Spatial analysis in support of physical planning

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PART I: INTRODUCTION

Chapter 1

SPATIAL ANALYSIS IN SUPPORT OF PHYSICAL PLANNING[1]

Introduction

Abstract: Spatial analysis is key to the formulation and evaluation of physical planning initiatives. The current thesis combines various forms of spatial analysis and many newly available and highly detailed spatial data sets in a series of studies related to different spatial-planning issues. Open-space preservation is the most common objective of the studied policy interventions, but concern for other spatial developments, such as changes in countryside vitality, water availability and flood risk, also receive attention. This chapter introduces the research topic; the most commonly applied spatial analysis methods and the outline of the thesis.

Key words: Spatial analysis; spatial data; research issues; physical planning; thesis outline.

1.   SETTING THE SCENE

A safe, attractive and healthy living environment with adequate services and employment within reach is the average resident's desire. Spatial developments that threaten these preferred conditions for living, recreation and employment are thus likely to receive extensive public and political interest. Such attention is certainly paid to the issues that directly threaten safety, as is the case with, for example, the increased flood risk associated with climate change. In fact, the spatial adaptations that may be needed to face climatic changes are a major new theme in current research related to physical planning (Kabat *et al.*, 2005). The concern for the deterioration of the physical environment caused by ongoing urbanisation processes is a theme that has been on the physical planning agenda for a much longer

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[1] Section 3 is a translated and abridged version of a chapter previously published in: Van Herwijnen, M., Koomen, E. and Beinat, E. (2002) *Methoden en systemen voor het afwegingskader Ruimtelijke Effecten*; *Een inventarisatie naar de methodologische aspecten van afwegingsmethoden en DSS toepassingen geschikt voor het Afwegingskader Ruimtelijke Effecten (AKRE)*, IvM-rapport nummer E02-14, Vrije Universiteit Amsterdam.

period. Fear for this 'urban sprawl' phenomenon has given rise to various policy interventions in the United States and many other western countries (Maruani and Amit-Cohen, 2007). In general such attempts aim to steer urbanisation processes through the enforcement of restrictions in sensitive areas and the promotion of urban development in other areas. The concern for regionally deteriorating socioeconomic conditions has also given rise to numerous spatial interventions that include the development of new infrastructure and business estates and the implementation of spatial and financial policies to stimulate specific regions or economic sectors.

Policy interventions aimed at organising the distribution of activities in space have a long history and are known under various names. Urban or town planning concerns the layout and location of cities and was already practised by the Romans. Another interesting historic example of urban planning is offered by the new towns (*villes neuves*) that were established in the 12th and 13th century in France and the Netherlands following economic and military-strategic objectives (Rutte, 2002). Regional or, more generally, physical or spatial planning typically deals with larger areas than individual cities and aims to ensure that spatial goals are achieved in the future (Van den Brink *et al.*, 2007). Land-use planning, obviously, deals with the organisation of land use and is, as such, more or less equivalent to the other forms of planning mentioned above. In fact, the above-terms are used interchangeably (Evans, 2004).

This thesis alternately uses the terms physical and spatial planning for those policy interventions that aim to steer spatial developments in such a way that societal and environmental conditions are improving, whilst also meeting other objectives related to, for example, economic development, water management and biodiversity conservation. Reconciling these often conflicting objectives is an extremely demanding task that calls for: clear undisputed information on current developments; insight in possible future trends; the preparation of alternative policy measures and an understanding of their impact. Spatial analysis can provide the required information on past, current and projected spatial developments as well as indicate the impact of existing and proposed policy measures as is demonstrated in this thesis. The research presented here combines various forms of spatial analysis with newly available and highly detailed spatial data sets in a set of studies related to different spatial planning issues. Open-space preservation is the most common objective of the studied policy interventions, but concern for other spatial developments related to, for example, countryside vitality, water availability and flood risk also receives attention. The following sections describe the research questions; some commonly applied spatial data analysis methods; and the spatial analysis process in relation to physical planning. The last section introduces the thesis outline.

2. RESEARCH QUESTIONS

The current thesis presents a number of studies that aim to contribute to the formulation and evaluation of physical planning policies geared towards steering spatial developments. These studies relate to both urban and rural areas and they focus on actual physical planning policies as well as some of the policy concepts and general notions that underlie these policies. Besides having a spatial planning focus the presented research also addresses several methodological issues related to data applicability, integration of analysis methods and simulation of land-use changes. The studies forming this thesis centre around three main research themes:

A. how can spatial developments be quantitatively characterized?;
B. to what extent do specific spatial policies impact spatial developments?;
C. how can simulations of future land use support policy makers?

