

# Serie Research Memoranda

## Urban and Regional Planning Models and GIS

W. Douven  
M. Grothe  
P. Nijkamp  
H.J. Scholten

Research-Memorandum 1992-74  
December 1992





## Abstract

### Urban and Regional Planning Models and GIS

Wim Douven   Michel Grothe   Peter Nijkamp   Henk Scholten

Geographical Information Systems (GIS) have in recent years become an important part of regional and urban research. The combination of large data handling capabilities and computerized visualisation techniques explain the rapid growth path of GIS. A weak point is formed by its insufficient link with urban and regional modelling. The gap between modelling techniques and GIS needs to be bridged soon in order to 'reap the fruits' of this modern technology.

The paper will first give an overview of various caveats in the use of GIS and spatial modelling. Next, it will deal with two case studies which aim to overcome the above bottlenecks. The first one deals with a hybrid GIS and evaluation model for sustainable development of the Greek Sporades Islands. The second case study deals with GIS applications to elderly housing and neighbourhoods in the city of Amsterdam. The paper is concluded with some retrospective and prospective remarks.



## 1. Introduction

Information has become an important trademark of our modern society. Effective and accessible information systems are nowadays vital to both economic performance and strategic decision-making of nations, regions and cities. The rapid development of digital and electronic technologies, for instance, in the form of digital recording and transmission of sound and pictures, optical fibres for high speed transmission of information, super-fast computers, satellite broadcasting and video transmission, offers a new potential for sophisticated voice, data and image transmission of both private and public actors. From a geographical viewpoint the trend towards advanced information systems has in the past decades led to the design and use of geographic information systems (GIS). A GIS serves to offer a coherent representation of a set of geographical units or objects which - besides their locational position - can be characterized by one or more attributes (feature, label or thematic compound). Such information requires a consistent treatment of basic data, from the collection and storage stages to the manipulation and presentation of such data, in order to enhance the quality of decision-making (see Burrough 1986, Scholten and Stillwell 1990).

All such information systems may be highly important for the planning of our scarce space and of our living environment, not only on a global scale (e.g. monitoring of rain-forest development), but also on a local scale (e.g. physical planning). Within this framework, spatial information systems are increasingly combined with spatial interaction models, pattern recognition, systems theory, topology, statistics finite element analysis and evaluation analysis. The past twenty years have witnessed the development of various computer-based applications of information systems which have changed the activity patterns of people and the decision modes of private and public actors. Especially in the industrial sector, the design, manufacturing and quality control of products have been altered significantly with the introduction of Computer Aided Design and Computer Aided Manufacturing (CAD/CAM). In a similar manner, GIS tools are currently modifying our perception of geography and planning and our ways of spatial and environmental decision-making.

The conventional perception of GIS is that it is able to generate the following functions: handling geographical data entry, storage, analysis and mapping more rapidly, inexpensively and accurately than traditional non-automated methods allow. While effective record keeping, data analysis and information management are important benefits of GIS in daily operations, the greatest benefits of GIS are those resulting from its application to decision-making. A GIS can quickly and accurately provide decision-makers with information in the most concise form: a sophisticated polyvalent picture. A GIS produces maps and supporting tables of information that for many years used to be very difficult or time consuming to produce. A noticeable advantage of GIS is that it generates a multitude of relationships (using information from various sources) which can be made immediately accessible to decision-makers, who can then spend their time more efficiently by considering strategic policy issues rather than extracting data from volumes of written information (see also Fischer and Nijkamp 1993).

Especially the capability of modern GIS tools to answer 'what-if' questions

makes them appropriate as tools in decision support systems (DSS). In particular, interactive GIS-DSS methods are likely to offer a great potential for improved decision-making, as such methods enhance significantly the flexibility and choice freedom in relation to the knowledge and expertise of the user. The blend of GIS and DSS can be used in a wide range of modelling activities, such as: statistical and exploratory data analysis, financial accounting models, spatial behavioural models, evaluation models and visualisation techniques. A good illustration of the architecture and structure of a spatial GIS-DSS can be found in Armstrong and Densham (1990):

