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LAND USE SCANNER: An integrated GIS based model for long term projections of land use in urban and rural areas

Maarten Hilferink[1], **Piet Rietveld**[2]

[1] YUSE GSO Object Vision, Zijlweg 156, 2015BJ Haarlem, The Netherlands (e-mail: mhilferink@tip.nl)
[2] Vrije Universiteit Amsterdam, FEWEC, De Boelelaan 1105, 1081HV Amsterdam, The Netherlands (e-mail: prietveld@econ.vu.nl)

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Abstract. This paper describes the structure of the LAND USE SCANNER model, a GIS based model developed to generate spatial forecasts for various types of land use for a large number of grids. The model basically allocates land according to bid prices for various types of land use. The possibility of government intervention in land use is taken into account among others by adding aggregate constraints. The model includes all relevant land use types such as residential, industrial, agricultural, natural areas and water. The model is driven by sectoral models providing forecasts of aggregate land use in various land use categories. An application of the first version of the model is given for the Netherlands with some 200,000 grid cells. Further developments and refinements of the model are planned for the near future.

Key words: Land use, GIS, spatial modeling

JEL classification: Q24, R10, R14, R33

1. Introduction

Long term developments in land use in many industrialised countries indicate significant changes in the share of various types. Urban and agricultural land use have grown considerably over time at the expense of waste lands. Recently, however, in some countries a different pattern can be observed. Urban land use is still on the rise, but due to overproduction and intensification in agriculture, the amount of agricultural land is no longer increasing. A reversed trend may be observed where the amount of natural land will start to grow again. This growth is also partly the result of policies of nature development instigated both by public and private actors.

If we consider the various types of theories and models developed for the analysis of land use, we note that usually there is no integrated treatment of all land use types. Many models deal only with urban land use. Examples are the neo-classical models on the use of urban space (see for example Alonso (1964), Mills (1972) and Fujita (1989)). These models ignore agricultural and natural areas or treat them in a superficial way. The same holds true for the operational urban models such as developed by Anas (1982) and reviewed among others by Webster et al. (1988) (see also Wegener 1994; Hayashi and Roy 1996). In addition there exists a range of models on agricultural land use, such as the Grondbalansen (Land Balance) model developed by LEI-DLO (1996), partly based on the Von Thunen approach of bid-prices, but these usually do not consider natural and urban areas in a systematic way (Schipper 1996) or regard them as exogenous.

A major difficulty in many models is that they are based on the notion that the highest bidder determines the type of land use. However, the public sector has assumed an active role in many countries, so that actual land use is not merely the effect of market forces. Another difficulty is that costs of transition from one type of land use to other types may be substantial because certain types of land use imply high levels of investment which are useless for other land use types. This often leads to a considerable degree of inertia in land use patterns. In order to deal with these problems land use models should be formulated as dynamic ones.

An example of a dynamic land use model is the self-organising system model developed by Allen et al. (1986) and Engelen (1988), now known as the Constrained Cellular Automata model, which is suitable for investigating the dynamic behaviour of land use developments (see also Roy and Snickars 1996). Another model, based on a two level approach can be found in Landis (1994).

In this paper we present an operational land use model (LAND USE SCANNER)[1] to address a number of the issues above, in particular the integration of urban and non-urban types of land use. The model strongly builds on the large digital and geographic data bases that increasingly become available on various types of land use. LAND USE SCANNER, which has a strong GIS component serves as an integrating framework for these sectoral data bases. By linking the model with long range models for sectoral projections, it becomes an operational tool for the integrated development of future land use patterns.

The structure of the paper is as follows. In Sect. 2 we briefly present the basic features and components of the LAND USE SCANNER model. Section 3 contains the mathematical description of the model. In Sect. 4 issues of solution and calibration are discussed. Applications are presented in Sect. 5. Section 6 concludes.

2. The LAND USE SCANNER model: General description

2.1 General features

We start with a short characterisation of the properties of the LAND USE SCANNER. Some characteristic features of the model are:

Grid based The model describes for all grids in a system the relative proportions of land to be used for a number of land use types. Model specification and software allow large numbers of grids.

[1] In the Netherlands the LAND USE SCANNER model is known as RUIMTESCANNER.

The present version covers 193,399 grid cells of 500 by 500 m each, covering all of the Netherlands.

Exhaustive The model is exhaustive in the sense that all grids in a spatial unit (in our case a country) are considered. All types of land use are explicitly considered; thus there are no 'rest' categories left untreated. The model can be formulated in such a way that transfers of wet grids (sea, lakes) into land are allowed.

Dynamic The model deals with changes in land use taking into account present land use patterns. The suitabilities of the grids for certain types of land use are not assumed constant, but may change as the result of changes in land use in the course of time.

Satellite structure The model is driven by forecasts at a national or regional level in terms of variables such as population, agricultural production, infrastructure, etc.

Stochastic The outcomes of the model are to be interpreted as expected proportions of land to be used for various types of land use categories. The use of the model is not that it predicts land use in particular small grids in the future. The main use of the model is that it gives the implications for the spatial patterns of land use of processes such as population growth, production (manufacturing, agriculture, etc.), and natural conservation.

Regenerative The results of the LAND USE SCANNER model are presented in terms of expected values as opposed to non-regenerative realisations of stochastic processes.

Policy oriented Several types of sectoral policies have strong spatial implications. LAND USE SCANNER makes these implications explicit. The model helps solving questions referring to the types of grids in which major policy conflicts can be expected to emerge. It can also be used to investigate the implications of sectoral and macro policies for human settlement and land use patterns.

Integrated The model provides an integration framework for sectoral data bases and sectoral policy proposals by confronting these inputs in a spatial-analytical context.

The property of integration means that the LAND USE SCANNER can function as a tool to improve communication between analysts working in various fields of land use (for example urban functions versus agriculture versus natural land use). The model also helps to improve consistency between projections made in these fields. Thus a potential use of the LAND USE SCANNER is that is does not only function as a modelling tool, but also as a communication tool between analysts in various policy fields.

2.2. Land use categories

The following types of land use are identified in the present version of the model:

1. Urban: residential, industrial, roads, railways, and airports.
2. Agriculture: pasture, corn, arable land (potatoes, beets, cereals), flower bulbs, orchards, cultivation under glass, and other agriculture.

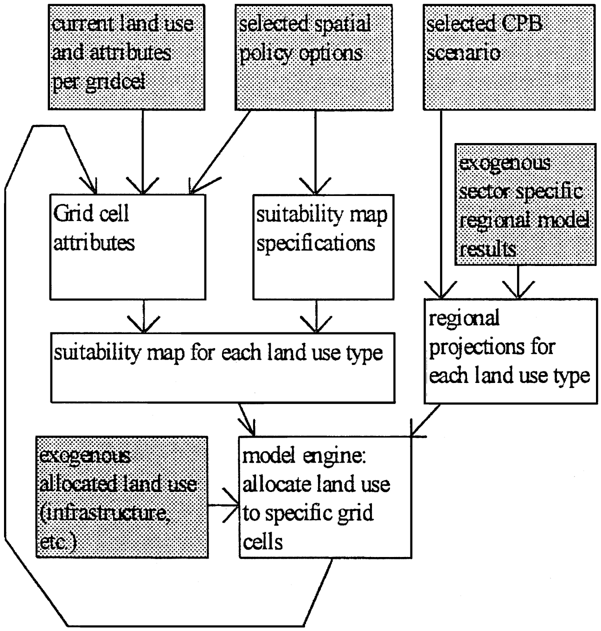


Fig. 1. Model components

3. Natural areas: wood, nature.
4. Water.

We arrive at 15 different land use types. This number of land use types can be extended. Data are available for more finely meshed distinctions, thus leading to up to 40 land use categories.

