INTEGRATED LAND-USE AND NETWORK MODELLING

Ir. A. Keuren and Prof. Ir. F.M. Sanders
Delft University of Technology
Department of Infrastructure
Delft
The Netherlands

ABSTRACT

In this paper, the integration of modelling the changes in land-use and the changes in the infrastructure network will be described. Emphasis is laid on the automatic development of the network instead of changing the network by hand before simulating the changes in the land-use pattern.
The approach and working procedure were tested by developing a pilot model simulating the spatial situation on the Frisian island Ameland (The Netherlands). The pilot is developed within the geographical information system Arcinfo. In this pilot model, special attention is paid to the extension of the infrastructure network and the allocation of more than one activity.
Network analysis for the purpose of network extension is based on graph theory. Selection of links is based on the increase of the total accessibility within the network system as a result of adding a link to the network. The allocation of activities is based on several selection criteria and takes place within a cellular grid. Several methods of selecting cells and links and the choices made will be discussed.

1 INTRODUCTION

Spatial Decision Support Systems (SDSS) are helpful tools for spatial decision-makers and planners to reduce the decision time and to increase the accuracy of the solution (Crossland 1995).
Since the advent of computers many spatial models have been developed focusing on one or several types of land-use, whether or not integrated with transportation modelling. Examples are the Lowry model (Lee 1973), the Leeds Integrated Land-use Transport Model (LILT) (Mackett 1983), the Integrated Transportation and Land Use Package (ITLUP) developed by Putman (1983), the Dortmund housing market model (Wegener 1985), Wingo’s transportation and land-use model (Barra 1989), MEPLAN (Echenique et al. 1990) and the Islay Land Use Decision Support System (ILUDSS) (Zhu et al. 1996). Wegener (1994) gives an overview of twelve operational urban models. The former models were developed using common computer languages. Recently, however, graphical tools such as cellular automata (CA) and geographical information systems (GIS) have been used in spatial modelling. CA are a powerful tool for describing the dynamics of human settlement (Semboloni 1997), while GIS provide tools for spatial analysis and presentation. Some examples of literature on the use of CA and GIS in spatial modelling are Diamond and Wright (1988), Batty and Xie (1994), Batty and Densham (1996), Mann (1996), Zhu (1996), Clark et al. (1997), Couclelis (1997) Semboloni (1997), White et al. (1997), Wagner (1997) and Wu and Webster (1998).
Characteristic for all these models is that the physical network is considered to be exogenous and fixed during simulation. The effect of the development of the infrastructure network on changes in the distribution of activities, and the other way around, is not included in the simulation.

Separately from the development of spatial models research, on the automated network design has been carried out by Dionne and Florian (1979), Magnanti (1984), Minoux (1989), Janson et al. (1991), Kribbe and Sanders (1996) and Solanki et al. (1998).
This paper deals with integrating the modelling of the development of infrastructure networks and of changes in the distribution of activities. A pilot model has been developed within the geographical information system Arcinfo. The pilot model was developed for several reasons. Firstly, to discover the practical problems of modelling. Secondly, to support the formulation of theories. Finally, to find out the possibilities and limitations of Arcinfo.
The model has been applied to the Dutch Frisian island Ameland (figure 1). An island was chosen to be studied to avoid the problem of defining the boundaries of the area and to avoid exogenous influences. The island Ameland was particularly chosen because of its relative simplicity. The island has four villages, some holiday parks and a rather simple network of roads. The island is a popular holiday resort among the Dutch people. The northern side of the island is largely occupied by nature areas. The southern part is primarily used for agriculture.
The pilot model was tested by evaluating the changes in the land-use pattern and the development of the network of Ameland. The findings of these tests were used to further develop the model and to make practical and theoretical choices.
In this paper, first, the modelling of the real world and the procedures of the model will briefly be described (section 2). Next, an explanation will follow about some details of the model and about important choices that were made (section 3). In section 4, some results will be described. The paper will be concluded with some points of discussion.

2 SHORT OVERVIEW OF THE MODEL

In this section, the procedures in the model and their interrelation will be described. The main procedures that are distinguished are exclusion of non-suitable areas, potential surface analysis, allocation of activities and network analysis. However, before the procedures are described, the modelling of the static real world is

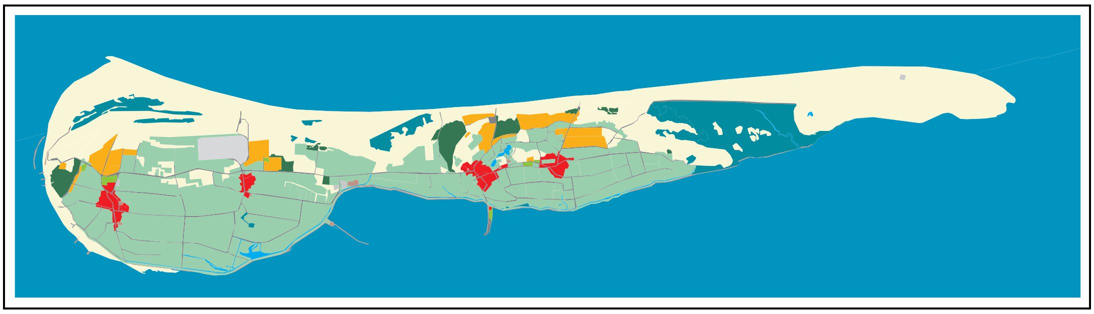

Figure 1: **The Dutch Frisian island Ameland. (Source: Centraal Bureau voor de Statistiek)**

described. Firstly, the modelling of the infrastructure network is described. After this, the way of modelling the land-use pattern is explained.

2.1 **Modelling the infrastructure network**

In this research, the infrastructure network is defined as the system of physical connections that enables passenger and freight transport. Examples are roads, railways, waterways and pipelines. Communication networks, for telephone and computers are being left out of consideration in this research. For the sake of simplicity, at first, only roads will be considered. In the network analysis, the infrastructure network is simplified to a graph, according to graph theory (see Haggett et al. 1969). In a graph, the geographical position of nodes and links is not relevant. What is relevant is which nodes are connected with each other. In this case the nodes represent cities and roads are represented by the links in the graph. The projection of reality to graph is shown in figure 2. A characteristic is associated with both the nodes and the links. With each node a weight is associated that is expressed in number of inhabitants, number of houses, number of jobs or working area. Characteristics of a link can be length, travel time and capacity.

2.2 **Modelling the land-use pattern**

The study area is divided in square cells of equal size, a so-called cellular grid (figure 3). Each cell is characterised by three types of features. The most obvious type of features are the properties of the cell itself. These properties are actual land-use, juridical status, soil type, groundwater level, number of inhabitants, number of jobs, number of houses and working area. Beside the properties of the cell itself, two types of derivative characteristics are distinguished, both depending on spatial relations.