The studies related to quantifying spatial developments (theme A) aim at providing insight in ongoing processes mostly linked to urbanisation as a solid base for policy formulation. These studies have a strong methodological focus as they include many new and highly detailed spatial data sets and various advanced analysis techniques including hedonic pricing, self-organizing maps and complex regression analyses. More specifically the following sub questions are dealt with:

1. how can the value of open space be quantified from a city dwellers' perspective (Chapter 3)?;
2. how can current urban intensification processes be described (Chapter 4)?;
3. how can urban concentration and land-use diversity be characterised in maps of future land use (Chapter 9)?

All these issues are considered relevant for policy makers as they provide objective information on the very starting points of their interventions. A proper assessment of the value of open space (Chapter 3) may provide objective input to policy measures that aim to preserve open space with different financial instruments. Whereas methodologies that are able to capture ongoing urban intensification (Chapter 4) and concentration processes (Chapter 9) are valuable in assessing the current state of these aspects and, furthermore, are essential in monitoring the success of intensification and concentration policies.

The studies related to the impact of spatial policies on spatial developments (theme B) focus on predominantly rural areas and aim to answer an additional three sub questions:

4. how can the effectiveness of current open space preservation policies be assessed at the national level (Chapter 5)?;
5. how can this effectiveness be explained at the local level (Chapter 6)?;

6. to what extent are rural areas suffering from a loss of socioeconomic vitality (Chapter 7)?

The relevance of the studies on the effectiveness of spatial policies related to open-space preservation (Chapters 5 and 6) for policy makers is self evident; a quantitative evaluation of the impact of such policies is essential when their abolishment, prolongation or adjustment is considered. The supposed lack of countryside vitality that is attributed to the current Dutch restrictive open space preservation policies is one of the motivations for the current shift towards less restrictive policies in rural areas. The quantitative definition of the rural vitality concept and the critical assessment of its current state (Chapter 7) provide important ingredients for the ongoing debate on the appropriateness of the shift in policies that would create more economic development potential in rural areas.

The studies related to the simulation of future land use (theme C) clearly combine a methodological focus related to the potential merits of current land-use models with an outlook on the policy implications of their results. As an introduction to the rather specific topic of land-use modelling, Chapter 2 introduces the approaches that are common in this field and, furthermore, discusses their position in the various phases of the spatial planning process. More specifically the included land-use modelling studies address the following sub questions:

7. what future lies ahead for agricultural land in the Netherlands (Chapter 8)?;
8. to which extent do future land-use patterns meet the current planning objectives of urban concentration and land-use diversity (Chapter 9)?;
9. how can land-use simulations be used to assess possible water shortages in the future (Chapter 10)?;
10. how can the impact of spatial safety strategies on future flood risk be assessed (Chapter 11)?

The simulation of the future of agricultural land use (Chapter 8) presents a reference point to policy makers in their discussions on possible and unwanted spatial developments in rural areas. Likewise, the assessment of simulated future land-use patterns in terms of urban concentration and land-use diversity (Chapter 9) provides planners with the possibly divergent outcomes of different spatial planning scenarios. The assessment of the likely impacts of land-use change on the hydrological system (Chapter 10) is specifically interesting for water managers who are interested in limiting the possible risk of damage to, for example crops, caused by moisture shortages. The integration of land-use modelling and flood-risk assessment into a discussion support system (Chapter 11) allows for an inspection of the possible impacts of various safety strategies.

    Almost all of the chapters that together form this thesis have appeared or are expected to appear in peer-reviewed scientific journals or edited books. The details are described in Table 1-1. A more extensive discussion of the outline of this thesis is provided in a following section. First, however, it is considered appropriate to discuss briefly some of the basic principles of spatial data analysis, as all presented studies have in common that they rely heavily on the use of spatial analysis techniques in combination with large amounts of highly detailed spatial data.

