low grow scenario (Figure 24c). The influence of the changed infrastructure on retail can almost be neglected. When after the relocation retail remains at the Moesdijk area, it even starts to grow.

When comparing differences between the scenarios, industrial growth takes place first only at the Kampershoek area, later also in a little corner of agricultural land use central in Weert south of the railroad. But industrial cells emerge here only when the Kampershoek is completely filled by industrial land use. Retail has no negative influence on urban land use. If the N280 is not relocated, urban remains north of the Moesdijk area. Instead, shrinkage takes place within the city centre of Weert. Especially in the shrinkage scenario this phenomena becomes visible (Figure 22a). The two scenario variants “Moesdijk” and “Kampershoek” (Figure 25) were implemented via zoning maps in METRONAMICA. As retail is not allowed anymore on the Moesdijk area, it moves to the north of the Kampershoek and grows in a blobby cluster. The then available space on the Moesdijk area is however not taken over by industrial land use. It seems that the Moesdijk has only little attraction for industry. Instead, it emerges in the north of the city Weert, close to the highway.

---

4 Within the map comparison (Figure 22c, 23c, 24c and 25c), map 1 always refers to the simulation variant “N280 as is” and map 2 refers to the variant “N280 changed”.

---

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Figure 22: Simulation results for the shrinkage scenario in the competition variant: a) Simulated map with N280 as is (left corner above); b) Simulated map with N280 changed (right corner above); c) comparison of both maps with the MCK.
Figure 23: Simulation results for the level-off scenario in the competition variant: a) Simulated map with N280 as is (left corner above); b) Simulated map with N280 changed (right corner above); c) comparison of both maps with the MCK.
Figure 24: Simulation results for the low grow scenario in the competition variant: a) Simulated map with N280 as is (left corner above); b) Simulated map with N280 changed (right corner above); c) comparison of both maps with the MCK.
Figure 25: Simulation results for the low grow scenario in the Moesdijk and Kampershoek variant: a) Simulated map with N280 as is (left corner above); b) Simulated map with N280 changed (right corner above); c) comparison of both maps with the MCK.
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4.4 16-cell radius neighbourhood results

In the following the simulation results for 2004 with the 8- and 16-cell neighbourhood are shown. Animations and final land use maps the simulations with a 16 cell neighbourhood can be found on the data CD. After having carried out all simulations with an 8-cell neighbourhood, the rules were left as they are, but spread out over 16 cells in the modelling environment. Practically, a longer spline (see Annex V) was introduced for each rule, expecting that a larger radius would be relevant in modelling the dynamics. First, the simulation was also run from the year 1997 until 2004 (see Figure 27). The achieved Kappa was much lower than the one compared to the RCM (see chapter 4.2.1 and Figure 26). Also all categorical Kappa were lower than the one obtained within the calibration procedure (see Table 20 vs. Table 19).

Kappa of land use map 2004 and simulated map 2004 with 16 cell radius neighbourhood

![Figure 26: Obtained Kappa for the land use map 2004 and the simulated map 2004 with a 16 cell radius neighbourhood.](image)

Table 20: Categorical Kappa for the land use map 2004 and the simulated map 2004 with 16 cell radius neighbourhood.

<table>
<thead>
<tr>
<th>Land use map 2004 and simulated map 2004 with a 16 cell radius neighbourhood</th>
<th>Kappa</th>
<th>KLoc</th>
<th>KHisto</th>
</tr>
</thead>
<tbody>
<tr>
<td>bare soil</td>
<td>0.819</td>
<td>0.878</td>
<td>0.933</td>
</tr>
<tr>
<td>mature</td>
<td>0.666</td>
<td>0.666</td>
<td>0.933</td>
</tr>
<tr>
<td>sparse nat. veg.</td>
<td>0.62</td>
<td>0.62</td>
<td>0.933</td>
</tr>
<tr>
<td>grass in built up</td>
<td>0.884</td>
<td>0.884</td>
<td>1</td>
</tr>
<tr>
<td>agriculture</td>
<td>0.922</td>
<td>0.922</td>
<td>1</td>
</tr>
<tr>
<td>forest</td>
<td>0.944</td>
<td>0.944</td>
<td>1</td>
</tr>
<tr>
<td>urban</td>
<td>0.849</td>
<td>0.849</td>
<td>1</td>
</tr>
<tr>
<td>peri-urban</td>
<td>0.854</td>
<td>0.854</td>
<td>1</td>
</tr>
<tr>
<td>industry</td>
<td>0.51</td>
<td>0.51</td>
<td>1</td>
</tr>
<tr>
<td>retail</td>
<td>0.95</td>
<td>0.95</td>
<td>1</td>
</tr>
<tr>
<td>water</td>
<td>0.954</td>
<td>0.954</td>
<td>1</td>
</tr>
<tr>
<td>roads</td>
<td>0.994</td>
<td>0.994</td>
<td>1</td>
</tr>
</tbody>
</table>

The simulation with a larger neighbourhood results in very blobby clusters. The map comparison (Figure 27c) visualizes that retail and industry is much more widespread in the 8-cell neighbourhood simulation than in the one with a 16 cell neighbourhood. Also the simulation results for 2040 underline this behaviour (see Figure 28). Three exemplary scenarios are shown here. Within all three scenarios the land use classes grow in blobby, round clusters very dense. As a result emerges a large field of bare soil in the area of the Kampershoek as well as a large, round field of grass in build up in the centre of the municipality. Retail remains to stay at the Moesdijk area. Interesting to point out is that industry does not grow on the Kampershoek.

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Figure 27: Comparison of simulation results for the year 2004: 16 cell against 8 cell radius neighbourhood. a) Simulated map with N280 as is (left corner above); b) Simulated map with N280 changed (right corner above); c) comparison of both maps with the MCK.
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Figure 28: Exemplary simulation results for the year 2040 with a 16 cell radius neighbourhood.
5 Discussion and Conclusion

The following discussion and conclusion is based on the in chapter 1 defined research questions. Each paragraph analyzes the obtained results and gives an outlook for further research possibilities and elaborates on drawbacks. In the summary a final elaboration on the overall research question will be given.