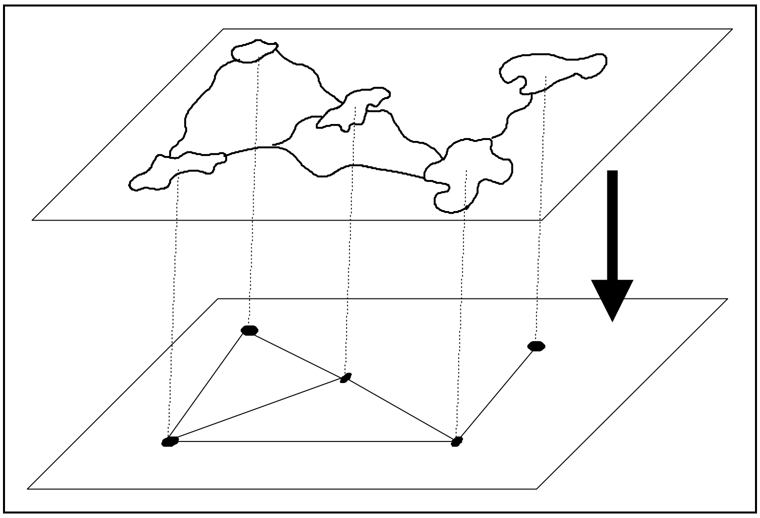

Figure 2: **Projection of reality to graph.**

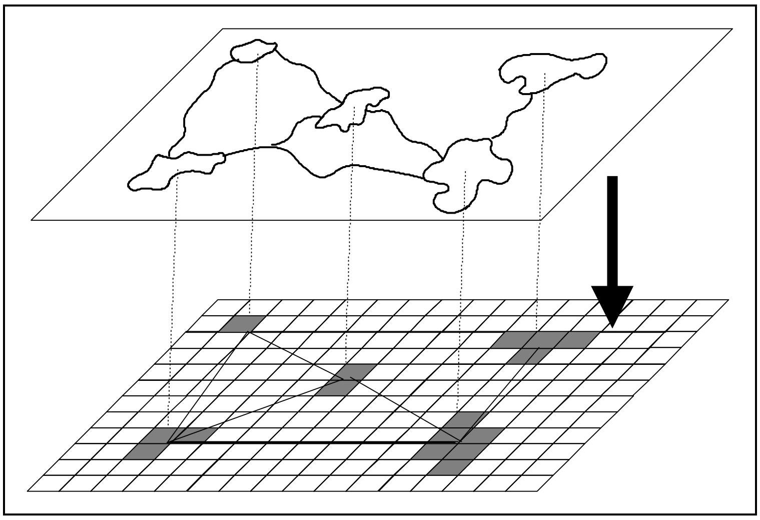

Figure 3: **Projection of reality to cellular grid.**

These are characteristics depending on adjacent surroundings, such as distance to conflicting or complementary land-uses, and characteristics depending on distant spatial relations along the infrastructure network, such as the accessibility of a cell with respect to other cells.
A cell is considered homogenous which means that a cell can only have one value for each characteristic. In reality, a cell could be occupied by more than one land-use. In the model the land-use that occupies more than one half of the cell, is assumed to be the land-use that occupies the whole cell.

2.3 **The procedures in the model**

Figure 4 illustrates the procedures and their interrelationship. The model is fed by exogenous data. In a socio-economic macro-model the additionally needed land-use is calculated, based on the exogenous input and the actual spatial situation in the study area. After exclusion of non-suitable areas, a potential surface analysis, a cost-calculation and a multi-criteria evaluation, an activity is allocated for the needed area of land. Additionally, through network analysis it is determined whether the network should be adapted to the new situation. This process is repeated for the period to be considered.
In this section, the main procedures of the model will be described. Respectively, the exclusion of non-suitable areas, the potential surface analysis, the allocation of land-use and the network analysis will be described.

2.3.1 *Calculation of additionally needed land*

In figure 4 the socio-economic macro-model is embedded in the allocation model. In this way, the additionally needed land is calculated for each time-step, where changes in the land-use pattern are considered in the calculation. Another option is to position

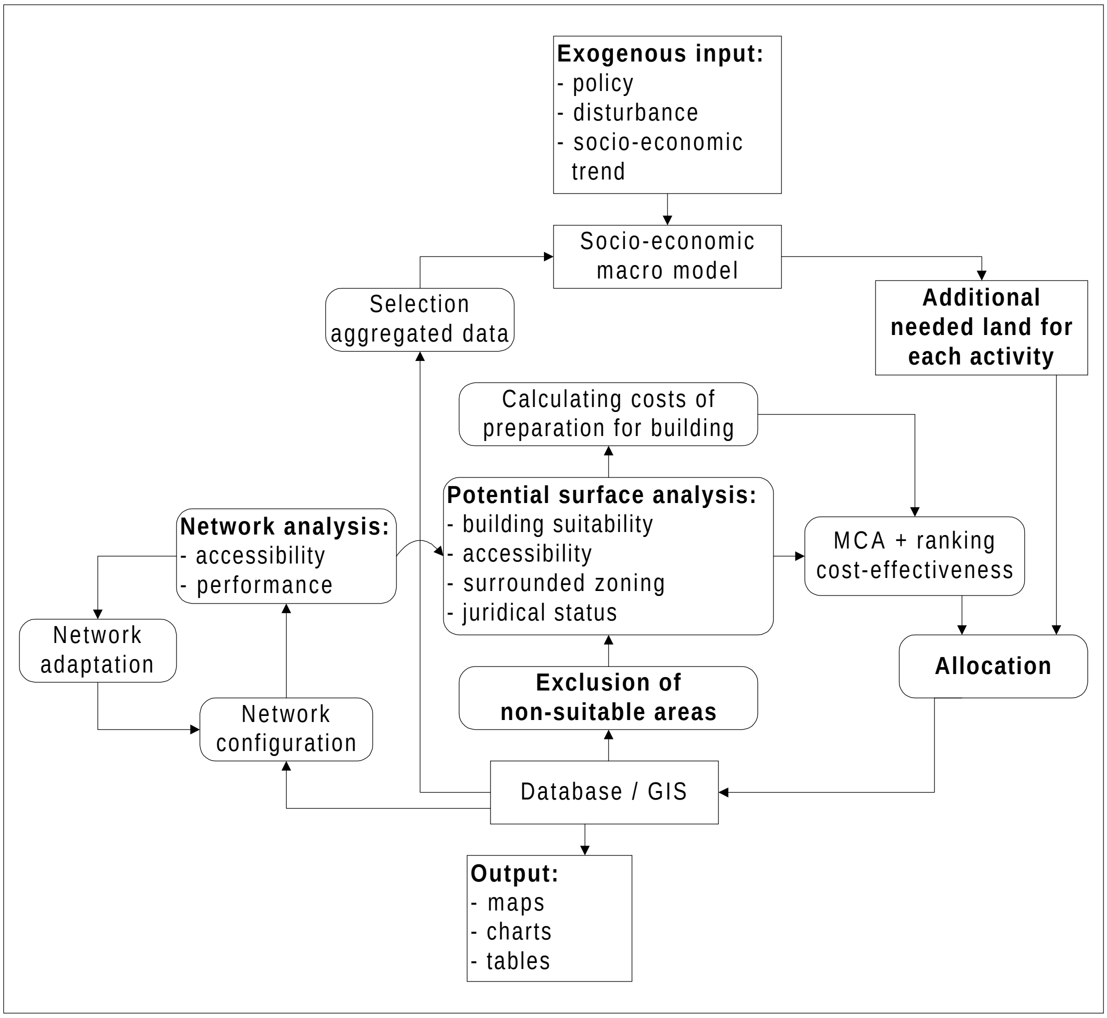

Figure 4: **Flowchart of the model**

the socio-economic macro-model outside the allocation model. The additionally needed land is calculated once for the whole time-period to be considered in the simulation. Intervening changes in the land-use pattern are not considered in this way. For the moment, the socio-economic macro-model is positioned outside the allocation model.