2.3. Scenarios

In order to cope with basic uncertainties about the future, the model is connected to a scenario study of economic development in the medium run. These scenarios have been developed by the Dutch Central Planning Bureau (CPB 1997). The scenarios can be characterised as follows:

Divided Europe — In this scenario protectionist tendencies in individual European countries are strong. Economic growth is low. The number of inhabitants in the Netherlands grows to 16.2 million. The current European Common Agriculture Policy is continued.

European co-ordination — The integration of individual European countries is accelerated. Economic growth is moderate although the number of inhabitants is 17.8 million. A unified European policy is implemented implying a certain level of protection of agriculture in the common market.

Global competition — Market forces dominate the world economy. Economic growth is high and although the number of inhabitants is

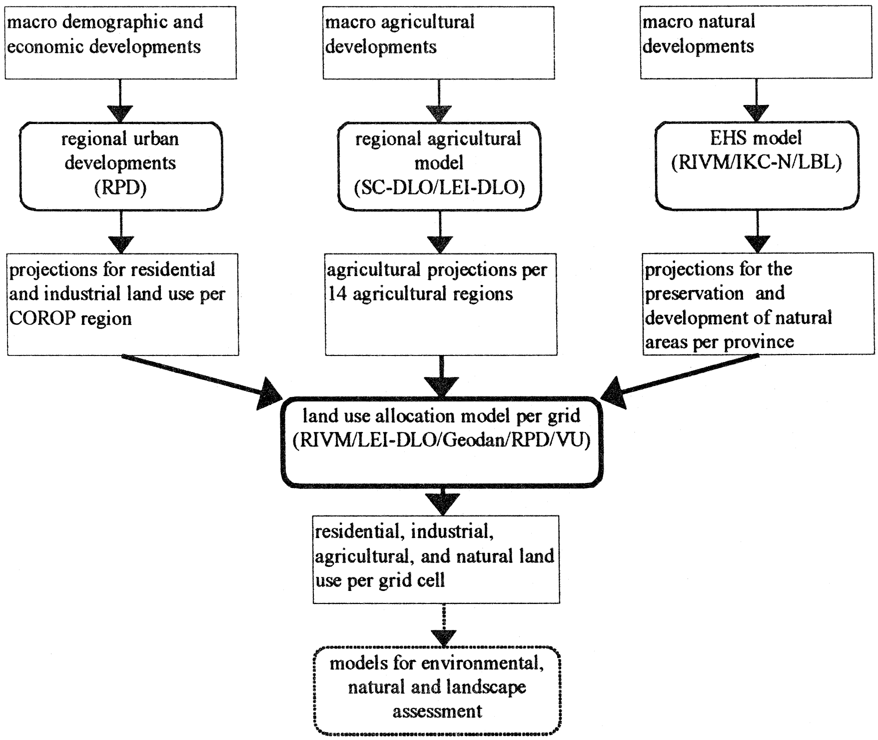


Fig. 2. Driving and co-operating models

16.9 million, the growth of residential areas is higher than in the European co-ordination scenario due to increased individualisation. The current Common Agricultural Policy is abandoned and the agricultural sector must compete in the world market.

2.4. Regional constraints; driving models

The LAND USE SCANNER model is driven by outcomes of other sector specific models which generate results at a much lower spatial detail. The outcomes relate to the year 2020. The projections for urban functions and agricultural land use have been made for the various scenarios mentioned in the preceding section. Thus, a check has to be conducted to ensure consistency of inputs (see below in Sect. 3.3).

Below follows a short description of the regional constraints used in the model (see Fig. 2). More details can be found in Schotten et al. (1997).

Projections for urban land use in terms of amounts of hectare residential and industrial area have been generated by the RPD (national physical planning agency) at the COROP level. The COROP regions are purely statistical spatial units somewhere between provinces and municipalities. They correspond approximately with labour market regions. There are 40 COROP regions in the Netherlands.

Projections for agricultural land use in terms of hectare for most types of crops have been made by the LEI-DLO (agricultural economic institute) and the SC-DLO (Staring Centre). These projections have been made at the level of agricultural regions. There are 14 of these regions in the Netherlands.

For natural areas regional constraints are included for 66 regions. These constraints and targets have been formulated by the RIVM (the national institute for health and the environment), the IKC-N (integral expertise centre-nature) and the LBL (the institute for land development and administration of agricultural land). The constraints imply that the total amount of land used by nature must be at least the amount which is set as a minimum amount for each region.

2.5. *Suitability maps*

A suitability map is generated for each land use type to indicate the suitability of each grid cell for that type. These suitability maps are calculated by combining:

- soil quality
- transition costs, given previous land use
- accessibility of facilities and infrastructure
- amount of similar land use in the neighbourhood.

In Sect. 4 more details are given about the suitability maps.

2.6. *Policy maps*

Land use developments occur within the boundaries of governmental planning regulations. These include:

- policy towards building permits for residential and industrial land use,
- policy regarding the preservation and development of natural areas.

Note that these restricting policy factors are grid specific. As will be explained in Sect. 4, the policy maps are "subtracted" or "added" to take government policies into account.

3. Model: Mathematical formulation

3.1. *Introduction*

A core variable of the model is the suitability s_{cj} for land use of type j in grid cell c. This suitability represents the net benefits (benefits minus costs) of land use type j in cell c[2]. The higher the suitability for land use type j, the higher the

[2] In case spatial policies have been formulated, the suitability scores are adjusted by subtracting or adding scores for policy intervention based on the policy maps (Sect. 2.6). The resulting "adjusted suitability" values will, for convenience, be called "suitability".

probability x_{cj} that the cell will be used for this type. In the simplest version of our model we use an unconstrained logit type approach to determine this probability:

$$x_{cj} = \frac{\exp(\beta \cdot s_{cj})}{\sum_{j'} \exp(\beta \cdot s_{cj})} \quad \text{for all } c \text{ and } j. \tag{1}$$

Thus, when β is zero, all types of land use have the same probability; i.e. the suitability factors s_{cj} do not play any role in determining these shares. On the other hand, when β goes to infinity, the limit of the probability of the category with the highest suitability is equal to 1.

In terms of expected values, the expected volume of land use L_{cj} for category j in cell c equals:

$$L_{cj} = x_{cj} \cdot L_c \quad \text{for all } c \text{ and } j, \tag{2}$$

where L_c denotes the total volume of land in cell c. With equally sized cells L_c would of course be equal for all c. Unequally sized cells may occur in the case of cells located near the national border, or cells being partly water (if a transfer from water to non-water land use is not allowed), or contain present land use based on exogenous data, such as infrastructure developments.