Table 1-1. Overview of the publications related to the chapters of this thesis

Chapter	Related publication(s)
1	Van Herwijnen, M., Koomen, E. and Beinat, E. (2002) *Methoden en systemen voor het afwegingskader Ruimtelijke Effecten; Een inventarisatie naar de methodologische aspecten van afwegingsmethoden en DSS toepassingen geschikt voor het Afwegingskader Ruimtelijke Effecten (AKRE)*, IvM-rapport nummer E02-14, Vrije Universiteit Amsterdam.
2	Koomen, E. and Stillwell, J. (2007) Modelling land-use change. Chapter 1 in: Koomen, E., Stillwell, J., Bakema, A. and Scholten, H.J. (eds.) *Modelling land-use change; progress and applications, Springer*, Dordrecht, pp. 1-21.
	Koomen, E., Rietveld P. and De Nijs, T. (2008) Modelling land-use change for policy support; editorial, *Annals of Regional Science* 42 (1): 1-10.
3	Dekkers, J. and Koomen, E. Valuation of open space; hedonic house price analyses in the Dutch Randstad region, *Ecological Economics* (submitted).
4	Koomen, E., Rietveld, P. and Bação, F. The third dimension in urban geography; the urban volume approach, *Environment and Planning B* (submitted).
5	Koomen, E., Dekkers, J. and Van Dijk, T. (2008) Open-space preservation in the Netherlands: planning, practice and prospects, *Land Use Policy* (forthcoming)
6	Van Rij, E., Dekkers, J. and Koomen, E. (2008) Analysing the success of open space preservation in the Netherlands: the Midden-Delfland case, *Tijdschrift voor Economische en Sociale Geografie* 99 (1): 115-124.
7	Koomen, E. and Van Wilgenburg, R. (2006) Platteland en kleine kernen verrassend vitaal; kwantitatieve analyse van de sociaal-economische veranderingen van ruraal Nederland. In: Schrijnen, P.M. (ed.), *Nieuwe economie nieuwe ruimte, nieuwe ruimte nieuwe economie*; bijdragen aan de PlanDag 2006, pp. 85-94.
8	Koomen, E., Kuhlman, T., Groen, J. and Bouwman, A. (2005) Simulating the future of agricultural land use in the Netherlands, *Tijdschrift voor Economische en Sociale Geografie* 96 (2): 218-224.
9	Ritsema van Eck, J. and Koomen, E. (2008) Characterising urban concentration and land-use diversity in simulations of future land use, *Annals of Regional Science* 42 (1): 123-140.
10	Dekkers, J. and Koomen, E. (2007) Land-use simulation for water management. Chapter 20 in: Koomen, E., Stillwell, J., Bakema, A. and Scholten, H.J. (eds.) *Modelling land-use change; progress and applications*, Springer, Dordrecht, pp. 355-373.
11	Van der Hoeven, N., Aerts, J., Van der Klis, H. and Koomen, E. (2008) An Integrated Discussion Support System for New Dutch Flood Risk Management Strategies. Chapter 8 in: Geertman, S. and Stillwell, J. (eds.) *Planning Support Systems: Best Practices and New Methods*, Springer, Berlin (forthcoming).

3.   SPATIAL DATA ANALYSIS METHODS

Since the introduction of the Geographical Information System (GIS) in the 1960s (Scholten and Buurman, 2000) it has become possible to store, retrieve and display spatial data in a structured way with computers (Rogerson and Fotheringham, 1994). Proper analysis of spatial data, however, only started in the mid 1990s, as is reflected in the host of literature on this topic published around that time (see, for example, Fotheringham and Rogerson, 1994; Birkin *et al.*, 1996; Fischer *et al.*, 1996a). In fact, spatial analysis and GIS were long considered to be complementary, but separate fields (Anselin and Getis, 1992; Nijkamp and Scholten, 1993; O'Kelly, 1994; Fischer *et al.*, 1996b).

This distinction has now become blurred by the strongly increased analytical capabilities of GIS, the explosive growth in spatial data availability and the continuing integration of GIS in other sorts of information systems. These trends have, amongst others, resulted in a growing family of integrated spatial decision support systems (SDSS) or planning support systems (PSS) that receive a lot of research attention (e.g. Geertman and Stillwell, 2002; Van Herwijnen, 1999; Uran, 2002 and Janssen *et al.*, 2002). This introduction refrains from introducing the general history, basics and applicability of GIS as this is done extensively elsewhere (e.g. Longley *et al.*, 2005; Scholten *et al.*, 2008). Instead, a number of basic methods to visualise and analyse spatial data are described here to properly position the studies included in this thesis.

The distinction and description of spatial data analysis methods combines elements of previous methodological reviews presented by Birkin *et al.* (1996) and Van Herwijnen (1999). For an in-depth description of these methods and the more specific related analysis techniques the reader is referred to textbooks dedicated to this subject (e.g. De Smith *et al.*, 2007).

3.1   Transformation

Transformation methods form the basis of data visualisation and essentially change a certain form of data representation into another to enhance specific features. Many conventions exist in cartography that help creating clear and commonly understood representations of spatial data. A clear description of this is provided by, amongst many others, Monmonier (1996) and Kraak and Ormeling (1996). Two commonly applied transformation methods are: *classification* and *filtering*.

Classification is used to diminish the variability in data values and can emphasize a certain portion of a spatial data set. By adjusting the classification in a visual representation of a data set specific phenomena can

be enhanced or obscured, indicating that the selection of the appropriate class boundaries is crucial. *Filtering* changes the value at each location in a data set based on the original values at that location and its surroundings. This approach is common in raster files and commonly uses a 5- or 9-cell neighbourhood. Different mathematical operators (average, median, minimum et cetera) can be used to obtain a new value for the central cell in the neighbourhood. Distance related weighing is often used here when the selected neighbourhoods are large. Chapter 4 describes the use of a number of different filtering techniques to distil meaningful information from highly detailed spatial data sets.