Additionally to the different ways of calculating the additionally needed land in time, two ways of calculating the needed land over space can be distinguished. The needed land can be specified for the whole study area, as is done in this study. The allocation of the activities then is fully determined within the allocation model. To realise a certain distribution over the area, the needed land for each city can be specified.

2.3.2 *Exclusion of non-suitable areas*

The first step is to reduce the search area. All non-suitable areas are excluded. The exclusion is based on the actual land-use, the juridical state and the distance to incompatible land-uses. For each activity to be allocated, different areas can be excluded. After the exclusion of non-suitable areas, all the potential cells for the activity to be allocated are left.

2.3.3 *Potential surface analysis*

After the exclusion of non-suitable areas, the suitability of the potential cells is determined for each activity to be allocated. Each cell is judged on three types of criteria similar to the characteristics of a cell. These are the properties of the cell itself, the adjacent surroundings and the distant spatial relations along the infrastructure network. The exact composition of the criteria-set depends on the land-use to be allocated. For example, the set of criteria for housing could be composed of soil type, groundwater level, presence of adjacent housing, internal accessibility and external accessibility. These criteria will be explained later in this paper. The observations for each characteristic are classified to a score for each corresponding criterion. After the classification a multi-criteria analysis is executed to get a total score for each cell. The total score for each cell is obtained by summation of all the scores. A weighted summation is executed to reflect the importance of the criteria.

2.3.4 *Allocation of activities*

The next step in the simulation is the allocation of activities. To start with, the allocation is limited to residential and industrial activities. The activity is allocated to the best scoring cell or cells. If more than one activity has to be allocated, the activity which is given preference to, will be allocated first. This means that all the described steps will be executed for the one activity firstly, then for the next activity et cetera.

2.3.5 *Network analysis*

The allocation of activities takes place within a fixed network. However, after several steps of allocation, the network may become insufficient to serve all people in a region appropriately. According to the dynamics of the infrastructure network, the quality of the network therefore is checked after five steps of allocation. The quality of the network is expressed as the sum of the accessibility of all nodes. The quality, or accessibility, is considered no longer sufficient if a new link can be added to the network that leads to a significant increase of the accessibility within the whole network. The increase of the accessibility should at least equal the threshold value. This threshold value is a specified percentage of the actual accessibility. So after five steps of allocation, the network is extended with the link that gives the largest increase, provided that this increase at least equals the threshold value.

After the network analysis, the allocation procedure is gone through again, whether or not with an extended network.

The number of potential new links is limited by considering the most realistic links between the given nodes. The most realistic links are specified in a so-called virtual network. Further details about this virtual network follow in section 3.6.2.

3 DETAILED EXPLANATION

In this section, an explanation follows about some details of the model and some important choices that were made. Firstly, the use of a cellular grid will be explained. Secondly, a further explanation follows about the exclusion of non-suitable areas. Thirdly, four allocation criteria and the way they are classified and summed will be described. After this, four methods of allocation will be described. Finally, the use of a threshold value and the use of a virtual network will be explained.

3.1 **Cellular grid**

The study area is divided into square cells of equal size. The advantage of doing this is that the area of the alternative locations is equal, so they are comparable to each other. When applying a cellular grid, it is important to use a right cell-size. A cell is considered homogenous which means that a cell can only have one value for each characteristic. The land-use that occupies more than one half of the cell, is assumed to be the land-use that occupies the whole cell. The cell-size, therefore, determines the accuracy of the model. The smaller the cell, the better the approach of the real world (figure 5). However, by reducing the cell-size, the number of cells increases very fast and, consequently, the calculation time increases very fast. So, accuracy and calculation time have to be weighed up against each other. For the regional scale-level, a cell-size of 100 by 100 meters was chosen.

3.2 **Exclusion of non-suitable areas**

The simulation begins with excluding all non-suitable areas of the study area. According to the flowchart in figure 4, the exclusion of non-suitable areas takes place before each allocation. However, the exclusion can be divided in two parts: (1) exclusion based on unchanging conditions and (2) exclusion based on changing conditions. The first mentioned exclusion only is carried out at the beginning of the simulation. In the case of Ameland, this means that all non-agricultural areas are excluded from allocation. The exclusion based on changing conditions is especially important when two conflicting activities have to be allocated. This exclusion has to

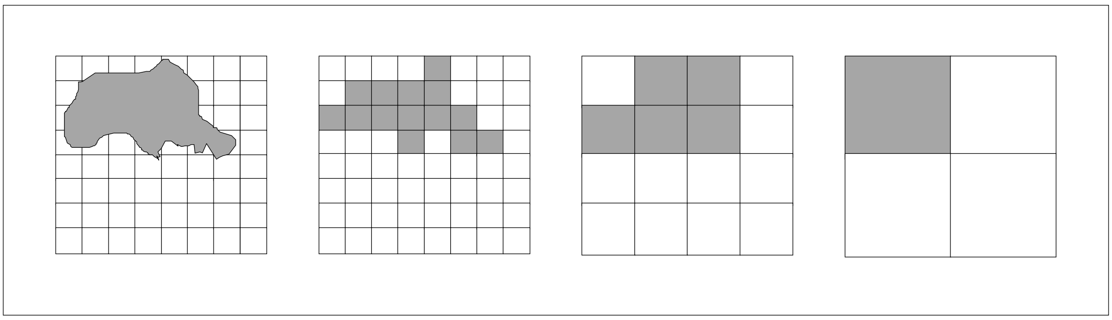

Figure 5: **Conversion from real to grid with different cell-sizes.**

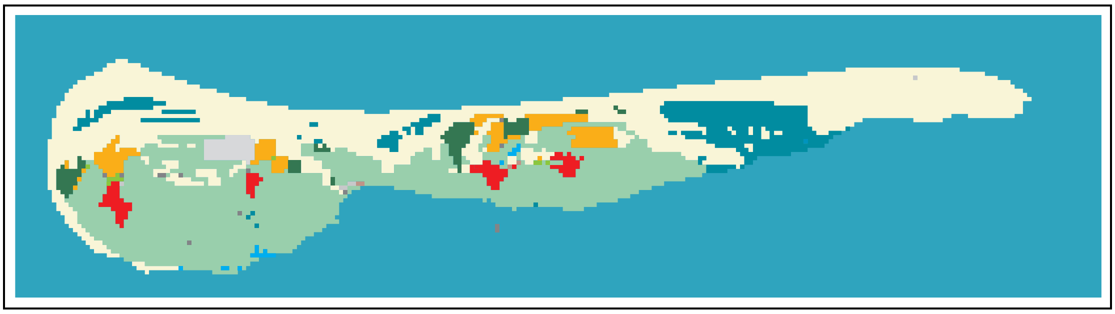

Figure 6: **A cellular grid applied to the Dutch Frisian island Ameland.**

take place every time an activity has been allocated. For example, if industries are allocated, the adjacent areas have to be excluded from allocation of housing.