5.1 Choice of model type

In what ways does METRONAMICA differ from other existing land use models?

All evaluated land use models deal directly with the behaviour that planners, policy makers, and the public can readily understand and analyze. They are able to capture complex interactions in the markets for land, development, and transportation and are valuable tools for improving the level of understanding of how an area develops and how various combinations of land use and transportation policies and investments are likely to shape these trends.

No modelling approach is capable to answer all questions (VERBURG et al. 2006). The appropriate approach of choosing a certain model type depends on the research questions and the characteristics of the study area (the temporal and spatial extend of the model). Regression models (like CLUE) are data intensive and based on physical suitability. They are rather suitable for modelling natural areas and not urbanized municipalities like Weert. CA models (like METRONAMICA) have proven utility for modelling ecological aspects of land-use/cover change, but face challenges when incorporating human decision making (PARKER et al. 2002, 9). They consist of transition rules that take besides others the neighbourhood into consideration and are better suited for an urban application. This problem also became visible while carrying out the research. Developments in Weert are based mainly on policies and plans, not on dynamics.

It has to be mentioned also that CA are not realistic descriptions of any particular phenomenon. They are not intended to be realistic representations of urban processes. Instead, they should be used as aid and they provide important insights into the nature of geographical processes. This is especially difficult to remember when working on a very local scale. It is not possible to predict reliable future developments. However it is possible to explore various possible futures and thus develop insights that may be of use in strategic planning.

It may be interesting to apply agent based models (see Annex I.4) to the study area. Where cellular models are focused on landscapes and transitions, focus agent-based models on human actions and explore interactions between agents and the environment, rather than simulating landscape change. Especially within Weert no real dynamic landscape change does
take place. Changes are based on implemented plans, not on dynamic growth. According to BENENSON and TORRENS (2004), one approach could be combination of CA and Multiagent Systems. A weakness of CA is the inability of automata cells to move within the modelling environment. This insufficiency is becomes especially visible when dealing with pedestrians, migrating households or relocating firms (ibid, 22). But within the application for Weert, especially relocating firms and households played a crucial role. It was not possible to model such developments in a sufficient way, and an agent based approach could lead to much better results. BENENSON and TORRENS described several geographic systems that are essential to simulate an urban system:

- Typology of entities
- The space in which they are situated
- The spatial relationship between entities
- The process governing the changes of entities’ characteristics
- The process governing the changes of their location and space

CA are incapable of representing autonomous mobile entities and agent based models underestimate the importance of space and relocation behaviour. Only a combination of CA and agent models is able to capture all above mentioned systems. BENENSON and TORRENS propose a new modelling framework called Geographic Automata Systems (GAS). GAS includes qualitative and quantitative investigation of the spatial and temporal behaviour of the five criteria. It is a unified scheme for representing discrete, object-based geographic systems, especially suitable for urban areas. For more detailed information on GAS it is referred to TORRENS and BENENSON (2005). Often, it is most appropriate to use a range of modelling approaches to study different aspects of the system. It was however not possible to apply different types of models for the research carried out, but it would be interesting to apply for example an agent based model and compare the simulation results with the ones obtained within this study.

### 5.2 Variables and datasets

*Research question: What are the variables and datasets that have to be considered as inputs for METRONAMICA?*

**Input data and variables**

The results showed that the input data should be much more detailed than the data that was available for such a local application of METRONAMICA. Then it would be able to model more detailed land use functions. In order to set efficient transition rules for this application, the urban area should be divided into sub-categories such as low-density building,
high-density building, wholesale etc. This has also been carried out by GENELETTI et al. (2007).
The applied land-use categories were sub-divided until they were able to capture the factors
that play a relevant role in the modelling process. Similar problems occurred due to the coarse
infrastructure dataset. For the local application, much more minor streets and maybe even
bike-paths should be included. With the accessibility map as applied, urban areas shrink when
the N280 is relocated. Reason could be that not enough other streets are available in the
dataset, but occur in reality.

Besides improving the input data, also different allocation mechanisms could be
tested. The one applied within this study sums up by equal share the neighbourhood effect,
suitability, accessibility and zoning (see chapter 2.5.1). It would be possible to emphasize on
the accessibility for example by giving it a higher weight in the final allocation, e.g. calculating it
times four. When doing so, roads for example could have a stronger impact and retail would
move to another place as soon as the N280 is relocated. In the current application retail only
moved from the Moesdijk area when respective zoning maps where introduced (see simulation
result for the low grow scenario “Kampershoek variant”, Figure 25b).

Cell size

Considering the applied cell size, the level of detail can be easily raised and an
application is possible also at higher spatial resolutions. Nonetheless noted VAN DELDEN and
ENGELEN (2006, 7) that raising the level of accuracy may hamper METRONAMICA’s
predictive capabilities. A higher resolution model would be expected not only to map land use
more accurately but also to produce more detailed results where generalisation is not
acceptable. A first application based on 25 x 25 m grid cells has already been carried out by
PHYN (2008), who concluded that:

- The cell neighbourhood is defined as the circular region around a cell out to a radius of
eight cells. A 100 m resolution model allows for neighbourhood influence up to 800 m
away from a cell. With a 25 m resolution, this distance is restricted to 200 m, meaning that
rules with a tail longer than 200 m in reality are not adequately modelled anymore.
- With a cell size of 25 m the model starts to represent single properties and therefore
decisions of individuals (owners of properties). METRONAMICA is not designed for
modelling decisions of individuals. It models generalised trends in behaviour of groups of
people and the impact those trends have on land use.