3.2   Aggregation

Spatial aggregation methods reduce the individual values of a data set to a single value for a specified region or the whole study area. The latter aggregation reduced the number of spatial dimension of the data set from 2 to 0, creating a non-spatial indicator or index value. This loss of spatial information is compensated by the delivery of a clear, unequivocal summary of the original content. Aggregation can also be performed at a regional level, producing a new much coarser representation of the original data.

Spatial aggregation methods either deliver spatial or non-spatial indicator values depending on the use of the spatial character of the original data. Aggregations based on general averages or total values are non-spatial as these are independent of the original spatial configuration of the data. The average size of certain types of interconnected areas (average size of all urban areas) is considered a spatial indicator value as this depends on how the urban areas are connected. Chapters 4, 7 and 9 apply a number of different aggregation techniques.

3.3   Combination

Combination of different spatial data layers is one of the key functions of GIS and it offers a powerful tool to provide an overview on many different data sets in one new integrated representation. By overlaying different data layers it is also possible to create a new data layer instead of merely visualising a result. The overlay operation is thus a typical spatial analysis operation available in any proper GIS. A classic example of this type of analysis is to define the area of overlap of two or more separate data layers indicating, for example, the area where new developments are not permitted following a large set of zoning regulations. Overlays are well suited to compare several data layers in a structured manner. Basically three different comparison options can be distinguished (Muehrcke, 1973):

1. a data set with another data set that represents the truth as is common in, for example, validation exercises;
2. a data set with another data set, for example, to compare the development over time of a specific phenomenon or to study spatial patterns of related spatial phenomena;
3. a data set with a theoretical data set, to test assumed relations.

Map-to-map comparisons are described in the Chapters 5 and 6 where the land-use conversions over time are analysed by means of cross-classification and the construction of transition matrices. Chapter 9 shows the potential of difference maps that indicate where, according to model simulations, new developments take place. Such difference maps are less adequate when more than two data sets are compared. In that case maps can be produced that locally aggregate results to describe, for example, the number of times that a certain location is supposed to be urbanised according to a set of future simulations.

3.4   Valuation

Valuation is an appropriate tool to help interpret the results of spatial analysis operations. By applying a normative and consequently subjective classification operation to analysis outcomes their value is better understood. In essence, this is not a spatial analysis method since it, generally, only applies to non-spatial valuation functions. The main aim of valuation is to make the content of related data sets comparable. It is a common tool in environmental impact assessments and decision support systems that aim to provide clear, easily interpreted outcomes to policy makers and stakeholders. Simple valuation exercises result in a limited number of categories distinguishing, for example, positive, negative or neutral outcomes in relation to a reference value. Monetary valuation that is common in, for example, cost benefit analyses is an example of a more elaborate valuation method. All valuation methods have in common that they allow for subsequent ranking of alternative outcomes and the application of multi-criteria analysis (see, for example, Van Herwijnen, 1999). A straightforward valuation of analysis outcomes is presented in Chapter 7 that distinguishes between positive, negative and neutral developments. A more elaborate valuation of flood risk simulation results in terms of economic damage and potential casualties is described in Chapter 11.

3.5   Proximity analysis

A classic type of GIS-assisted analysis deals with the assessment of distance, normally expressed as proximity. Buffer analyses that create zones

of influence (e.g. noise contours around roads) surrounding different types of shapes are typical examples of proximity analysis. Plain distance maps that describe the Euclidian or other type of distance to a specified object (e.g. railroad, city centre) offer useful input to various forms of spatial statistical analysis that, for example, aim to explain specific spatial phenomena. Chapter 3 and 4 provide examples of the use of these distance maps. More complex spatial studies related to proximity are network analyses that are common in infrastructure and transport research (Borzacchiello *et al.*, 2008).

3.6   Simulation

By describing the relevant relations of a system it is possible to simulate its future state. A common form of simulation (or modelling) is applied in impact assessments that describe the possible consequences of a specific event or policy. Such assessments follow predefined cause-effect relations that are made operational by one or more of the spatial data analysis methods described before. More complex examples of simulation are offered by the models that simulate, for example, the groundwater or land-use system. As the latter part of this thesis explicitly deals with models of land-use change, a more extensive introduction to this topic is provided in the next chapter. That chapter also discusses the optimisation approach that is often distinguished as a separate analysis method (e.g. Birkin *et al.*, 1996). This approach, aimed at finding optimal spatial configurations rather than simulating probable patterns, is, however, not applied in the studies that form this thesis.