3.3 **Allocation criteria**

Within the area left after exclusion of non-suitable areas, the suitability of all the cells for each activity to be allocated has to be determined. Each cell is judged on three types of criteria. The first type of criteria are the ones based on the properties of a cell itself. An example is the criterion soil suitability. The soil suitability is determined by soil-type and groundwater level. The second type of criteria is based on the properties of and relations to the adjacent surroundings, for example, nearness of existing built up area. Criteria based on spatial relations along the infrastructure network, such as accessibility of a city in relation to other cities, are the third type of criteria. For each activity to be allocated, a specific set of criteria is composed. To judge a cell on suitability for a future activity, the observed characteristics or values have to be translated to comparable scores by classifying them. For the classification of quantitative characteristics several calculation methods can be distinguished. The classification of qualitative characteristics can be done using expert judgement and differs with the type of data.

In this section, firstly, the quantitative classification in general is explained. Additionally, several allocation criteria and the way of classifying them is described.

3.3.1 *Classification*

Two methods can be distinguished to translate the observed values to comparable scores. One method is to standardise the values. There are several variants to standardise. For example, the observed values can be divided by the maximum observed value and multiplied by 10 to get a scale from zero to ten.

$$S_s = \frac{V}{V_{\max}} * n \qquad \textit{Equation 1}$$

With:

S_s = standardised score

V = observed value

V_{max} = maximum observed value

n = maximum standardised score

In addition, the minimum observed value can be involved. The minimum value can be set equal to zero. Therefore, the minimum value is subtracted from all the other values. The formula looks like:

$$S_s = \frac{V - V_{\min}}{V_{\max} - V_{\min}} * n$$ *Equation 2*

With:

V_{min} = minimum observed value

The other method is to classify the observed values. Qualitative as well as quantitative data can be made comparable in this way. Because we are dealing with both kinds of data, classification is preferred above standardisation.

Quantitative scores can be classified as follows. Firstly, the class size has to be determined. This is done by dividing the difference between the maximum and minimum observed value by the number of classes to be obtained.

$$C = \frac{V_{\max} - V_{\min}}{n}$$ *Equation 3*

With:

C = class size

n = number of classes

Then the upper limit of the lowest class can be obtained by adding the class size to the minimum observed value. The upper limit of the lowest class equals the lower limit of the next class. So, adding the class size to this limit gives the upper limit of this class et cetera. Finally, the scores can easily be joined with the classes.

3.3.2 *Soil type*

The soil types in the Netherlands were classified and mapped by STIBOKA, the Dutch Institute for Soil Mapping. The main types that are distinguished are sand, clay and peat (Vries And Denneboom 1992). These three types have been classified as follows. Sand is the most suitable soil type for building and therefore gets score five. Clay and peat respectively have been given the scores three and one.

3.3.3 *Groundwater level*

On the soil maps of STIBOKA also the groundwater levels are given. The upper and lower limits of the groundwater levels are the limits of the classes. The classes are shown in table 1. The limits of the classes equal the limits of the groundwater levels in winter as classified for the Netherlands (Vries And Denneboom 1992).

Table 1: **Classification of groundwater level**

Class	Limits
1	< 50 cm
2	50-80 cm
3	80-120 cm
4	120-150 cm
5	< 150 cm

3.3.4 *Internal accessibility*

The internal accessibility is defined as the accessibility of each cell related to all the other cells within the city. The purpose of calculating the internal accessibility is to compare cells within a city or at the border of a city. The internal accessibility is calculated as follows:

$$A_i = \sum \frac{W_j}{d_{ij}}, j \neq i \qquad \textit{Equation 4}$$

With:

A_i = accessibility of cell *i*
W_j = weight of cell *j*
d_{ij} = distance between cells *i* and *j*

In words: The accessibility is the sum of the quotients of the weight of each cell *j* and the distance between cells *i* and *j*. The weight of a cell could be the population of a cell, the number of jobs, number of houses or working area. The weight of a cell is calculated by dividing the total population by the number of built-up cells. The distance between cells is the straight distance calculated with the Pythagorean theorem.

3.3.5 *External accessibility*

To allocate housing, the external accessibility is one of the criteria that is used. The external accessibility is defined as the effort all people in the study area have to make to reach a specific node in the network. The effort it takes to reach a node depends on the distance to that node. The external accessibility is calculated to compare the

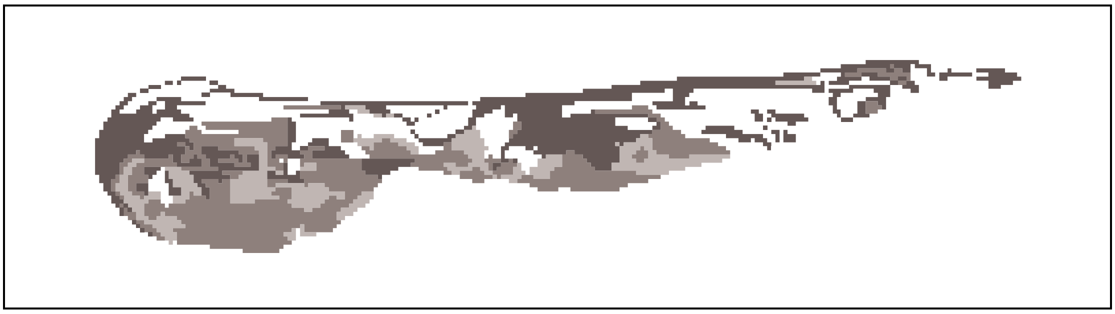

Figure 7: **The classes of the groundwater level of Ameland. The darker the colour, the higher the class.**