The model as formulated here does not guarantee that the allocation of space across possible land uses is in accordance with overall demand conditions. Therefore, side constraints have to be imposed in order to ensure that at the relevant levels of aggregation total demand is met.

This leads to a reformulation of the model as a constrained logit model. Let D_j be a restriction on total demand for land use category j. We use the expression "for the constrained j" when an *aggregate constraint* D_j has been formulated for the particular land use type j. In addition, let M_{cj} denote the expected amount of land in cell c that will be used for category j taking into account the side constraints. We then arrive at a doubly constrained model:

$$M_{cj} = a_j \cdot b_c \cdot \exp(\beta \cdot s_{cj}) \quad \text{for the constrained } j \text{ and all } c, \tag{3}$$

where a_j and b_c are balancing factors such that the following constraints are satisfied:

$$\sum_c M_{cj} = D_j \quad \text{for the constrained } j \tag{4}$$

$$\sum_j M_{cj} = L_c \quad \text{for all } c. \tag{5}$$

Equation (4) guarantees that the expected amount of land allocated for land use type j equals the imposed amount D_j. In addition, (5) states that the sum of the expected volumes of the various land use types per cell is equal to the total area of each cell.

For those land use types j for which no *aggregate constraint* D_j applies we arrive at:

$$M_{cj} = b_c \cdot \exp(\beta \cdot s_{cj}) \quad \text{for unconstrained } j \text{ and all } c \tag{3'}$$

under constraint (5) so that we may conclude that in this case a_j has been set equal to 1. Note that in the extreme case that none of the land use types has any *aggregate constraints*, we have

$$M_{cj} = L_{cj} \quad \text{for all } c \text{ and } j, \text{ and } b_c = \frac{L_c}{\sum_j \exp(\beta \cdot s_{cj})} \quad \text{for all } c.$$

Equations (4) and (5) obviously mean that supply of and demand for land use are fixed: they are inelastic towards the amount of available land. A relaxation of this zero elasticity is called for in a next version of the model. This would imply that feed-back is created from the LAND USE SCANNER to the sectoral models that deliver D_j.

It is clear that the constraints may imply that no feasible solution exsists. This can be checked by seeking for a starting solution of the system in a linear programming context. When no feasible solution is found, the aggregate constraints have to be reconsidered before the model can be used.

3.2. Balancing factors

The above reformulation as a doubly constrained land use model is helpful for an understanding of the structure of the model. The structure of the model is quite similar to doubly constrained spatial interaction models used in transportation research (see for example Fotheringham and O'Kelly 1989). We now turn to the interpretation of the balancing factors. From equations (3)–(5) it follows that:

$$b_c = \frac{L_c}{\sum_j a_j \cdot \exp(\beta \cdot s_{cj})} \quad \text{for all } c \tag{6a}$$

$$a_j = \frac{D_j}{\sum_c b_c \cdot \exp(\beta \cdot s_{cj})} \quad \text{for the constrained } j \tag{6b}$$

$$a_j = 1 \quad \text{for the other } j \tag{6c}$$

$\sum_c b_c \cdot \exp(\beta \cdot s_{cj})$ can be interpreted as the aggregate suitability of land use type j; when the suitability of land use type j would be low in terms of s_{cj}, the value of the denominator in (6b) is low as well. The balancing factor a_j is high when a high constraint D_j is combined with a low aggregate suitability.

In a similar way $\sum_j a_j \cdot \exp(\beta \cdot s_{cj})$ in (6a) can be interpreted as a measure of demand for land use in cell c. A high value of this expression means that the demand for the land in cell c for the various land use types (taking into account the urgency of the land use types as represented by a_j) is relatively high. It leads to a low value of the balancing factor b_c, and thus ensures that in equation (5) the total amount of land finally allocated in cell c does not exceed the supply of available land L_c.

Thus, the solution of the doubly constrained model yields as a side-product the shadow prices of land in the cells.

Another way to interpret the balancing factors is to rewrite equation (3) as:

$$M_{cj} = \exp(\beta \cdot [s_{cj} + \beta^{-1} \cdot \log(a_j) + \beta^{-1} \cdot \log(b_c)]) \quad \text{for the constrained } j \text{ and all } c. \tag{3''}$$

A large value of a_j implies a strong pressure on land use type j. It can be interpreted as a subsidy to this type of land use; the subsidy is given to ensure that the aggregate target for land use type j is achieved. The reverse case is a small value for a_j; this can be interpreted as a tax on this land use type to prevent that excess of the related target. Note that the case in between occurs when a_j equals 1, implying $\log(a_j) = 0$.

In order to clarify the role of the balancing factors, we perform the following transformation on (3″). Define land use price p_c in cell c as $-(1/\beta).\log(b_c)$ and price λ_j for constraint j as $+(1/\beta) \cdot \log(a_j)$, now M_{cj} can be considered as a demand function of land use price p_c.

$$M_{cj}(p_c) = \exp(\beta \cdot s_{cj} + \lambda_j - p_c) \tag{3'''}$$

This formulation also sheds light on the b_c factor. A high value of b_c means that use of cell c is discouraged. It can therefore be interpreted as an indicator of demand/supply conditions in each cell.

An increase in the aggregate demand of category j will lead to a shift in land use in the following way. The higher value of D_j will lead to a higher balancing factor a_j, which will lead to a corresponding increase in the expected land use in the various cells depending on the relative suitability of the cells for the various types of land use.

3.3. Extensions to the doubly constrained land use model

In reality the model is more complex than presented here.

One complication is that the constraints are not always in terms of equalities, but in terms of inequalities. Consider the constraint that:

$$\sum_c M_{cj} \geq D_j. \tag{4'}$$

Then in the case when the constraint is not binding, we have $a_j = 1$, and when the constraint is binding we have a_j as defined in (6b). Thus, in this case we arrive at:

$$a_j = \max\left\{1, \frac{D_j}{\sum_c b_c \cdot \exp(\beta \cdot s_{cj})}\right\} \quad \text{for all lower bounded } j. \tag{7}$$

In the case of an $\leq$ constraint we arrive at:

$$a_j = \min\left\{1, \frac{D_j}{\sum_c b_c \cdot \exp(\beta \cdot s_{cj})}\right\} \quad \text{for all upper bounded } j. \tag{8}$$

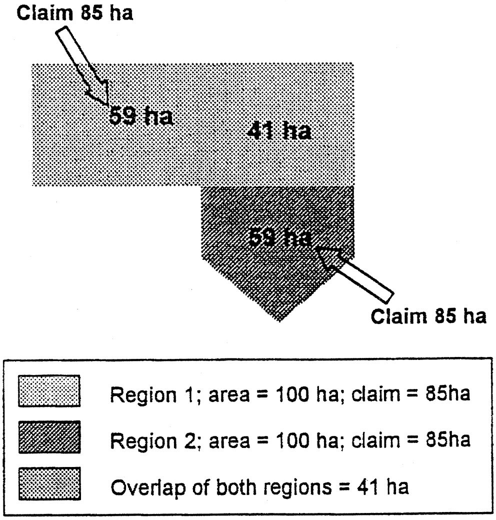


Fig. 3. Conflicting land use claims

Another complication is that the aggregate constraints not only function at the level of the country, but also at various regional levels. This means for example that population predictions have been made for labour market regions, or that agricultural production has been predicted at the level of agricultural areas. This leads to an extended version of the model where the balancing factor a_j becomes specific for each region for which a constraint has been formulated.