3.7   Application of the spatial data analysis methods

All of the analysis methods described in this section are to some extent applied in the studies included in this thesis. Table 1-2 lists the discussed analysis methods and indicates in which chapters they are applied. The overview makes it clear that combination methods are the most frequently applied techniques in this thesis. This is probably also true for many other GIS-assisted studies. The studies in this thesis, furthermore, make much use of aggregation and simulation methods. Aggregation is applied to both raster cells (Chapters 4, 9 and 11) and vector data (Chapter 7) to generalise the outcomes of analyses on highly detailed data sets to a level at which they are more easily visualised and interpreted. The valuation of outcomes has been applied in Chapters 7 and 11. The transformation of data through various filtering techniques is only prominent in Chapter 4. Pure cartographic transformations were applied in the creation of the maps for all different

chapters, but these have been left out of the overview below, as they are not considered to be part of the actual analysis of the data.

The combination of the described analysis methods opens possibilities for more advanced forms of spatial analysis, such as the modelling and simulation of spatial processes that are relevant for physical planning. This is the topic of the next introductory chapter and the Chapters 8-11.

Table 1-2. Application of spatial data analysis methods in the chapters of this thesis

Chapter	Transformation	Aggregation	Combination	Valuation	Proximity analysis	Simulation
2						X
3			X		X	
4	X	X	X		X	
5			X			
6			X			
7		X	X	X		
8						X
9		X	X			X
10						X
11		X	X	X		X

4.   SPATIAL ANALYSIS AND PHYSICAL PLANNING

The ultimate goal of spatial analysis is to transform spatial data into meaningful information. In the context of physical planning this means the provision of information that helps policy makers in preparing, developing and evaluating policy alternatives. The concluding section of Chapter 2 describes these different phases in the planning cycle and discusses the possible application of land-use models per phase. First, however, this section introduces the general process that transforms spatial data into relevant information. Subsequently, several spatial analysis issues are briefly shortly introduced that are particularly relevant for the physical planning related studies included in this thesis.

4.1   The spatial analysis process

Initial reviews of the main objectives of spatial data analysis distinguish between exploratory and explanatory (or confirmatory) spatial data analysis (e.g. Anselin and Getis, 1992). Within spatial analysis and the related field of spatial modelling the main objectives are forecasting or scenario generation, (policy) impact analysis and policy generation or design (Fischer *et al.*, 1996b). Considering that: 1) the fields of spatial data analysis and

spatial modelling are becoming more integrated, as was discussed in the previous section; and 2) these different objectives are sequential in the conventional modelling process (Batty and Xie, 1994) the following division of the spatial analysis process is proposed (Figure 1-1). The process is characterised here by a number of subsequent analysis phases that differ in the degree of understanding that is involved. Since the final evaluation or monitoring phase may provide information that is useful for the preceding phases the whole process is considered to be iterative. The text below shortly describes the different analysis phases and indicates how the chapters of this thesis can be linked to them. Table 1-3 presents these relations in a more concise form.
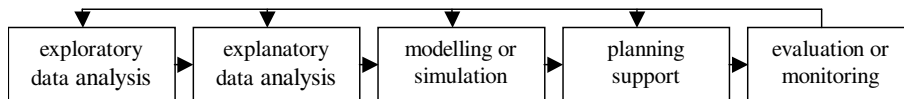
exploratory data analysis	explanatory data analysis	modelling or simulation	planning support	evaluation or monitoring

Figure 1-1. The iterative spatial analysis process.

Exploratory data analysis is usually a first step when new causal relations are sought. The inductive process of displaying spatial data to reveal patterns and anomalies and to suggest related processes was first developed by Tukey (1977) and is by many considered to be the main function of GIS or spatial analysis (Anselin and Getis, 1992; Douven and Scholten, 1995; Goodchild and Janelle, 2004). An example in a spatial planning context is the analysis of land-use change maps to discover ongoing spatial processes. Chapter 4 in this thesis applies various forms of exploratory data analysis, such as the self-organizing map approach, to assess the potential of the newly constructed urban volume data layer.

Explanatory data analysis goes a step further and introduces a notion of causality. This type of analysis is also known as confirmatory analysis as it seeks to confirm hypotheses related to observed spatial processes. Normally, it aims to explain such processes by applying statistical regression analysis. This is demonstrated in Chapter 4 where the possible relations suggested by different forms of visualisation and the self-organizing map approach are tested in a more formal combination of different regression analysis techniques. Chapter 3 also uses regression analysis to explain spatially differentiated house prices from a large set of (spatial) explanatory variables.

Once formal causal relations are established *modelling or simulation* can be used to assess the possible state of a system given certain initial conditions and expected events or (policy) interventions. The term modelling is usually applied to any quantitatively structured representation of an actual process, whereas the term simulation is often associated with the mimicking

of complex, generally social, processes to produce outlooks on possible future states. This terminology issue is evaded here and both terms are used interchangeably in this thesis. A relatively straightforward type of modelling consists of impact assessment analyses that describe the possible consequences of a specific event. This 'what if' approach calls for a quantitative description of cause-effect relations. More complex models simulate the development of complete physical or socioeconomic systems. The last four chapters of this thesis deal with such a type of model to simulate land-use patterns.