Also studies carried out by MÉNARD and MARCEAU (2005, 710) showed that the cell size does
have an influence on the simulation outcomes. Simulations with a 30 m cell size generated
dynamics very different from those performed with larger cell sizes. It was concluded here,
that using the finest resolution available is not always a wise decision and reiterates the
importance of adapting the cell size to the objects composing the landscape (ibid, 710).
The results obtained within this study showed however, that the cell size reasonably represented the land use processes in Weert. A clear drawback was seen due to inaccurate datasets, but not due to a too small cell size. Modelling on a cell size of 25 m was also carried out by GENELETTI (2007) who noted that such a cell corresponds to the scale of the spatial database that is normally used to support provincial planning. Coarser resolutions hamper a suitable geographic representation of patterns and phenomena that play a key role in planning at the province level, for example ecologically relevant patches or settlements.

**Calibration measures**

Considering calibration (use of Kappa and Zipf's law), any measurement to compare two maps can be extremely sensitive to the scale of analysis (VERBURG et al. 2006). It is advisable to compute the measurement at various scales to examine the degree to which the results are sensitive to change, which was however not possible in the course of this study. The Kappa resulted in helpful measurements. But one has to keep in mind the general critique on Kappa, if a cell-by-cell comparison can account for an entire area.

The validation measurement of Zipf's law has usually been applied to evaluate earlier simulations carried out with METRONAMICA. But the municipal area of Weert does not fulfil the requirements. The area is too small and not enough clusters can be seen. Also the data structure hinders. Streets, railroad and water bodies divide the urban areas into smaller chunks that are then calculated individually, even though they belong in fact to one area. To overcome this problem, different data should be applied or the available data changed. Zipf's law should rather be used for much larger areas, consisting of several regions or on a national scale. It can be concluded that at this moment no good methodology is available to validate results on this scale. The evaluation had to be based mainly on expert judgement.

### 5.3 Neighbourhood configuration

*Does the accuracy of the results calculated by METRONAMICA change when the model is applied with a different neighbourhood configuration?*

Until now, the configuration of neighbourhood scale and its impact on a model's behaviour have not been studied systematically, but the tendency is leaning towards extending it (LIU 2007, 3). The justification behind a larger neighbourhood is based on the difficulty in justifying transition rules in behavioural terms and the existence of distance-decay effects of the neighbouring cells to the central cell in question (ibid). Also within this study it was not possible to set all transitions rules in a sufficient way. Problems were resulting mainly from the datasets, because the two categories industry and retail had to be manually digitized. It was not possible to derive behaviour of these two categories from the past (e.g. the development from
1997 compared to 2004). The rules were only set with expert knowledge, not based on input datasets.

Studies carried out by MENARD et al. (2005) demonstrate that the neighbourhood configuration of a cellular automaton has less influence on the simulation outcome than expected. But other results obtained by KOCABAS and DRAGICEVIC (2006) showed that different neighbourhood scales do have an impact on the performance and outcome of a CA model to a large extent. The authors analysed the sensitivity of a CA model under different neighbourhood sizes and types. They showed that their CA model was sensitive to:

- Changes in spatial resolution when neighbourhood size and type are kept constant;
- Changes in spatial resolution when neighbourhood size is kept constant but neighbourhood type is being changed;
- Changes of neighbourhood size when spatial resolution and the neighbourhood type are kept constant; and
- Changes of neighbourhood type when spatial resolution is kept constant but the neighbourhood size is being changed (KOCABAS and DRAGICEVIC 2006, 950).

In order to investigate the impact of the neighbourhood scale on the model's performance and outcome, different neighbourhood sizes were applied in METRONAMICA: an 8-cell radius and a 16-cell radius. It was expected that a larger neighbourhood would be able to compensate for the rather small cell sizes. The results showed that a larger neighbourhood leads to less precise simulation results. The resulting land use maps consisted of blobby clusters. It is however not known if the additional amount of cells is leading to inaccurate results, or if the transition rules are then set wrong and the model actually should be calibrated again.

One concern was the computation time needed when extending the neighbourhood. But on the small study area of Weert no significant differences in computation time of the smaller or larger neighbourhood occurred.

When modelling again with a larger neighbourhood, it would be of additional interest to change also the shape of the neighbourhood. By doing so, also other aspects such as wind direction (travelling of sound or pollution) or water runoff direction could be integrated, depending on the type of research question.

5.4 Outlook METRONAMICA and SEA (tool from TU-Berlin)

Can METRONAMICA provide support to local urban design and planning?

Urban simulations are of particular interest to policy makers and planners since it becomes feasible when using them to analyse sustainable development trends in urban areas and regions. But planners also need to be able to forecast the effects of their planning policies,
as required for example in the directive on the assessment of the effects of certain plans and programmes on the environment (2001/42/EC) published by the European Commission (EC 2001). Generally is referred to this directive as strategic environmental assessment – SEA. The SEA is a systematic process of identifying and analyzing the environmental effects of policies, plans and programmes. It is based in principle on the process of the environmental impact assessment (EIA). The EIA however only assesses on the project level and does not account for strategic plans or programmes. It rather reacts to development proposals than anticipating or steering developments (GLASSON et al. 2005). Early definitions saw the SEA as an extension to the EIA, making its procedure more strategic and focussing on environmental impacts of plans that are already proposed. But newer definitions also include a social and even economic dimension and see it as a diagnostic tool (DALAL-CLAYTON and SADLER 2005). A definition by SADLER and VERHEEM (1996, 27) states:

*SEA is a systematic process for evaluating the environmental consequences of proposed policy, plan or programme initiatives in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision-making on par with economic and social considerations.*

The SEA process should take place before decisions are made and major alternatives are still open. It also considers cumulative impacts caused by several projects or by one projects subcomponents or ancillary developments. It is a decision-aiding tool rather than a decision making process, and it needs to be flexibly applied to policy and planning cycles (DALAL-CLAYTON and SADLER 2005, 17).