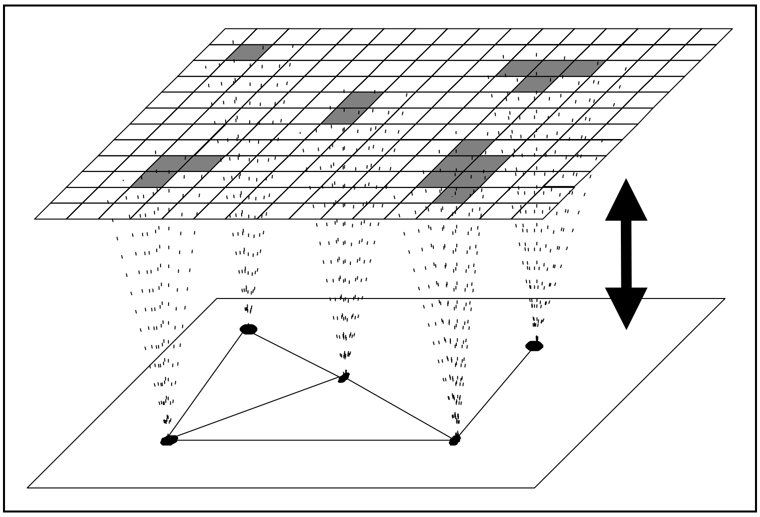

Figure 8: **Node to cell conversion and vice versa.**

different cities. This accessibility, therefore, is calculated on a higher scale level than the internal accessibility. The external accessibility is calculated using distances along the network. As explained earlier in this paper, the network is modelled as a graph. The cities are represented by nodes, while the roads are represented by the links in the graph. The external accessibility is calculated as follows:

$$A_i = \frac{W_i}{d_i} + \sum \frac{W_j}{d_{ij}}, j \neq i \qquad \textit{Equation 5}$$

With:

A_i = accessibility of node *i*
W_j = weight of node *j*
d_{ij} = distance along the network between nodes *i* and *j*
W_i = weight of node *i*
d_i = internal distance of node *i*

Two parts can be distinguished after the equal sign in equation 5. The second part concerns the real external accessibility, the effort that people from other cities have to make to reach city *i*.

The first part is an internal accessibility. This is not the same as the internal accessibility explained in the previous sub-section. This accessibility is calculated to compare cities and does not distinguish between the cells within the city. This internal accessibility is calculated for one node. It is calculated by dividing the total population of a city by the internal distance. The internal distance is calculated as the mean distance of all cells to each other within the city. It may look like the internal accessibility is accounted for twice when calculating the total score of a cell. However, because of the difference in scale level and, therefore, the different intention, there is no double count.

The external accessibility is calculated for each node in the network. To be able to use this criterion for the allocation a score for each cell is needed. Therefore, all the cells that belong to a node i.e. a city get the same score as this node (see figure 8).

3.4 **Multi-criteria evaluation**

To come to a total score for each cell and each activity, multi-criteria evaluation is applied. A multi-criteria evaluation method can serve to make an inventory, classify, analyse and conveniently arrange the available information concerning choice-possibilities in urban and regional planning (Voogd 1982). Two important features characterise the multi-criteria evaluation methods. Firstly, they start from a number of explicitly formulated criteria. Secondly, they are able to explicitly account for political priorities. The use of multi-criteria evaluation gives the opportunity to evaluate different land-use patterns depending on different policies. Firstly, the differences in policies can be modelled by changing the set of criteria. Secondly, a set of criterion priorities can be formulated. In this research, the priorities are represented by means of quantitative numbers, so-called weights.
After the scores for each criterion are multiplied with the weights, these weighted scores are summed to a total score.
Using a set of parameters as a multiplier for every criterion a calibration of the model can be executed, based on historical data and land-use patterns.

3.5 **Methods of allocation**

Various methods can be distinguished for the allocation of activities. In this paper, four methods will be described. Surely, this description does not contain all possible methods. Only those methods will be described, which are used in this research.
The various methods will be used to compare their effects on the land-use pattern. No selection of the best method will be made. It should be emphasised that one step in the model, does not have to correspond with one time-step in reality.

One cell each step
Only one cell will be allocated in each step. After this allocation, the potential surface analysis is repeated and another cell can be allocated et cetera. If two cells have the same best score, one of them is chosen arbitrarily. The advantage of this method is that changes on the most detailed level of the model are considered.

Several cells each step
In this method, not only the best cell is allocated. The best five or ten cells are determined and allocated. Then the potential surface analysis is repeated for the new situation et cetera. The disadvantage of this method is that not all possible changes in the land-use pattern are considered.

Evaluate a path of choices

Choosing the best cell each step gives no guarantee for the best final situation. The solution for this problem is to evaluate all combinations of successively chosen cells. A simple example illustrates that the number of possible combinations is so enormous that this is an inadequate approach. Suppose, out of 100 cells all the combinations of ten cells chosen successively have to be evaluated. The number of possible combinations (n) than is:

$$n = \frac{100!}{10!(100-10)!} = \frac{100!}{10!90!} = 1{,}73 * 10^{13} \qquad \textit{Equation 6}$$

Connected area of several cells each step

The disadvantage of the previous methods is that no connected area is allocated. In most cases, all the cells are spread over the study area. It could be desirable to allocate a connected area of certain size, bigger than one hectare. To find the best connected area of certain size a zonal search operation could be used. A restriction of this method is that the shape of the area has to be predefined. This does not have to be an objection. However, some flexibility would be desirable. The solution of this problem is still a subject of discussion.

3.6 **The network**

After several steps of allocation, the network may become insufficient to serve all people in region. Therefore, the quality of the network is checked through network analysis. In this section, firstly, the use of a threshold value to determine whether a new link should be added to the network, is described. Next, the virtual network is described that is used to limit the number of potential new links.

3.6.1 *Threshold value*

The quality of the network is expressed as the sum of the accessibility of all nodes. The network is extended if adding a link to the existing network leads to a significant increase of the accessibility of the system. Therefore, a threshold value has to be specified. The difficulty of specifying a threshold value is that the increase of accessibility as a result of adding a new link to the network is not constant. The increase depends on the density of the network. The effect of adding a new link to the network is smaller if the network is already very dense. Figure 9 shows the course of the increase in terms of percentages depending on the number of the link to be added to the network. The threshold value should roughly follow the same course. For example, the first link to be added to the network should at least result in an increase of 14.5 % of the total actual accessibility, while the increase resulting from the tenth link should equal at least 2.5 % of the actual accessibility.