When specific policy objectives are known it becomes possible to provide *planning support*. The outcomes of the modelling process are then used to propose or evaluate alternative policy options. This support can be given in the form of result presentations dedicated to specific policy themes or, more elaborately, through the development of specific decision or planning support systems. Most studies in this thesis relate to planning support, but only Chapter 11 deals explicitly with the development of an integrated system to support discussions on a specific policy theme.

Evaluation or monitoring is an important step after decisions are taken or planning strategies are implemented. Its goal is to analyse whether the actual impact matches the anticipated results. This final step in the planning process is often overlooked, causing possibly adverse impacts to remain unnoticed. Proper *ex-post* evaluation or monitoring can help adjust unsuccessful plans and will, furthermore, improve the planning knowledge base. Thus, ideally, the outcomes of this phase should feed back into previous stages of the spatial analysis process. This thesis includes three different *ex-post* evaluation studies (Chapter 5, 6 and 7). Chapter 9 and 11 include an *ex-ante* evaluation that assesses the likely impacts of proposed spatial strategies on specific policy issues. This type of evaluation confronts assumptions, related to the possible consequences of envisaged policy interventions, with specific impact assessments.

Table 1-3. The spatial analysis phases and related chapters of this thesis

Chapter	Exploratory data analysis	Explanatory data analysis	Modelling or simulation	Planning support	Evaluation or monitoring
2			X		
3		X			
4	X	X			
5				X	X
6				X	X
7				X	X
8			X	X	
9			X	X	X
10			X	X	
11			X	X	X

4.2   **Spatial analysis issues**

While applying spatial analysis for physical planning a number of research issues is particularly important. These issues are common to the application of spatial analysis in general, but they have specific implications for the physical planning context and the studies included in this thesis. The selected spatial analysis issues relate to *scale*, the treatment of *spatial effects* and, more general, the difficulty of obtaining *causal relations* from spatial analysis.

Scale, or spatial resolution, is one of the fundamental issues in spatial analysis. This is embedded in Tobler's much-quoted first law of geography that states: "everything is related to everything else, but near things are more related than distant things" (Tobler, 1970: 236). Scale is directly linked to this law as it refers to the distance between the objects of study. For spatial analysis, Tobler's law, amongst others, implies the obvious fact that studies at the national, regional or local level can produce very different results.

Another issue related to spatial scale is the fact that different processes may be dominant at different scales. These different scale levels may, furthermore, be linked. This becomes apparent from, for example, global-level processes of increased economic interaction and growth that, depending on the comparative advantages at the national level, are likely to increase the demand for certain economic sectors and decrease it for others. Depending on the local conditions of, for example, infrastructure and the available workforce these national processes may lead to the development of new business estates at one location and the closing down of another type of business at another. Therefore, it is important to address the multi-scale characteristics of socioeconomic systems by encompassing the scale dependencies of the interrelated socioeconomic and biophysical processes at various levels (Verburg *et al.*, 2004). The study on rural vitality (Chapter 7) shows that local socioeconomic developments may, indeed, strongly deviate from national averages. The applications of the *Land Use Scanner* model (Chapters 8-11) differentiate between different scale levels in the sense that they define the suitability for specific land-use functions according to local conditions and specify their demand at the national or regional level according to national trends and regional differences.

Studies related to physical planning normally belong to the branch of socioeconomic research and, as such, often rely on statistical data collected at the rather arbitrary level of socioeconomic or, worse, administrative levels. The seminal work of Openshaw on the modifiable area unit problem (e.g. Openshaw and Taylor, 1979; Openshaw 1984) has proven that the demarcation of these zones and, essentially, scale in general, significantly influences the outcomes of subsequent studies. Some, therefore, argue that in

socioeconomic science the actual geographic world is best approached as a continuous surface at the micro level (Goodchild and Janelle, 2004; Burger *et al.,* 2007). This approach is already common in spatial analysis of the physical world, implying that social scientists may be able to benefit from the experiences of scientists in the fields of, for example, physical geography and remote sensing.

To test the benefits of using continuous, micro-level data in the spatial analysis of socioeconomic phenomena, the studies in this thesis incorporate as much of these data as is currently feasible. This novel approach is particularly prominent in Chapter 4 that discusses the use of highly detailed topographical and height data sets to analyse urban patterns. Detailed continuous data sets are also important in the studies related to evaluation of the impact of spatial policies (Chapter 5 and 6).

The issue of temporal scale is closely related to spatial scale as events happening shortly after each other tend to be more closely related than events that are further apart in time. It follows then that some of the observations made above also apply to the issue of time or the combination of space and time (Peuquet, 2002). Time is important in physical planning studies as these typically focus on the exploration and explanation of past events or the modelling of possible future events. This implies that the careful selection of the appropriate temporal resolution is extremely important in a study. Unfortunately, this is often hampered by the limited availability of reliable and methodologically consistent time-series data. The studies in this thesis, therefore, usually have to make do with relatively short time spans that possibly limit the robustness of their outcomes.