As shown in Fig. 3 one may easily arrive at inconsistencies. In this example in region 1, the claim for land use type A is 85 hectare and in region 2 the claim for land use type B is also 85 hectare. We obviously have a conflict when the total area of both regions is only 159 hectare. As mentioned above (Sect. 3.1) the existence of a feasible solution can be checked by means of linear programming.

It is in principle also possible to formulate constraints at the level of individual grids. For example, by indicating that in certain grids particular types of land use are banned, or that other types of land use should be present for at least a given percentage of x%. Conceptually, there is no problem in dealing with this type of constraints. Computationally, it means of course that the total number of endogenous variables increases substantially. When constraints are formulated only at the national level, there are only 15 a_j variables, but when the constraints are formulated at the level of many small regions or even individual cells, the number increases substantially. Remember that 193,399 cells are covered in the model.

3.4. Solving the doubly constrained land use model

Solution of the model is done in an iterative way. In the case of equality constraints, it only boils down to finding the values of a_j and b_c in equations (6a–c).

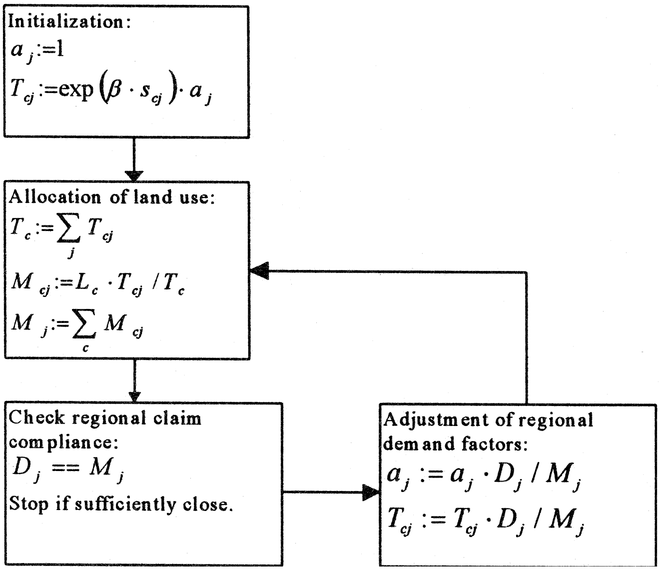


Fig. 4. Solving the doubly constrained land use model

Beginning with the arbitrary value 1 for each of the a_j, one can compute the resulting values for b_c by means of (6a). Then these b_c values are fed into equation (6b) leading to revised values for a_j.

In the case where some of the constraints are in terms of inequalities, one should use equations (7) and (8) instead of (6b). Once these factors have been determined, the implied land use pattern can easily be found by means of equation (3).

In order to compute a solution for the model, equation (6a) is used to substitute b_c in equation (3) so as to incorporate the land supply restriction given by (5) into the calculation of M_{cj}:

$$M_{cj} = L_c \cdot \frac{a_j \cdot \exp(\beta \cdot s_{cj})}{\sum_{j'} a_{j'} \cdot \exp(\beta \cdot s_{cj'})} \quad \text{for all } c \text{ and the constrained } j. \qquad (3'''')$$

To find values for a_j that satisfy the land use restrictions given by (4), a_j is iteratively adjusted until the restrictions are sufficiently met

$$a'_j = a_j \cdot \frac{D_j}{\sum_c M_{cj}} \quad \text{for the constrained } j. \qquad (6b')$$

In order to speed up the iteration process, $a_j \cdot \exp(\beta \cdot s_{cj})$ is substituted by T_{cj}, $\sum_{j'} a_{j'} \cdot \exp(\beta \cdot s_{cj'})$ is substituted by T_c and $\sum_c M_{cj}$ is substituted by M_j.

The iteration algorithm is summarised in Fig. 4. It differs in two ways from a doubly constrained spatial interaction model. First of all, it can both deal with equality and with inequality constraints. Second, the constraints per land use category may relate to quite different (and non-overlapping) regional units such as agricultural areas, labour market regions or housing areas.

The algorithm leads to a rapid convergence process. Convergence is measured by the fit between projected land use D_j and allocated land use M_j. After about 25 iterations the changes in the balancing factors become extremely small. It takes a personal computer with a Pentium processor (32 Mb) about three minutes to yield a converged solution. This makes the model a friendly tool in an interactive policy preparation process.

4. Determination of suitability maps

The starting values of s_{cj} for the various land use types have been approximated in the following way. For all land use categories the suitability is measured at a scale from -10 to 10.

For residential land use our point of departure is that current use for residential purposes in 1995 will remain residential in 2020. This means that existing residential land use is exogenously fixed.

For the coming decade a number of locations have already been indicated where large construction projects will take place (VINEX locations). These locations receive a maximum score of 10. In addition, a number of somewhat softer indications (search directions) have been formulated in the policy documents. These locations receive a score of 5. In addition to these inputs from national policy considerations, more market oriented developments are also included in the suitability indices. These market oriented developments refer to higher attractiveness of grid cells when they are near to existing urban areas (operationalised via an accessibility indicator) and near railway stations. The weights attached to these factors have been based on interactive procedures with experts. Other factors may be added to take into account attractiveness of the natural environment, accessibility of the national expressway system, etc.

Industrial land use is treated in a similar way; present industrial use is again assumed to remain unchanged. Areas with a firm physical planning assignment receive a score of 10, etc. Suitability further depends on the accessibility of existing work locations and infrastructure networks. The weights have again been determined by experts.

For the various agricultural types of land use we assume that suitability of grids depends partly on the existing levels of these land use types in the grids. This indicates that changes in land use imply certain costs. As a result of these costs we will observe a certain level of inertia. In addition to this component, the suitability indices depend on detailed agronomical information about the productivity of the grids for the various types of agricultural land use.

Effects of neighbouring zones on the suitability are implemented by using a potential function with a parameterised range and decay. The suitability for residential use is assumed to be much higher in the neighbourhood of other residential areas, working locations, etc. Similar spatial dependencies are implemented for the determination of suitability for working industrial and agricultural land use. Other spatial factors such as distances to the markets, availability of services have not been considered thus far.

Suitability of land use for nature and woods is based on a range of policy documents in this field where areas of high natural quality have been indicated.