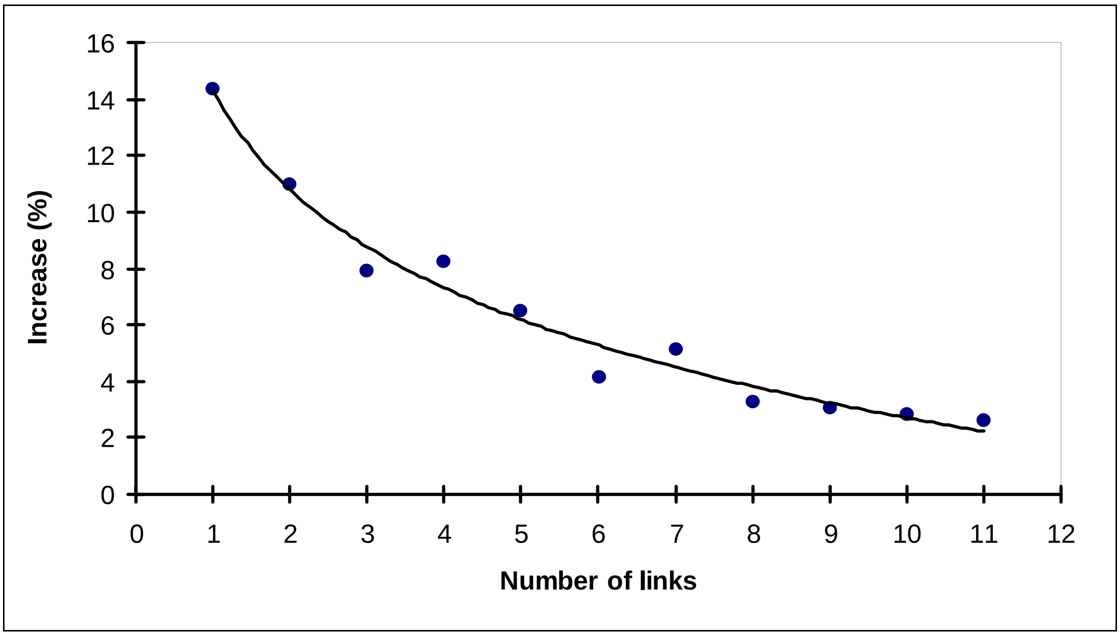

Figure 9: **The increase of accessibility in terms of percentages, depending on the number of the link to be added.**

3.6.2 *The virtual network*

To decide whether or not a new link is added to the network, all potential new links have to be looked at. A new link could be any conceivable link between any two nodes within the study area. Figure 7-a shows a so-called network of maximum connectivity, which contains all possible links. The network contains 23 nodes, and therefore 529 links. Even if there were already 25 links within the real network, far too many possibilities of extending the network would have to be evaluated. Besides, many links are not realistic. This can be seen in figure 7-b. Nodes A and B are connected by five links in a straight line. Obviously, a direct link between A and B is redundant, because the intermediate nodes have to be connected too. To avoid unnecessary calculations, a so-called virtual network can be designed. This is a network of all relevant potential future links. The virtual network is a fictitious network out of which new links can be chosen. The virtual network is designed by removing all the non-realistic links out of the network of maximum connectivity for example based on a so-called detour factor. The virtual network should be a little more extensive than the actual future network (figure 7-c).

4 CASE-STUDY

The pilot model was tested on the island Ameland. Residential areas and holiday parks were allocated. The criteria used for judging the suitability for residential area have been explained in the previous sections. These were the soil type, groundwater

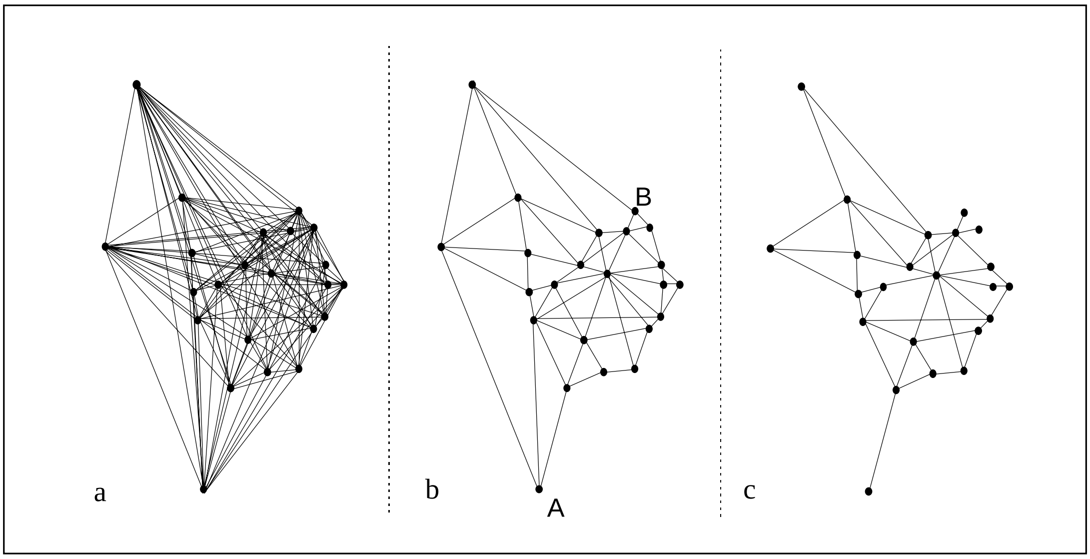

Figure 10: **Examples of (a) the network of maximum connectivity, (b) the virtual network and (c) the actual network.**

level, internal accessibility and external accessibility. The criteria set for judging the suitability for holiday parks consisted of soil type, groundwater level, the accessibility of the villages and the accessibility of the woods on the island. The criteria sets have been kept very small and are not meant to be complete. In this section some results of the tests are presented.

Earlier in this paper, four methods of allocation were described: allocating one cell each step, allocating several cells each step, evaluating a path of choices and allocating a connected area of several cells each step. The first two of those methods of allocation have been tested. Figure 11 shows the resulting patterns when allocating one cell each step and when allocating five cells each step. In both cases, ten cells of residential area and ten cells for holiday parks were allocated. In case one cell is allocated each step, only the village at the left of the island grows. Each step, the best scoring cell is situated at the border of that village. A different pattern results when five cells are allocated each step. The second village on the right now grows even more than the left village. Apparently, the cells at the edge of this village are not the best scoring cells, but they certainly belong to the best five. The differences in the growth of holiday parks are much smaller and more difficult to observe.