Spatial effects refer to two types of characteristics that make spatial data special: dependence and heterogeneity (Anselin, 1990). The former effect is also known as spatial autocorrelation and corresponds to Tobler's law: near things are more related than distant things. Spatial heterogeneity, on the other hand, indicates that the dependence structure is inconsistent across space. In economics and econometrics these spatial effects are often considered to: "complicate any straightforward understanding of spatial data" (Anselin and Getis, 1992: 23). As such they are viewed upon as possible sources of error that should be controlled (Klotz, 1999; Bell and Bockstael, 2000).

In geography, on the other hand, the spatial effects are generally considered to contain valuable sources of information. This is especially true for the concept of spatial dependence that is often used in an explanatory spatial data analysis to describe spatial relations and help formulate a related hypothesis to explain them. The concept of neighbourhood dependence, in fact, forms the basis for the cellular automata type of spatially explicit land-use models (e.g. Batty, 1997; Couclelis, 1997; White and Engelen, 2000),

more extensively discussed in Chapter 2. A rarer application of spatial dependence in land-use modelling is found in the autologistic regression models that simulate land-use patterns from statistically observed neighbourhood relations (McMillen, 2001; Dendoncker *et al.*, 2007).

The different treatment of spatial effects in economics and geography is described well by Bateman *et al.* (2000: 222) who point out the: "fundamental differences in the way that geographers and spatial econometricians view the concept of space". Irwin and Geoghegan (2001) refer in this respect to the 'correct' and 'creative' use of space. In their opinion the former applies to the econometric and the latter to the geographic treatment of spatial effects. Since the studies in this thesis are performed by a geographer disguised as an economist both approaches are followed. An exploratory analysis relying on an assessment of spatial dependence is included in the urban volume study (Chapter 4), whereas a thorough treatment of spatial autocorrelation is offered in Chapter 3.

Another fundamental research issue relates to the possibility of obtaining *causal relations* from spatial data analysis. Some argue that this type of analysis is best suited to explore rather than explain spatial processes (Goodchild and Janelle, 2004). In their opinion statistical analyses performed on spatial data only describe these processes. Similar arguments are made by others, who argue that a notion of causality should be added to statistical models describing land-use change processes (Veldkamp and Lambin, 2001; Parker *et al.*, 2003). Looking back at 40 years of spatial analysis, Berry (2004) concludes that many of the initial technical constraints to spatial analysis (e.g. lack of computer power, limited data availability) have disappeared. In his opinion, the tremendous improvements in, for example, computer power and data availability now call for new rounds of fully spatio-temporal and multidisciplinary spatial theory to steer spatial analysis. The studies in this thesis do not claim to present such integrated new theories, but many offer a multidisciplinary approach combining elements of geographical information science, geography, economics and other sciences. The studies, furthermore, incorporate notions of causality in their treatment of spatial processes as is exemplified by the inclusion of stakeholder opinions in the assessment of the success of open-space preservation (Chapter 6) and the evaluation of regional rural vitality (Chapter 7).

5.   THESIS OUTLINE

The general outline of the thesis is provided in Figure 1-2. The chapter directly following this introduction discusses some of the basic theoretical

ideas, concepts and methodologies that underpin the modelling of land-use change. It represents an overview of the types of approaches that have been adopted by researchers hitherto and links these to a recent compilation of advances in land-use modelling. By way of conclusion, a short overview on typical policy related applications of land-use change models is offered. The subsequent five chapters relate to the *analysis of past and current spatial developments*. The next four chapters then describe the *simulation of future spatial developments*.

Chapters 3 and 4, more specifically, focus on urban areas that are less influenced by spatial policies. Chapter 3 aims to analyse the value of open space for citizens by applying a hedonic pricing model of residential property values. The analysis is supported by extensive sets of detailed spatial data. Three local Dutch housing market case studies in the Randstad region are presented in which open space is distinguished on three different scale levels, ranging from a view of a small local open space to the proximity of a large regional open space for recreational purposes. The presented quantitative valuation of this asset can help policy makers improve their decisions in weighing up the pros and cons of diverse planning alternatives.

Chapter 4 presents a new methodology that measures density in urban systems. By combining highly detailed height measurements with, amongst others, topographical data we are able to quantify urban volume. This new approach is tested in two separate case studies that respectively relate to the temporal and spatial dimension of the urban environment. In the first study the growth of the city of Amsterdam over the past century is examined. The urban volume indicator is used to visualise and quantify the urban extension and intensification process. To critically analyse the spatio-temporal development of Amsterdam the self-organizing map approach is applied. Special attention is given to highlighting any signs of recent polynuclear development. The second case study compares the building height frequency and spatial distribution of high-density zones in the four major Dutch cities. Additionally, the presence of built-up areas and the actual urban volume values are simultaneously explained with a Heckman selection model.