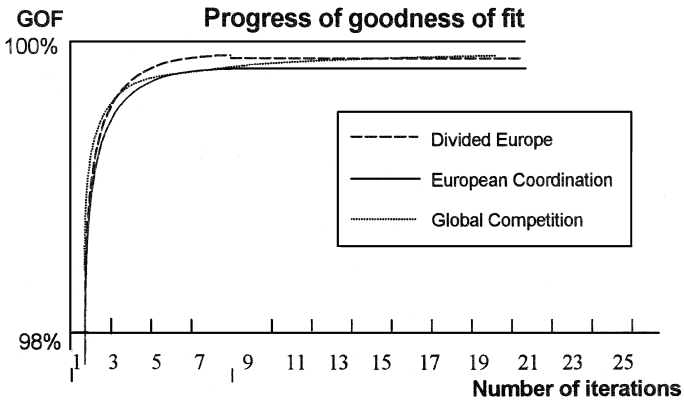


Fig. 5. Goodness of Fit as a function of the number of iterations.

The other land use types (various types of infrastructure and water) have been kept exogenous in the model thus far. These types of land use are either assumed to be constant in time, or they are plugged into the model as exogenous changes (for example the construction of a new high-speed railway line, or a new airport).

5. Calibration of the model

The LAND USE SCANNER model as it is used here yields projections on land use in a future year (2020), given the land use in the base year (1995), taking into account aggregate constraints and suitability of grid cells. In order to calibrate this model we should apply it to an earlier base year (say 1970), and find the combination of suitability indices and β parameter that yield the best prediction for the actually observed land use A_{cj} in the year 1995. Of course, it will not be possible to calibrate the suitability indices themselves, because there are a great many of them (193,399 times 11). What has to be done is to find the parameters that link explanatory factors to suitability indices. For example, suitability for residential land use depends on factors such as the accessibility of urban areas, presence of natural areas, etc. Once these parameters have been estimated one can easily determine suitability maps for each type of land use (Sect. 2.5) by weighted summation of underlying maps.

In order to calibrate the model the following steps are used (see Fig. 6).

More effective procedures can be derived from this template by improving the selection of parameter values using the results from previous iterations, although the optimisation process can become more sensitive to being caught in a local optimum.

Unfortunately, data on past land use for the given land use categories at the given level of spatial detail is not yet available. Therefore, full calibration of the model must wait until such data is ready for use. As explained in Sect. 4, in the present version of the model the weights underlying the suitability indices are based on judgements expressed by experts in the various fields of land use (urban, agricultural and natural) during a series of interactive sessions.

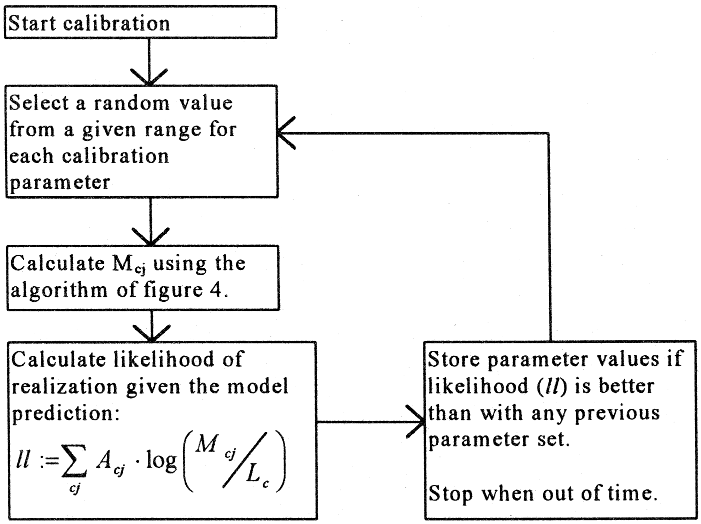


Fig. 6. Calibration of land use model

Table 1. Log likelihood of allocation as a function of β

β	log likelihood (ll)
1.00	−13,888,418.65
0.75	−12,227,652.15
0.50	−10,948,746.00
0.25	**−10,405,420.64**
0.20	−10,407,837.50
0.15	−10,459,590.32
0.10	−10,566,501.79

This leaves the problem of how to estimate the β parameter. This parameter has a strong impact on model outcomes, because as explained in Sect. 3.1, it determines the extent to which mixed land use will occur in cells. A high β parameter implies a high degree of homogeneity of land use per cell. With a low β parameter there will be a strong degree of mixed land use per cell. The calibration scheme presented in Fig. 6 has been used to estimate β.

As a starting point of the calibration we have applied the model on the 1995 situation and compared the results with different values for β with the results of 1995 itself. With this approach we did not test the ability to predict land use changes, but merely tested the sensitivity to changes of parameters and the model's capability to generate an expressive allocation. Since the β parameter is accustomed to adjusting the scale of the suitability maps, this analysis has clarified an appropriate rescaling of these maps. One should be aware, however, that the calibration of β by means of cross section data does not necessarily lead to an estimate that would also be applicable in a dynamic context. This means that when historical data will become available also the β parameter will have to be re-estimated.

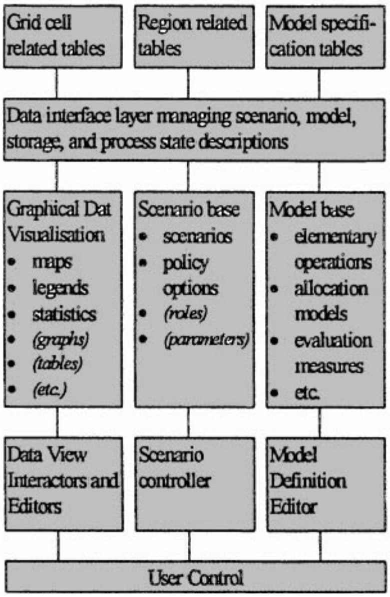


Fig. 7. Logical System Architecture

6. Application of the LAND USE SCANNER model

6.1. An implementation in a Geographic Information System (GIS)

An information system has been developed in C + + in order to implement and use the LAND USE SCANNER model. A configuration script is used to define scenario's and chains of allocation model applications. For each allocation model application, an expression script is used to identify for each land use type j how its suitability factors should be calculated.

The LAND USE SCANNER system manages sets of tables, some related to grid cells and others related to regions. The grid cell related tables contain attributes on current land use A_{cj}, attractiveness factors, localised policy data, etc. The region related tables contain attributes on regional claims D_j. Each table can be identified as scenario specific.

Each table attribute manages an array of attribute data, which can be exogenous or user specified. A user specified attribute data array is calculated by the LAND USE SCANNER system by applying a user given model expression. A user can modify each land use type j related expression that is used to calculate the attractivity factors s_{cj} by using the model definition editor (see Fig. 7). Since model functions operate on attribute data arrays as a whole, they can and do include operations that consider the neighbourhood of grid-cells in order to model spatial relations.