The following paragraphs evaluate if METRONAMICA is able to provide suitable technical support to a formal SEA procedure. Background of this interest is a SEA information management tool for urban development plans, developed by the department of geo-information processing for landscape and environmental planning at the Technical University Berlin. In the case of plans, the SEA contains a report with information to assess the acceptability of impacts, and propositions for modification and mitigation. Most of this information has a spatial component because geographical distribution of impacts plays a relevant role in determining how they are perceived by decision-makers, stakeholders, and the public (GENELETTI et al. 2007). Although this applies to all kinds of plans, it is particularly evident for land use plans, whose implications have an explicit spatial nature. When creating the required SEA report, available guidelines do not recommend the use of spatial data. The performances of a plan rely on matrix-based assessments, and are generalised and assessed by aggregated indicator values, rather than by their geographical distributions (ibid, 409).

Several applications of spatial models are known that aimed at simulating the impacts different development scenarios induce. The Geoland spatial observatory applied a multi-agent- as well as a cellular automata model (KASANKO et al. 2007). The project concluded that
Chapter 5 – Discussion and Conclusion

both modelling approaches opened completely new avenues for planners to see the impact of future policy scenarios on land use. The possibility of testing the influence of zoning regulations, improved accessibility and market instruments on future land use was warmly welcomed by regional and local planners (ibid, 9). GENELETTI et al. (2007) constructed a spatial decision-support tool for the SEA of a land use plan. First the outcomes of implementing the plan proposal were identified, and then expected changes caused by the implementation of the spatial strategy predicted. The analysis was conducted using the SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) based on raster maps with a cell size of 25 m. The analysis contributes to zoning proposals as well as mitigation and compensation measures. With the output modifications can be targeted to specific sites, and aimed at solving locally critical conditions (ibid, 421).

METRONAMICA would also be a suitable tool for carrying out the required impact analysis for the SEA report. Here, the effects of a proposed plan and its main alternatives are identified, projected and evaluated. This part usually is to greater part uncertain, because it is difficult to relate political proposals to environmental effects in time or space. One methodology applied are projection methods that deal with uncertainty and include trend extrapolation or scenario development (DALAL-CLAYTON and SADLER 2005). Scenarios can then be modelled within METRONAMICA and easily compared to each other. Also for the decision making process, simulations carried out in METRONAMICA could be used. Within this part of the SEA the proposed plan is approved, rejected or modified by the final decision-making body. Especially cumulative impacts that must be regarded within the report are possible to capture in the modelling environment. Also public participation that plays an essential role in the SEA process is facilitated, because output datasets are easily understandable. Drawback is only the wide range need of input datasets. A common critique on the SEA are the high costs involved into the procedure (DALAL-CLAYTON and SADLER 2005). An application of METRONAMICA could require even more financial resources.

5.5 Final Conclusion

Can METRONAMICA provide accurate results and usable support when being applied at the local level with a high spatial resolution?

METRONAMICA is generally able to provide reliable results. However problems exist regarding the cellular automaton. For Weert, being an area located in the Netherlands, spatial development is mainly planned. Almost no dynamics exist. Similar circumstances would be found in almost all European countries. It would be interesting to apply the model on a less planned area, for example in a less developed country. Here more dynamics could be expected that the cellular automaton would be able to simulate.
One important aspect is that of available datasets. For a local application quite accurate data would be needed in order to set the transition rules more accurate. Neither the small cell size nor the larger neighbourhood did hamper the simulation. But the user should take into consideration that a new calibration is needed when the neighbourhood has been changed. This is quite time consuming and was not possible to realize within this study.

The results achieved are able to be used for further planning. The Kampershoek seems to be a good position for further industrial growth, but the retail should be realized on the Moesdijk area, and it is advisable not to relocate the N280.

Considering further research, it would be interesting to investigate if a similar application in a developing country achieves better simulation results. Here, the datasets can be expected to be of low quality, but at the same time much more unplanned dynamics exist that the cellular automaton captures and simulates.
References


FAKPLAN BV, 2005. "Weert city map, 9th print".


References


Annex I: Allocation methods

I.1. Cellular automata

Cellular automata were developed first by Ulam in the 1940s and at the same time used by his colleague Neumann to investigate the logical nature of self-reproducing systems. They were then developed further by the mathematician Conway in 1970. He developed a parlour game, called “The Game of Life”. The game could be modelled on an infinite grid of cells. Cells that were active or ‘alive’ are subject to a series of local rules and pertain to the birth of new cells and the death of existing ones (BATTY and XIE 1994). Today CA are being used by researchers from a variety of disciplines to investigate questions concerning the origin and evolution of structures and spatial complexity.

Cellular automata consist of a number of cells located on a regular grid. Each cell belongs to one known cell state (land use type). The system involves interactions within a defined local region, called the neighbourhood (WADE and SOMMER 2006). Standard CA typically use either the ‘von Neumann neighbourhood’ (the four cells adjoining the sides of the given cell) or the ‘Moore neighbourhood’ (the eight adjacent cells) (see Figure I.1). There is no interaction within all pairs of cells, making the model very computationally (WHITE et al. 1997). As the model runs, cells are then converted from one state into another according to transition rules. This simulation takes place in discrete time steps.

![Figure I.1: a) the von Neumann neighbourhood and b) the Moor neighbourhood.](image)

CAs have two characteristics that are not desirable when modelling urban land-use dynamics: a) They are defined on a homogenous cell space, meaning that a cell is characterized by its current value that may change due to transition rules. The cells have no inherent qualities themselves that could affect the transitions. A given neighbourhood will therefore result in the same cell transition, regardless of the cells’ location on the grid. b) CAs are unconstrained, meaning that the total number of cells in each state is determined by the application of the transition rules to the current configuration of cell states (WHITE and ENGELEN 1997, 236).