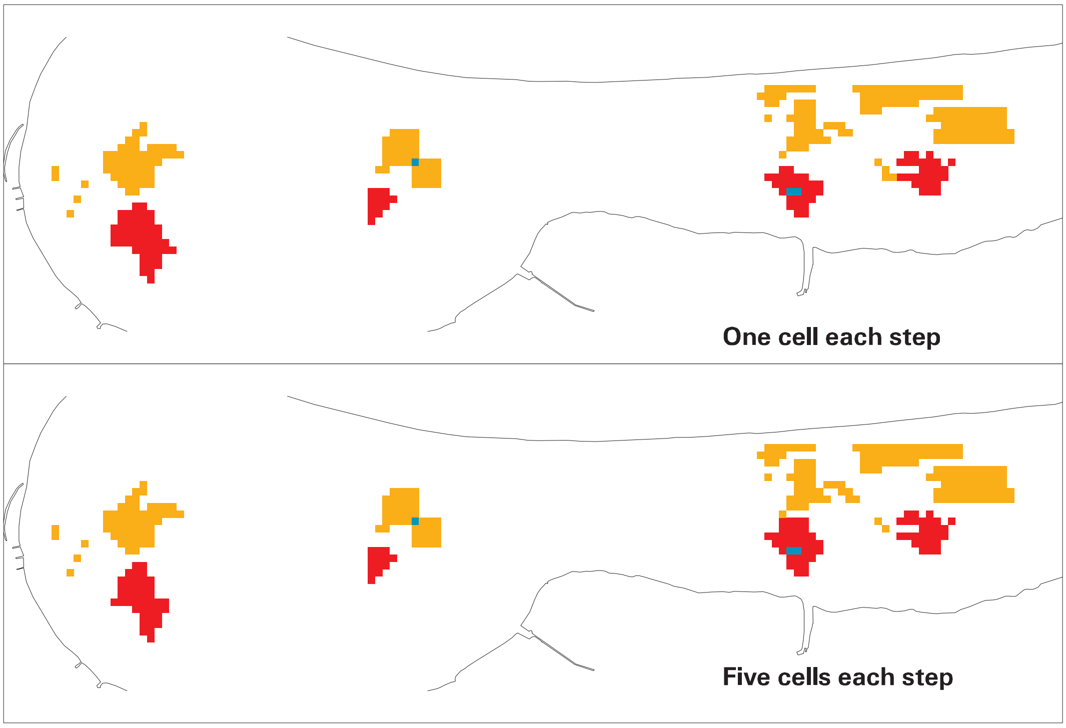

Figure 11: **The differences in patterns resulting from two methods of allocation. Dark grey spots are the villages, while the light grey spots are the holiday parks. The upper picture shows the pattern resulting when one cell is allocated each step. The lower picture shows the pattern resulting when five cells are allocated each step.**

Figure 12 shows three stages of the spatial development of Ameland according to the pilot model. The task was to allocate 50 hectare for each activity in twenty years. Each step, five cells, is five hectare, were allocated, where each step represented two years. The allocation criteria were given equal priority. The upper picture shows the initial situation. The dark spots are the villages, while the light spots are the holiday parks. Only the two largest villages grow. Probably, the accessibility, both internal and external, has the greatest influence on the allocation. The internal accessibility probably causes the formation of rather compact villages. The holiday parks mainly concentrate between the two villages on the right. The allocation is more dispersed than that of the residential area, where the allocation along the road is notable.
The initial network was fictitious because in reality the holiday parks are connected by roads too. For the sake of simplicity, only the villages were considered to be connected. For the infrastructure network no specific task was to be fulfilled. The development of the network depended on the development of the holiday parks and villages. Every step, the network quality was checked. In the first five steps, the links to the holiday parks on the left were added to the network. The next five steps, the two links on the were added. So not every step a link was added to the network.

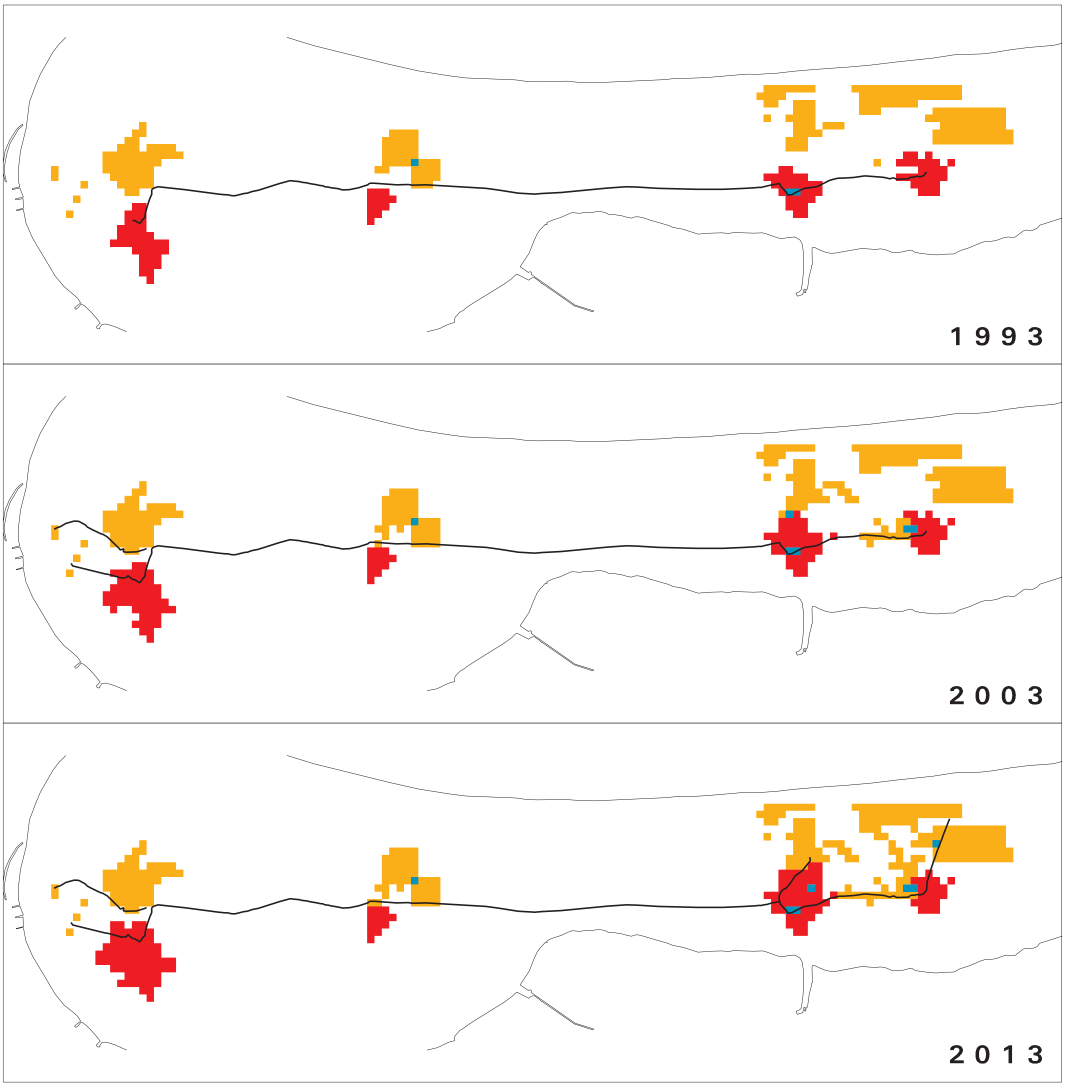

Figure 12: **Three stages of the spatial development of Ameland according to the pilot model. The dark grey spots are the villages, while the light grey spots are the holiday parks.**

5 DISCUSSION

First of all, it can be stated that the dynamic modelling has come out well. In each step, the changes in the previous steps are accounted for, where the development of the land-use pattern as well as the development of the network are considered both. The development of the network, however, is still too artificial. The network is modelled on a very abstract level, and in particular the reality value of the threshold value is questionable. Besides, the use of a virtual network on the one hand reduces calculation time, but, on the other hand, limits the flexibility of the simulation. Not only by fixing the number of potential links, but, maybe even more important, by fixing the number of nodes. So, all potential nodes have to be specified. The question is how to cover all potential nodes, particularly when more than one activity is involved.