Thus, a user can specify how the land use type specific suitability maps should be calculated and how regional claims D_j should be derived from the results of sector specific regional models. Furthermore, the LAND USE SCANNER enables the user to specify his/her own model evaluation meas-

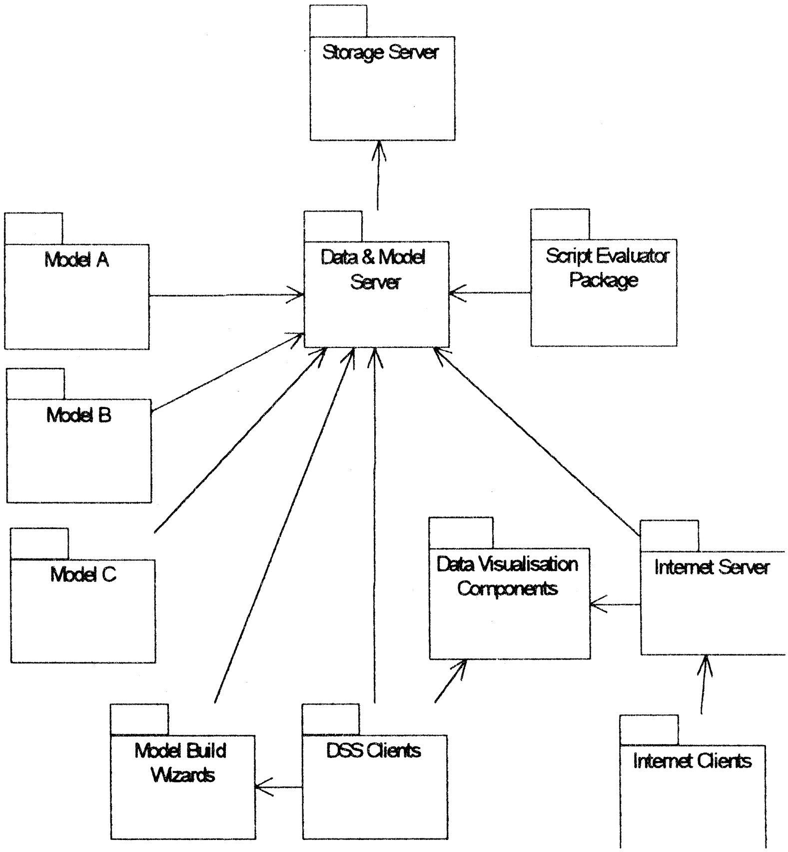


Fig. 8. Physical System Architecture

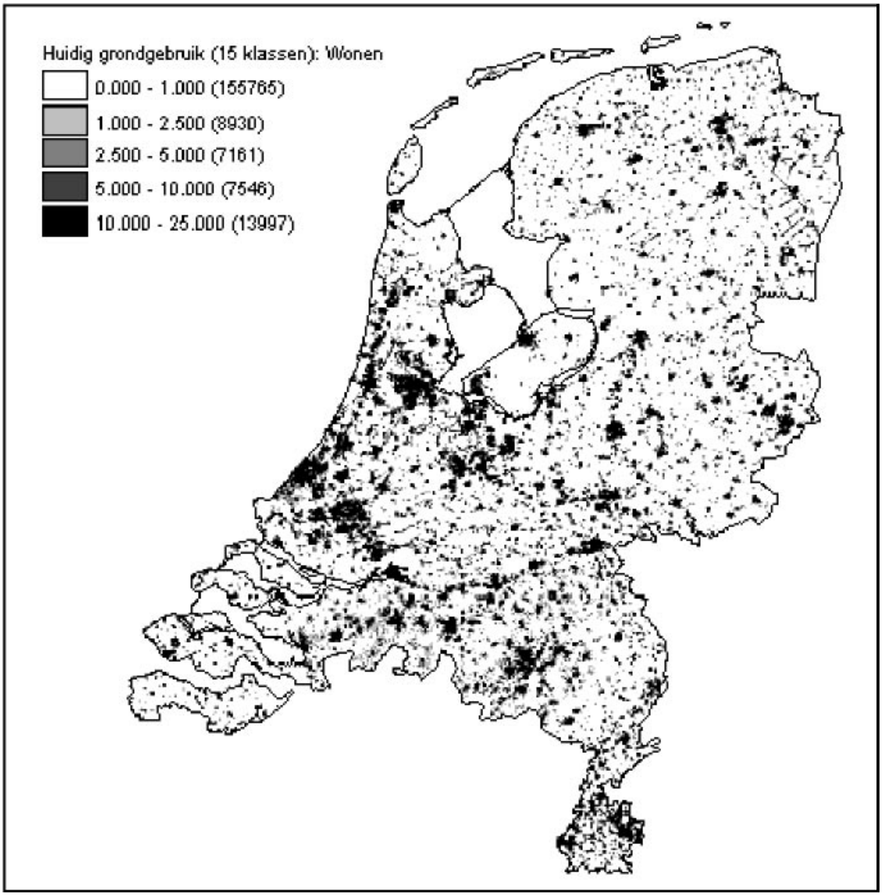
ures in order to evaluate the model results by calculating measures for land use diversity, land scarcity, etc.

Each attribute and model result can be visualised by the user in a map view. This enables the user to inspect:

- exogenous data, i.e. current land use, localised policy data, attractiveness data, etc.
- calculated intermediate model results such as maps with a measure of the surroundings for each grid cell, suitability maps, regional claims
- allocated future land use
- user specified evaluation measures on allocated future land use

6.2. *Resulting maps*

The following are examples of maps that resulted from the use of the LAND USE SCANNER system.



Map 1. Current residential land use

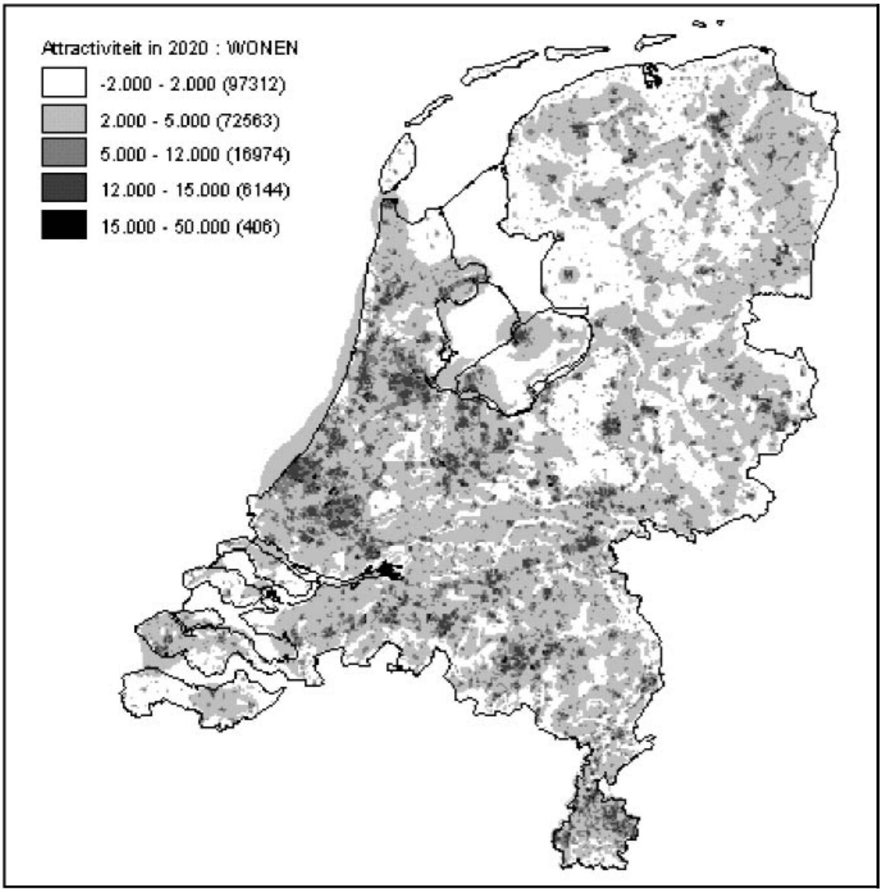
Map 1. Current residential land use

Map 1 shows current (1995) residential land use. Areas with zero or negligible residential land use are white. The areas in black have residential land use of 40% or more of the grid area (500 m × 500 m). The map clearly shows the polycentric urban structure, especially in the highly urbanised western part of the country.