Land use depends on three factors: the inherent qualities of the land itself, the effect of neighbouring land-use activities and the aggregate level of demand for land for each activity (WHITE and ENGELEN 1997). Some cells are thus intrinsically more desirable for certain
activities than others. Also must be accounted for pre-conditions that make some parcels inherently more desirable for particular uses, such as slope, drainage or legal restrictions.

It has to be mentioned, that by their very generality, CA are not realistic descriptions of any particular phenomenon. They are not intended to be realistic representations of urban processes. Instead, they should be used as aid and they provide important insights into the nature of geographical processes (WHITE and ENGELEN 1993).

To overcome some of the problems mentioned in using CA to simulate land use change processes, many of the current land use models include other elements besides the CA component. METRONAMICA for example includes suitability maps to incorporate the inherent qualities of the land itself.

I.2: Regression models

Regression models aim at predicting unknown variables from one or more other known variables. The model studies how changes in one or more variables change the value of another variable. Generalising it is possible to say that one variable is used to ‘explain’ the variation in another variable (STOCKBURGER 1998). One example would be to ‘explain’ the output of a wind mill by the wind speed.

Variables which are used to explain other variables are called explanatory variables: the wind speed (see Figure I.2) would be an explanatory variable. These variables can be continuous, categorical or both. The variable which is ‘explained’ is called the response variable. For example, a wind power generator responds to a given wind speed with a certain output. Thus, in the example, the current output would be the response variable. Response variables are always regarded as random variables, whereas explanatory variables are usually regarded as non-random.

![Figure I.2: Example plot of a regression model: current output (response variable) against wind speed (explanatory variable) (STOCKBURGER 1998).](image)

In order to construct a regression model, both the information which is going to be used to make the prediction and the information which is to be predicted must be obtained...
from a sample of objects or individuals. It is necessary to have information on both variables before the model can be constructed. Regression models provide the scientist with a powerful tool, allowing predictions about past, present, or future events to be made with information about past or present events (STOCKBURGER 1998). In such models, the calculation of the spatial distribution of land use changes is a static modelling process. Although these models can be used to predict future land-use change, they often do not account for feedback (VERBURG et al. 2006). Regression models also downplay decision making and social phenomena such as institutions, unless they are tied to a theoretical framework or a statistical technique (PARKER et al. 2002).

I.3: Logit models

Logistic models are a form of generalized linear regression models, used when the response variable is discrete and non-normally distributed (DUNTEMAN and HO 2006). The logistic function was invented in the 19th century for the description of the growth of populations and the course of autocatalytic chemical reactions, or chain reactions by the mathematician Pierre Francois Verhulst (1804 - 1849).

When generalizing to more than two alternatives, it is referred to as multinomial logit models. These models are a straightforward extension of logistic models and often used when categories are unordered.

I.4: Agent based models

This group of models uses individual agents as the basic unit of simulation. Agents are autonomous (having control over their actions and internal state in order to achieve goals), they share an environment though agent communication and interactions, and they make decisions that tie behaviour to the environment (VERBURG et al. 2006). Agents must not be individuals; they can also represent biological cells, animals, an organization or a village (PARKER et al. 2002). A land market is one example of an important environment through which agents interact. Examples for agent based models are the MameLuke model applied on the Phillipines (HUIGEN 2004), the LUCITA model applied in the Brazilian Amazonas (DEADMAN et al. 2004), and the SAMBA model applied in northern Vietnam (CASTELLA et al. 2005).

Agents have the possibility to change state depending on their neighbourhood and can also migrate to other locations at any distance from their current position (BENENSON and TORRENS 2004, 7). Similar to CA consider agent based models a neighbourhood, which must not be regularly distributed. Often, agents are located on nodes of a network, where
neighbourhoods are then formed by network neighbour relationships (ibid). The spatial behaviour of agents representing car drivers can thus include the choice of links, street junctions, etc.

Considering the model allocation, an autonomous agent reacts to changes in the environment given the importance of the environment to goals and actions (PARKER et al. 2002, 11). Besides reaction, models are also based on rational choice theory, assuming that actors are rational optimizers with foresight and infinite analytical ability. Agents are here capable of solving complex mathematical optimization problems in order to maximize their well-being and can balance long-run vs. short-run payoffs even in the face of uncertainty. The development of bounded rational agents now relates their actions also to the environment. Rather than implementing one optimal solution, agents make inductive, discrete, and evolving choices that move them towards achieving their goals (ibid).

Agent based models make it possible to simulate the emergent properties of systems (VERBURG et al. 2006, 124). If the decision rules are set in such way that they represent human decision making, they can simulate the behaviour of a heterogeneous group of actors. Hence, these models are particularly suited for representing complex spatial interactions under heterogeneous conditions and for modelling decentralised, autonomous decision making. They emphasize on the decision-making process of the agents and on the social organization of the landscape (ibid).

However, most agents based models focus on simplified situations to explore interactions between agents and the environment, rather than simulating landscape change. A disadvantage of using agents is the difficulty to link agent behaviour to the actual land areas and to adequately represent spatial behaviour. Also needs their validation specific attention, since no adequate measurements are available yet (ibid).

**Annex II: Short introduction into the Dutch peripheral retail policy**

Since decades Dutch citizens can reach convenience shops easily and quickly, often within walking distance. The reason for this structure was the restrictive governmental policy, where only few branches were allowed to establish at the urban fringe or peripheral locations. In 2004, the policy changed: the government now leaves the implementation of retail location policy to the regional and local governments. It is now possible that more establishments at the periphery will be allowed and that shopping malls at greenfield sides will become reality.

**Historical background:**
In 1973 were PDV (peripheral retailing establishments, NL: Perifere Detailhandelsvestiging) first introduced in order to protect the existing system of shops and structure of supply. The protective policy aimed at inhibiting the settlement of retail at the periphery. Exceptions were large-scale enterprises that verifiably did not fit spatially into existing shopping areas and enterprises selling flammable and explosive goods as well as goods taking up a lot of space (cars, boats, and caravans), building materials and large-scale furniture trade. Nowadays nearly every community in the Netherlands has at least one PDV-location (KOEHLER 2005).