Chapter 5, 6 and 7 focus on rural areas that are subject to a stronger impact of spatial policies. Chapter 5 analyses the contribution of Dutch spatial policies to open-space preservation by comparing actual land-use developments within different restrictive planning regimes. The presented analysis differs from comparable efforts that usually rely on census statistics through use of local-level geographical data and related spatial analysis techniques. The approach has the advantage of being able to analyse the impact of spatially explicit regional zoning regulations. In addition to comparing regions with strict and less strict regimes, this chapter also

assesses the importance of another open-space characterisation. The latter refers to a distinction in agriculturally shaped and exploited landscapes and natural areas. The chapter concludes with a discussion on possible spatial planning implications.

I Introduction

1 Spatial analysis in support of physical planning; introduction	2 Modelling land-use change; theories and methods

II Analysis of past and current spatial developments

Quantifying spatial developments	*Impact of spatial policies on rural areas*
3 Valuation of open space; three hedonic house price analyses in the Dutch Randstad region	5 Open-space preservation in the Netherlands; planning, practice and prospects
	6 Analysing the success of open-space preservation in the Netherlands; the Midden-Delfland case
4 The third dimension in urban geography; the urban volume approach	7 Indicators of rural vitality; A GIS-based analysis of socio-economic development

III Simulation of future spatial developments

8 Simulating the future of agricultural land use in the Netherlands	9 Characterising urban concentration and land-use diversity in simulations of future land use	10 Land-use simulation for water management; application of the Land Use Scanner in two large-scale scenario studies	11 An integrated discussion support system for new Dutch flood risk management strategies

IV Conclusion

12 Conclusion and discussion

Figure 1-2. Thesis outline.

The subsequent chapter analyses the success of open-space preservation at the local level for Midden-Delfland, an open area in the metropolitan western part of the country. A specific combination of policy instruments and government regulation has made the preservation of open space in this area very successful even compared to other buffer zones. A quantitative analysis of the land-use changes and a more qualitative review of the applied policy instruments are presented here in attempt to explain this success. The analysis can help planners in finding ways to effectively protect contested open areas.

The last of the chapters dealing with the analysis of spatial developments in rural areas proposes a methodology to quantify the policy concept of rural vitality following a strict socioeconomic interpretation. The use of highly detailed spatial data is crucial in this approach that allows the assessment of the structural characteristics and performance of countryside vitality in the Netherlands. The study shows that developments as regards population, employment and facilities in small settlements in the generally well-accessible Netherlands do not differ greatly from the national trends. The results thus question the basis for the specific rural development objectives of the new National Spatial Strategy.

The following four chapters describe simulations of future spatial developments carried out with the *Land Use Scanner* model. Chapter 8 looks into the future of agricultural land in the Netherlands where the agricultural sector has lost much of its importance over the last 50 years in terms of the number of people involved and its relative contribution to the economy – even though production is still increasing. Yet, the area under agricultural use has changed relatively little: farmland still dominates the country. The question for the future is how expected further changes in agriculture will affect agricultural land use: how much land will be taken out of production and to what use it will be put. This is especially relevant now that the Dutch government has decided to loosen its grip on spatial planning. Two opposing socioeconomic scenarios are therefore drafted that offer a coherent view on agricultural change, external pressures and government intervention. Implementing these in a land-use simulation model provides an initial answer to the possible future of agricultural land in the country.

Chapter 9 presents two sets of functional indicators that were implemented and tested for the assessment of spatial aspects of future land-use configurations as simulated by a land-use model. This is potentially useful for the ex-ante evaluation of spatial planning policies. The indicators were applied in a Dutch case study and relate to two important themes in Dutch spatial planning: compact urbanisation and mixing of land uses. After a short introduction of these themes, the sets of indicators are presented which are used for their evaluation. These indicators are applied to

simulations based on two scenarios for land-use development in the Netherlands up to 2030. After a discussion of the results we conclude that the combined application of land-use models and indicators produces new and potentially useful information for policy makers, although both the model and the associated indicators are still in a state of development.

The impact of land-use change on local hydrological characteristics and, more specifically, water shortage is discussed in Chapter 10. Future land use is an important component in studies that focus on the upcoming challenges for water management. This chapter describes two applications of the *Land Use Scanner* model on a national or larger scale, in which the scenario method is used to simulate future land-use patterns in view of climate change.

Climate change is also an important component in Chapter 11 that describes the development of a discussion support system to facilitate the debate on flood risk management strategies. It aims to provide insight into the impact of various strategies in terms of flood probability and flood risk expressed as potential economic damage and number of casualties.

The final chapter summarises the results of this thesis and discusses the extent to which the initial research questions have been answered. This discussion will focus on the policy implications of the findings as well as the methodological lessons learned.

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