Until now, no attention was paid to the calibration of the model. Special attention has to be paid to the measure of accessibility. The advantage of this measure is that it requires relatively few data. However, it is questionable whether this measure adequately reflects reality. A second point of attention with respect to the calibration of the model is the composition of the criteria-sets. However, this composition depends on the activity to allocate, the characteristics of the area and the policy to be pursued. A third aspect on which the model can be calibrated, is the method of allocation. In any case, an analysis of sensibility should be executed.

In the existing model the needed land-use for a certain period has been determined for the entire study area. The allocation concerns the selection of cells in which all cities and villages are compared to each other. The result may be that some places do not or hardly grow. In practice, often local needs have to be met. This requires a modelling in which a distinction is made in (1) an obligatory area for each city and village in the study area to be allocated and (2) an area to be allocated, freely spread over the study area. This is one way of modelling the control of spatial development through policy.
Another way of modelling this control is changing the composition of the criteria-set and set of weights. In some way, the composition of these sets can reflect a kind of policy. Different scenarios of policy can be analysed by changing the composition of criteria and weight sets.

The advantage of using a geographical information system like Arcinfo is that it contains many standard procedures for spatial analysis. These procedures can easily be combined to perform the desired calculations. Another advantage is the facility to easily present maps of the final situation and of intermediate time-steps. The disadvantage of Arcinfo is that some procedures take much calculation time. Performing some procedures outside the geographical information system should be considered.

REFERENCES

Barra, T. de la (1989) *Integrated land-use and transport modelling.* Decision chains and hierarchies. Cambridge Urban and Architectural Studies. University Press.

Batty, M. and Y. Xie (1994) From cells to cities, *Environment and Planning B: Planning and Design* 21, pp. S31-S48.

Batty, M. and P.J. Densham (1996) *Decision Support, GIS, and Urban Planning*, Centre of Advanced Spatial Analysis, University College London, UK.

Clark, K.C., S. Hoppen and L. Gaydos (1997) A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area, *Environment and Planning B: Planning and Design* 24, pp.247-261.

Couclelis, H. (1997) From cellular automata to urban models: new principles for model development and implementation, *Environment and Planning B: Planning and Design* 24, pp. 165-174.

Crossland, M.D., B.E. Wynne and W.C. Perkins (1995) Spatial decision support systems: An overview of technology and a test of efficacy, *Decision Support Systems* 14, pp. 219-235.

Diamond, J.T. and J.R. Wright (1988) Design of an integrated spatial information system for multiobjective land-use planning, *Environment and Planning B: Planning and Design* 15, pp. 205-214.

Dionne, R. and M. Florian (1979) Exact and Approximate Algorithms for Optimal Network Design, *Networks* 9, pp. 37-59.

Echenique, M. H., A.D.J. Flowerdew, J.D. Hunt, T.R. Mayo, I.J. Skidmore and D.C. Simmonds (1990)The MEPLAN Models of Bilbao, Leeds and Dortmund. *Transport Reviews* 10, pp.309-322.

Haggett P. and R.J. Chorley (1969) *Network analysis in geography*.

Janson, B.N., L.S. Buckels and B.E. Peterson (1991) Network Design Programming of U.S. Highway Improvements, *Journal of Transportation Engineering* 117(4), pp. 457-478.

Keuren, A. (1997) De invloed van over grenzen in de ruimtelijke modellering, *Planologische Diskussiebijdragen, 1997, Deel 1*, Delft.

Keuren, A. (1997), Joint spatial modelling of infrastructure network and distribution of activities, *Conference proceeding part 2 of the 3rd TRAIL Year Congress 1997, Transport, Infrastructure and Logistics, new times and innovative solutions offered*. Den Haag/Scheveningen.

Kribbe, W. and F. Sanders (1996) Growth of spatial network constructions: a decision support systems oriented approach, *3rd Design & Decision Support Systems in Architecture & Urban Planning Conference*, Spa.

Mackett, R.J. (1983) *The Leeds Integrated Land-Use Transport Models (LILT).* Supplementary Report SR 805. Crowthorne: Transport and Road Research Laboratory.

Magnanti, T.L. and R.T. Wong (1984) Network Design and Transportation Planning: Models and Algorithms, *Transportation Science* 18(1), pp. 1-55.

Lee, C. (1973) *Models in planning. An introduction to the use of quantitative models in planning*. Newcastle upon Tyne.
Mann, S. (1996) *Spatial Process Modelling fo Regional Environmental Decision Making*, Spatial Information Research Centre, University of Otago, New Zealand.
Minoux, M. (1989) Network Synthesis and Optimum Network Design Problems: Model, Solution Methods and Applications, *Networks* 19, 313-360.
Putman, S.H. (1983) *Integrated urban models; Policy analysis of transportation and land use*. London.
Sanders, F.M. (1997) Allocation modelling using cellular automata, in Lasker, G.E. (ed.), *Advances in support systems research*. Baden-Baden.
Sanders, F.M. and A. Keuren (1997) *The strategic position of the Randstad within the European infrastructure network.* Research Project Internationale Nederlanden Groep, Amsterdam.
Sanders, F.M and R.J. Verhaeghe (1997) Projection of the urbanisation pattern for the Jabotek region, *5th Asian Urbanisation Conference*, August 1997.
Semboloni, F. (1997) An urban and regional model based on cellular automata, *Environment and Planning B: Planning and Design* 24, pp. 589-612.
Solanki, R.S, J.K. Gorti and R. Southworth (1998) Using decompostion in large-scale highway network design with a quasi-optimization heuristic, *Transportation Research B* 32(2), pp. 127-140.
Voogd, H. (1982*) Multicriteria evaluation for urban and regional planning*. Delfsche Uitgevers Maatschappij B.V. Delft.
Vries, F. de and J. Denneboom (1992) (in Dutch) *De bodemkaart van Nederland digitaal*, Technical Document 1, Agricultural Research Department, Winand Staring Centre for Integrated Land, Soil and Water Research, Wageningen.
Wagner, D.F. (1997) Cellular automata and geographic information systems, *Environment and Planning B: Planning and Design* 24, pp. 219-234.
Wegener, M. (1985) The Dortmund housing market model: A Monte Carlo simulation of a regional housing market, in Beckmann, M. en W. Krelle; *Microeconomic models of housing markets*. Springer Verlag Berlin Heidelberg New York Tokyo.
Wegener, M. (1994) Operational Urban Models, *Journal of the American Planning Association* v. 60, n. 1, pp. 17-29.
White, R., G. Engelen and I. Uljee (1997) The use of constrained cellular automata for high-resolution modelling of urban land-use dynamics, *Environment and Planning B: Planning and Design* 24, pp. 323-343.
Wu, F. and C.J. Webster (1998) Simulation of land development through the integration of cellular automata and multicriteria evaluation, *Environment and Planning B: Planning and Design* 25, pp. 103-126.
Zhu, X, R.J. Aspinall and R.G. Healey (1996) ILUDSS: A knowledge-based spatial decision support system for strategic land-use planning, *Computers and Electronics in Agriculture* 15, pp. 279-301.