In 1993 the government introduced also the GDV (concentrated large-scale retail establishments, NL: Geconcentreerd Grootschalige Detailhandelsvestiging) as a supplement to the PDV. Solitaire large-scale retail businesses were allowed outside existing shopping areas at designated locations. At first only possible at 13 city nodes, later every municipality was allowed to develop a GDV site. The national government no longer limited the branches, but the communities were responsible for introducing further limitations. The only condition was a minimum gross floor space of 1500 m². However, no further GDVs were developed (KOEHLER 2005).

With the newest spatial planning report, the Nota Ruimte from 2004, the PDV/GDV-policy has now been replaced by an integrative location policy. The aim of this new policy is to offer an appealing and attractive location to each company, in order to support the workforce of cities and villages (KOEHLER 2005). The Dutch government emphasises that there is no ‘standard recipe’ in order to determine what a ‘good’ place is, but that some basis rules have to be considered:

- Pre-existing as well as new companies and facilities that cause noise attract high amounts of traffic or produce/handle unsecure goods should not be located in or nearby residential areas. They have to be offered space at special territories.
- Companies and facilities with high flows of goods and/or traffic must be offered locations with a good traffic connection (VROM 2004).

It is not sure yet, which impact the Nota Ruimte will have. One effect is the danger that peripheral retail establishments take so much purchase power out of the pre-existent shopping areas that shops in city centres have to close down. Especially shop owners in the city centre of Weert and in the business park Moesdijk fear this. The peripheral retail establishments on the other hand create new jobs and improve people’s quality of life for those who found new employment. This is part of the Kampershoek stakeholders’ vision.
Annex III: Input datasets

The following paragraphs describe in more detail the used input datasets: the LGN (Landelijk Grondgebruiksbestand Nederland) and the BBG (Bestand BodemGebruik Nederland). Table III.1 gives an overview which datasets are used best for analyzing which kind of land use class. A digital picture (jpg) of the input datasets can be found on the CD.

Table III.1: Main land use classes and best dataset combination for carrying out analysis (Koomen et al. 2006, 68).

<table>
<thead>
<tr>
<th>Land use category</th>
<th>Recommended dataset combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build up</td>
<td>LGN and BBG</td>
</tr>
<tr>
<td>Scattered building development</td>
<td>LGN and BBG</td>
</tr>
<tr>
<td>Agriculture</td>
<td>LGN and BBG</td>
</tr>
<tr>
<td>Linear plantation</td>
<td>Top10vector</td>
</tr>
<tr>
<td>Nature</td>
<td>LGN and BBG</td>
</tr>
<tr>
<td>Water</td>
<td>LGN and BBG</td>
</tr>
<tr>
<td>Remaining categories</td>
<td>LGN and BBG</td>
</tr>
</tbody>
</table>

III.1: Dutch National Land Cover Database - LGN

Due to lack of suitable land cover data for environmental studies it is was decided in 1987 to produce a national land cover database of the Netherlands (NL: Landelijk Grondgebruiksbestand Nederland, LGN) using satellite images (Landsat TM and SPOT) and ancillary data (Thunnissen and De Wit 2000). The LGN-database consists of raster cells of 25 m x 25 m which cover the entire Netherlands, and for each cell land cover is determined. Its nomenclature includes crop types, forest types, water, various urban classes and several ecological classes. For the current application of METRONAMICA, all occurring land use classes within the municipality Weert are listed in chapter 3.1.5. These where aggregated to 10 new classes (column “Aggregated Class”).

LGN1: The first version of the LGN database (LGN1) was produced by automatic classification of manually stratified single-date satellite images from 1986 (Thunnissen and De Wit 2000). The disadvantage of this classification was that various land use classes could not be differentiated because they possessed similar spectral properties.

LGN2: This database was produced using Landsat TM satellite images from 1992 and 1994 (Thunnissen and De Wit 2000). Because the LGN1 classification yielded only poor classification results (60% overall accuracy for crops), it was replaced by a multi-temporal approach during the production of the LGN2, obtaining a 75% overall accuracy considering crop classification (De Wit and Clevers 2004).

LGN 3: The third version of the LGN 3 was produced on basis of Landsat TM satellite images from 1995 and 1997 (Thunnissen and De Wit 2000). Higher classification accuracy than for LGN2 could be achieved by using a stratified multi-temporal approach on
Visual interpretation based. The approach yielded in 85% overall accuracy and 75% accuracy for individual classes, but the use of visual interpretation was time-consuming and expensive (De Wit and Clevers 2004, 3). Its nomenclature consists of 39 classes.

Table III.2: Values and land use classes from the LGN and their aggregation for the application within METRONAMICA (Hazew 2005, 65ff).