Map 2. Suitability of land for residential use

For the coming decades a considerable increase in demand of land for residential use is foreseen. The suitability of land for residential use is calculated by applying a weighted addition of:

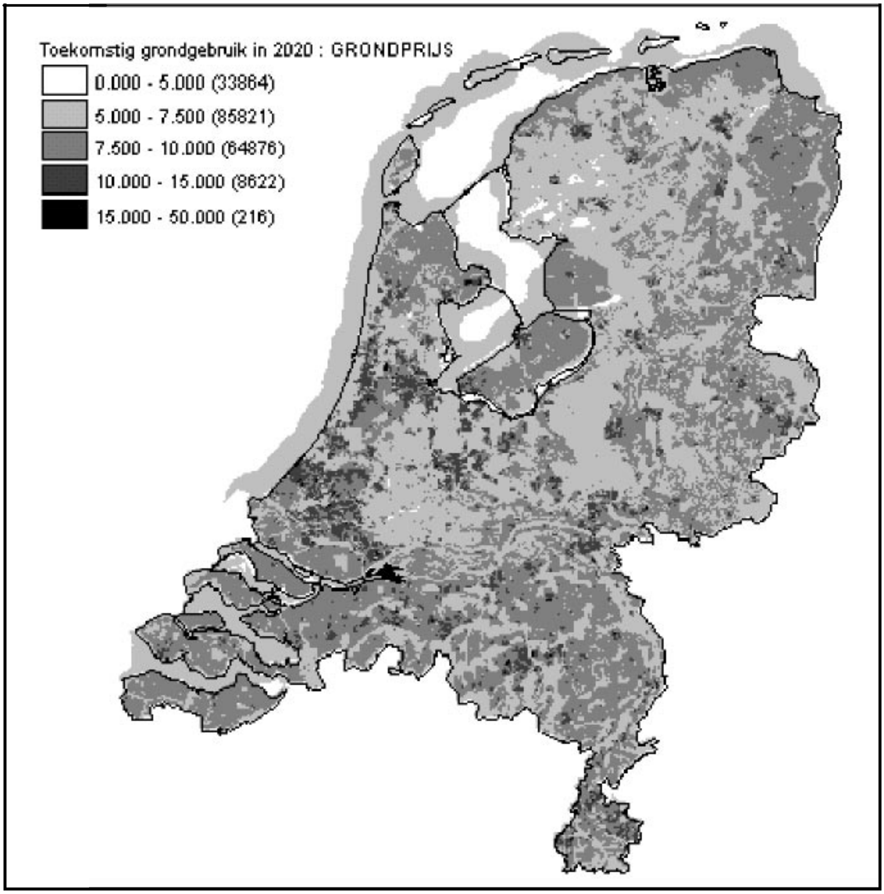
- governmental policy toward building locations,
- a normalised potential to surrounding current residential land use,



Map 2. Suitability of land for residential use

- a normalised potential to surrounding current work opportunities,
- a normalised potential to surrounding transport infrastructure

This list includes factors consistent with the given national physical planning policies which aim at locating new residential sites near to existing cities and with high (public transport) accessibility. Other factors such as the attractiveness of the residential environment have not been included. Such factors would of course play a role when a more market oriented pattern of residential locations would be allowed. The map indeed clearly expresses high levels of suitability in and around existing urban areas. A more market oriented development of residential land use would reflect a much higher attractiveness of regions in the intermediate zone at a distance of some 30–80 km from the highly urbanised western part of the country.



Map 3

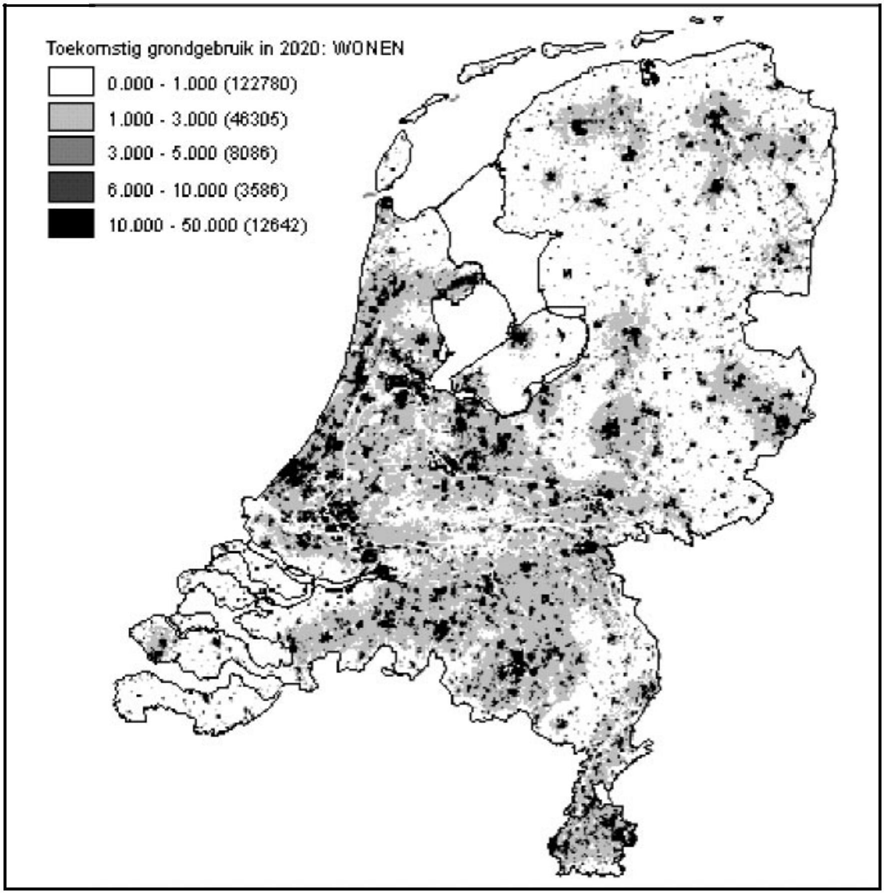
Map 3. Calculated land scarcity indicators given *European Coordination*.