<table>
<thead>
<tr>
<th>Value LGN</th>
<th>Class LGN</th>
<th>Aggregated Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>pasture</td>
<td>agriculture</td>
</tr>
<tr>
<td>2</td>
<td>maize</td>
<td>agriculture</td>
</tr>
<tr>
<td>3</td>
<td>potatoes</td>
<td>agriculture</td>
</tr>
<tr>
<td>4</td>
<td>beets</td>
<td>agriculture</td>
</tr>
<tr>
<td>5</td>
<td>cereals</td>
<td>agriculture</td>
</tr>
<tr>
<td>6</td>
<td>other agriculture</td>
<td>agriculture</td>
</tr>
<tr>
<td>8</td>
<td>green house</td>
<td>agriculture</td>
</tr>
<tr>
<td>9</td>
<td>orchard</td>
<td>agriculture</td>
</tr>
<tr>
<td>10</td>
<td>flower bulbs</td>
<td>agriculture</td>
</tr>
<tr>
<td>11</td>
<td>deciduous forest</td>
<td>forest</td>
</tr>
<tr>
<td>12</td>
<td>coniferous forest</td>
<td>forest</td>
</tr>
<tr>
<td>16</td>
<td>sweet water</td>
<td>water</td>
</tr>
<tr>
<td>18</td>
<td>continuous urban area</td>
<td>urban</td>
</tr>
<tr>
<td>19</td>
<td>buildings in built-up area</td>
<td>peri-urban</td>
</tr>
<tr>
<td>20</td>
<td>deciduous forest in urban area</td>
<td>forest</td>
</tr>
<tr>
<td>21</td>
<td>coniferous forest in urban area</td>
<td>forest</td>
</tr>
<tr>
<td>22</td>
<td>forest with high density of buildings</td>
<td>peri-urban</td>
</tr>
<tr>
<td>23</td>
<td>grass in build-up area</td>
<td>grass in build-up area</td>
</tr>
<tr>
<td>24</td>
<td>bare soil in built-up rural area</td>
<td>bare soil</td>
</tr>
<tr>
<td>25</td>
<td>main roads and railways</td>
<td>roads</td>
</tr>
<tr>
<td>26</td>
<td>buildings in agricultural area</td>
<td>peri-urban</td>
</tr>
<tr>
<td>35</td>
<td>shifting sands</td>
<td>nature</td>
</tr>
<tr>
<td>36</td>
<td>heath land</td>
<td>nature</td>
</tr>
<tr>
<td>37</td>
<td>heath lands with minor grass influence</td>
<td>nature</td>
</tr>
<tr>
<td>38</td>
<td>heath lands with major grass influence</td>
<td>nature</td>
</tr>
<tr>
<td>45</td>
<td>sparse natural vegetation</td>
<td>sparse natural vegetation</td>
</tr>
<tr>
<td>46</td>
<td>bare soil in natural vegetation</td>
<td>nature</td>
</tr>
</tbody>
</table>

LGN 4: the 4th version of LGN is based on Landsat TM images from 1999 and 2000 (De Wit 2003). When the LGN versions 1 - 3 were compared for land use changes, it became clear that their updating methodology did not differentiate between true land use changes and other changes (corrected misinterpretations, geometrical errors). For the LGN4, a new methodology was developed, carried out in two-steps: First, the LGN3 database was updated only with real land use changes, resulting in a pre-LGN4 containing all land use changes between 1995 and 2000. Then the pre-LGN4 was checked and changes were applied that fixed previous misinterpretations, geometrical errors or other changes that were necessary to apply but which were not changes in land use (De Wit 2003). During the up-dating of the LGN database the classification method improved considerably, resulting in a sharp increase of classification accuracy. At the national level the classification has an overall accuracy of 90.4% (De Wit and Clevers 2004). It consists of 39 classes.
LG5: Due to the failure of Landsat 7 and the limited availability of useful images a combination of Landsat ETM7 and TM5, LISS-1c and ERS-SAR images from the years 2003 and 2004 were made use of (HAZEU 2006). Besides additional data such as the Top10Vector, aerial photographs and agricultural statistics were used. The accuracy for agricultural crops resulted in 80.5%. The overall accuracy has dropped with 10% compared to the LGN4 due to the limited availability of useful satellite imagery for the crop classification (HAZEU 2006, 6).

### III.2: Land Use Base of Statistics Netherlands - BBG 2000

The Land Use Base of Statistics Netherlands (NL: BBG, Bestand Bodem Gebruik), is a dataset containing information about land use in the Netherlands, saved in a GIS. The data is used as basis for figures and statistics about the Dutch land use published by the CBS (Statistics Netherlands) (VAN LEEUWEN 2004). Since the 1940’s publishes the CBS facts and figures about land use in the Netherlands. 1989 were first analyses carried out in a GIS and the Bodemstatistiek (ground statistics) created. By 1996 changed the name to Bestand BodemGebruik (BBG). The most current available version is from the year 2000, available in shape-file format, consisting of polygon features only. It has a scale of 1:10,000m. For the creation of its basic geometry was the Top10vector used, the Dutch digital topographic map in vector format at a scale 1:10,000m (VAN LEEUWEN 2004). The BBG is divided in to 37 forms of land use, grouped into eight main categories. It emphasizes on urban land use and contains only few classes in rural areas (KOOMEN et al. 2006). All areas smaller than 0.5 hectare are excluded, which makes it less precise than the Top10vector (KOOMEN et al. 2006).

**Infrastructure:** The BBG divides infrastructure into three classes: railroad, main streets and airport. It does not separate into different types of streets and does not contain any local and municipal streets, partly metalled or unmetalled streets, bike paths, hiking paths and foot paths (TDK 2006). The infrastructure is available in polygon format only, representing the width of these objects as in reality. For the application of METRONAMICA had all polygons be changed into line features and attributes distinguishing between different types of streets had to be added manually.

**Industry:** The BBG is the only nation-wide available dataset in the Netherlands containing within build up area the category “business park” (KOOMEN et al. 2006). One has to keep in mind though the lower limit of areas being smaller than 1ha. KOOMEN, NIEUWHUIZEN et al. (2006) notes that the BBG is currently the only possibility to monitor development of business parks in the Netherlands. It lacks however information about the buildings density, which could be solved when combining additional information from the Top10vector (ibid). The BBG is the only current available dataset for assessing the spatial amount of social functions (living, work, recreation) carried out in the Netherlands (CBS 2008).
Annex IV: Maps

IV.1: City map Weert

Figure IV.1: City map Weert. Indication in red circles the location of the two industrial areas Kampershoek and Moesdijk. (Map source: maps.google.com, 18.08.2008)

IV.2: Maps Dutch National Land Cover Database, LGN 3 and 5

Figure IV.2: Map Dutch National Land Cover Database, LNG 5 from 2004.
Figure IV.3: Map Dutch National Land Cover Database, LNG 5 from 2004.

**IV.3: Map Land Use Base of Statistics Netherlands, BBG 2000**

Figure IV.4: Map Land Use Base of Statistics Netherlands, BBG from 2000.
IV.4: Land use maps for the years 1997 and 2004

Figure IV.5: Applied land use map from 1997, created from LGN3, BBG 2000 and expert knowledge.

Figure IV.6: Applied land use map from 2004, created from LGN5, BBG 2000 and expert knowledge.
IV.5: Zoning maps

Figure IV.7: Zoning map with visible transportation network for land use function “urban”

Figure IV.8: Zoning map for land use function “industry” and “retail” for the scenario variant “competition” (overlay transportation network).

Figure IV.9: Zoning maps for the land use function “retail” introduced in the scenario variants “Moesdijk retail” and “Kampershoek retail”.

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IV.6: Network and accessibility maps

Figure IV.10: Accessibility map for the land use feature retail.

Figure IV.11: Accessibility map for the land use feature urban.
Figure IV.12: Applied network maps, and subsets once with N280 as is today and once with proposed relocated version.

**Legend**
- Municipal road
- Provincial street
- National expressway A2
- Railway
- Railway station
- Exit expressway
- School

**Applied Network Map**
Indicated planned changes considering the Provincial street N280

Extend municipality Weert, the Netherlands

Course of the N280 as is today

Proposed relocated N280 in the future

Annex V: Neighbourhood rules

In the following all neighbourhood rules implemented within METRONAMICA are presented. Reach rule is described and then displayed by the spline as set in the modelling environment. The land use categories are arranged similar to the legend of the land use map.

Grass in build up area:
1) This land use class has a high inertia, meaning that it will not easily be taken over by other land uses. However this category does not cluster; also single cells are possible to emerge. The importance of other grass in build up cells is only low and the neighbourhood radius only has a radius of 3 cells.
2) Grass in build up takes over bare soil, also distant cells, neighbourhood radius of 8.
3) Considering urban and industry the impact is zero, hence no attraction or repulsion. Cells emerge close to urban and industrial cells and like to be adjacent.

Sparse natural vegetation:
1) Sparse vegetation has a high inertia of 2000, meaning that it is not easily been taken over by other cells. Cells with sparse natural like to be adjacent to other sparse natural cells, but the land use does not grow in large clusters. Hence, the neighbourhood radius extends only by 3 cells.
2) Sparse natural vegetation does not take over nature (inertia of -200). Natural areas undergo maintenance and are taking care of, avoiding uncontrolled growth.
3) Sparse natural can be taken over by forest (inertia of -1000). New sparse natural vegetation cells emerge close to forest (value 7 at distance 1) and may change into forest later.

Agriculture
1) Agriculture has no inertia; hence it can easily been taken over by other land uses. However cells tend to be close to each other at a smaller distance of up to two cells.
2) Similar to sparse natural vegetation does also agriculture not take over nature (inertia of -1000). Natural areas are protected and cannot be used for agricultural purposes.
Annex V – Neighbourhood rules

Figure V.3: Two implemented neighbourhood rules for the land use feature agriculture.

Forest:
1) Forest has, similar to grass in build up and sparse natural vegetation, a high inertia of 2000. Cells then like to be close to each other up to a cell radius of 2.

Figure V.4: Implemented neighbourhood rule for the land use feature forest.

Urban:
1) Urban has a very high inertia of 3000, making it almost impossible to be taken over by other land uses. It generally grows in clusters, implemented by a radius of 8 cells.
2) New cells emerge with preference near cells with the land use class grass in build up.
3) Also agricultural cells are of importance for urban, simulating urban sprawl.

Figure V.5: Three implemented neighbourhood rules for the land use feature urban.

Peri-Urban:
1) This category has a high inertia, however lower than urban. It happens from time to time that cells are taken over for example by peripheral industry and retail. Peri-urban does not grow in large clusters, but cells close by are of influence (radius of 3 cells).
2) Peri-urban cells are strongly repelled by industry, also when industry is further away.
3) Similar to retail, however the repulsion is of less strength (-10 at cell distance 1).

Figure V.6: Three implemented neighbourhood rules for the land use feature peri-urban.
Annex V – Neighbourhood rules

Industry:
1) Industry is grows in clusters close to existing industry. It has a very high inertia, meaning that it is almost not possible for other land uses to emerge on industrial cells.

Figure V.7: Three implemented neighbourhood rules for the land use feature industry.

Retail:
1) Retail has a high inertia. It is grows in clusters. Cells are even stronger attracted to each other than industrial ones, because speckled retail areas do not attract customers.
2) Urban cells should be adjacent, these being potential customers. More distant urban cells are less important because at larger distances people choose often the car to do shopping.
3) Retail chooses to take over industrial cells if possible up to a moderate distance (radius of 5 cells). This behaviour is based on the fact that industrial cells provide future growth possibilities for retail. Owners of industrial areas tend to sell their property when possible for retail, rising this way the value of their land.

Figure V.8: Four implemented neighbourhood rules for the land use feature retail.

Annex VI: Content Data CD

Folder “Input datasets”: containing in digital jpeg format: BBG map, LGN3 and 5 map, city map of the municipality Weert, land use maps 1997 and 2004, zoning maps, accessibility maps.

Folder “Animations 8-cell neighbourhood”: all simulations with an 8 cell neighbourhood.

Folder “Animations 16-cell neighbourhood”: all simulations with a 16 cell neighbourhood.

Folder “Maps 8 cell neighbourhood”: all final simulation maps with 8 cell neighbourhood.

Folder “Maps 16 cell neighbourhood”: all final simulation maps with 16 cell neighbourhood.
Eidesstattliche Erklärung:

I hereby declare that this thesis has been written only by the undersigned and without any assistance from third parties.

Die selbstständige und eigenhändige Anfertigung versichert an Eides statt.

Berlin,