The land scarcity indicators (demand for land use) are defined for each cell by:

$$p_c = \beta^{-1} \cdot \log\left[\sum_j \cdot a_j \exp(\beta \cdot s_{cj})\right]$$

using the a_j factors that result from allocating the claims. Thus we may expect high land scarcities in those cells c where suitabilities are high for highly demanded land use types.

The map shows a pattern with high values in the Western part of the Netherlands. It clearly shows that the land scarcity indicators according to this scenario are high in and near the most urbanised regions. Urban functions (residential, industrial) play a dominant role in the bidding process for the use of land according to this scenario. Low land scarcity values are found in the Veluwe region (a large natural area located in the centre of the country) where



Map 4

restrictions on the use for urban functions imply low values for the scarcity indicator. If the restrictions on land use for urban functions would be lifted in the natural areas, one may expect much higher values for the scarcity indicator in these areas. This underlines the importance of policy constraints in land use patterns.

Map 4. Allocated residential land use

In Map 4 we show the allocation of residential land use in the coming decades as generated by LAND USE SCANNER. By comparing this map with Map 1, we see that in the *European Coordination* scenario, growth in residential land use mainly takes place near the existing urban areas. The new spatial pattern of the distribution of population is clearly less differentiated than the present one. It appears that large regions can be discerned with high shares of urban land use; these regions consist of various existing cities and the corridors in between. This does not only hold true for the Randstad area located in the Western part, but also for city regions in the Southern and Eastern part of the country.

A closer comparison of Maps 1 and 4 shows that the so called Green Heart area (the lowly urbanised area in between the large cities of Amsterdam, Rotterdam, the Hague and Utrecht) will experience a substantial increase in residential land use in this scenario. Thus the present government policies to keep this area 'open' against market forces are not very successful in this scenario.

The maps shown here provide only a limited example of the possibilities of the LAND USE scanner. Alternative long term scenarios for the economy would result in different pictures. Also changes in the intensity of policies to restrict the growth of urban functions in natural areas would lead to considerably different results.

7. Conclusions

The strength of LAND USE SCANNER is that it integrates detailed databases and sectoral models from quite different backgrounds in a consistent spatial framework. It generates predictions for land use and effects based on future spatial developments with different scenario's. It has helped not only as a modelling tool, but also as a communication device to support the exchange of ideas, modelling concepts, and spatial data between institutes that are involved in spatial planning and/or related research.

One may wonder to what extent this model is transferable to other countries. It is clear that from a data viewpoint, the Netherlands may have an advantage above other countries. However, also with less detailed databases, the model still makes sense. A related critical success factor is the willingness to co-operate of various agencies supplying data and using model results. This willingness can be greatly improved when these agencies become co-owner of the model so that they can use if for their own policy preparation purposes. Another factor is that the tradition of long term planning in the Netherlands has stimulated this development. It should be emphasised, however, that also without such a planning context, a LAND USE SCANNER type of model can be quite useful for example to survey possible medium term developments in land use as a consequence of various technological trajectories or physical processes.

The LAND USE SCANNER model can be/is being extended into several directions.

1. *Intensities of land use* have not yet been included. A possible way to achieve this is by making aggregate demand for a certain land use category dependent on its shadow price. A high shadow price would imply an incentive to make the land use type concerned more land intensive.
2. The *interrelationships with the driving sectoral models* is uni-directional thus far. A structure where outcomes of LAND USE SCANNER would feed back into the driving models would improve the quality of the model system as a whole.
3. *Sectoral detail* of the model can still be improved. Especially for the urban and natural functions a more detailed treatment would be called for.

4. *Calibration* of the model has focussed on the β parameter thus far. A more extensive historic calibration including multiple parameters together is required.
5. Because of its integrated character, uncertainties and errors propagate through the whole grid system. Sensitivity analysis is needed to find out the extent to which changes in the input have an impact on outcomes. Such type of analysis helps to formulate priorities in terms of calibration of the parameter.
6. *Links between actual land prices and shadow prices* as generated by the model can be investigated in more detail and should be compared with the results of other land use models.
7. *Incompatibilities and synergies between land use types* in a cell may have to be included.
8. *Spatial spill-over effects* have not yet received much attention. These neighbourhood effects can be both positive or negative (the suitability of land use type j in a cell is increased/decreased when in a neighbour cell there would be a good amount of land use type j').
9. There is a need to add to the model a number of *summary indicators of the spatial patterns* generated. Examples are indicators of the heterogeneity of land use among cells or regions, the size of urban areas, etc. These indicators can also be used in an evaluative context to compare different land use policies.
10. There is a need for the implementation of further support of *interactive modelling* and model result management.

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Online information. See: http://www.geodan.nl/simnl/index.htm

References

Alonso W (1964) Location and land use. Harvard University Press, Cambridge
Allen PM, Engelen G, Sanglier M (1986) Self-organizing systems and the laws of socioeconomic geography. European Journal of Operational Research 25:127–140
Anas A (1982) Residential location models and urban transportation. Academic Press, New York
Beurden AUCJ van, Hilferink MThA (1993) Spatial analysis with GIS at RIVM. A background overview of spatial analysis with GIS in research for environment and public health. RIVM, Bilthoven
Central Planning Bureau, economie en fysieke omgeving. The Hague 1997
Cramer JS (1991) The LOGIT model: an introduction for economists. Edward Arnold, London
Cramer JS (1986) Econometric applications of maximum likelihood methods. Cambridge University Press, Cambridge
Fujita M (1989) Urban economic theory. Cambridge University Press, Cambridge
Engelen G (1988) The theory of self-organization and modelling complex urban systems. European Journal of Operational Research 37:42–47
Fotheringham AS, O'Kelly ME (1989) Spatial interaction models: formulations and applications. Kluwer, Dordrecht
Hayashi Y, Roy J (eds) (1996) Transport, land-use and the environment. Kluwer, Dordrecht
Landis J (1994) The California urban futures model: a new generation of metropolitan simulation models. Environment and Planning B 21:399–420

Mills ES (1972) Studies in the structure of the urban economy. Johns Hopkins University Press, Baltimore

Roy GG, Snickars F (1996) City life; a study of cellular automata in urban dynamics. In: Fischer M, Scholten HJ, Unwin D (eds) Spatial analytical perspectives and GIS. Taylor and Francis, London, pp 213–229

Sanders L (1996) Dynamic modelling of urban systems. In: Fischer M, Scholten HJ, Unwin D (eds) Spatial analytical perspectives and GIS. Taylor and Francis, London, pp 229–245

Schipper RA (1996) Farming in a fragile future. Wageningen Agricultural University, Wageningen

Schotten CGJ, Velde RJ van de, Scholten HJ, Boersma WT, Hilferink MThA, Ransijn M, Rietveld P, Zut R (1997) De ruimtescanner; geintegreerd ruimtelijk informatiesysteem voor de simulatie van toekomstig ruimtegebruik. RIVM-rapport 711902. RIVM, Bilthoven

Webster FV, Bly PH, Paulley NJ (1988) Urban land use and transport interaction. Avebury, Aldershot

Wegener M (1994) Operational urban models: state of the art. Journal of the American Planning Association 60:17–30