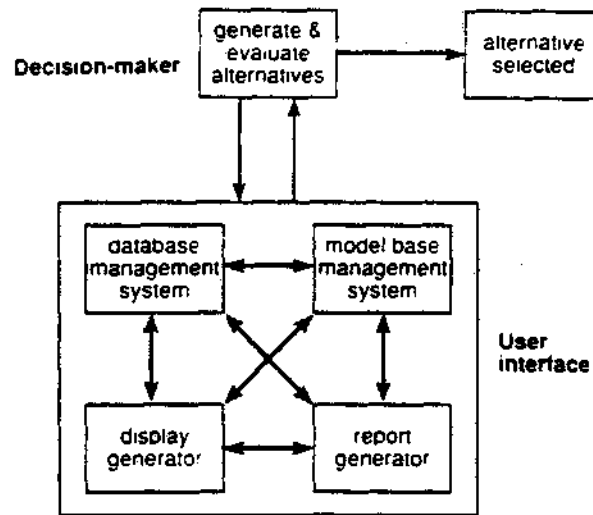


Figure 1. Architecture of a spatial DSS

A major research challenge rests in linking the traditional GIS functions (measuring, recording, storing, analyzing and visualizing) to spatial analysis (selection, information manipulation, data exploration and confirmation) so as to improve the quality of decision-making (see Anselin and Getis 1992). Clearly, error analysis is an important complementary tool for judging the validity of inferences (see Fisher 1991), while also limitations in data modelling and flaws in software design have to be recognized (Van Beurden and Scholten 1990).

In conclusion, GIS has demonstrated its great potential in a wide range of applications. Its ability to store and combine geographical data from different sources in a logical, coherent and structured way, to carry out in a flexible manner various analytical manipulations and to present the results in an appealing visual way (e.g., sophisticated overlay maps) enhances its popularity. Many organizations and research laboratories in various fields gather spatially related data for planning and policy purposes and use increasingly the GIS methodology to store and handle such data. GIS is nowadays successfully implemented for planning, monitoring and maintaining spatial objects, while it has the potential to play a role in structured spatial research (see Douven and Scholten 1993). Nevertheless, there is still a major discrepancy between GIS as an instrument for handling spatial data and GIS as a tool for exploratory, explanatory or decision-supporting spatial analysis (see Openshaw 1991).

Despite the popularity of GIS, its role as an ancillary tool for balanced

decision-making still leaves much to be desired. This paper will first discuss the critical success factors for a further penetration of GIS. The main focus will then be on the linkage between GIS and spatial analysis, while the final part of the paper will provide empirical illustrations of recent GIS applications, viz. sustainable development of the Greek Sporades Islands and elderly housing and neighbourhoods in Amsterdam.

## 2. Critical Success Factors of GIS Adoption

Like for all new products, GIS has to overcome various barriers in order to be adopted and to reach a stage of full market penetration. This product life cycle approach is well-known from the diffusion literature. It should be emphasized here that the new GIS products are polyvalent in nature - such as: efficient data base management, support of model calculations/simulations, flexible geographical presentation, possibilities for locational simulations, flexible geographical scale adjustments etc -, so that these functions for improved decision-making have to be judged from multiple angles. High product quality (i.e., sophisticated GIS technology) and market orientation (e.g., user-friendliness and cost-effectiveness) are a sine qua non for a market success of new GIS products.

In a recent paper (see Maggi et al. 1992) attention has been called for the critical success (and failure) factors of the introduction of new information and telecommunications technologies using the so-called Pentagon prism. In the authors' view the successful introduction, adoption and penetration of such new technologies depends, in general, on five critical success factors:

- hardware (engineering e.g.)
- software (information, e.g.)
- orgware (management, e.g.)
- finware (costs, e.g.)
- ecoware (environmental impacts, e.g.)

These five factors which hold also for a successful introduction of GIS technology, can be incorporated in the so-called Pentagon prism (see Figure 2), which has been used as a systematic way of screening on necessary conditions for market penetration. All five factors are simultaneously and intrinsically playing a critical role.

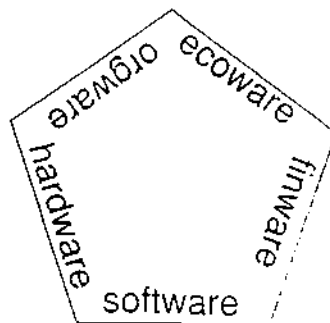


Figure 2. The Pentagon prism

A parallel reasoning can be adopted for GIS. The success of GIS is critically dependent on:

- hardware: sophisticated workstations, computer equipment, multi-colour computer cartography, visualisation technologies, etc.
- software: availability of reliable data, accompanied by advanced data recording and treatment techniques, integrated GIS and spatial analysis methods (e.g., GIS-based spatial interaction models), or educational and training schemes for GIS based spatial analysis.
- orgware: user-friendly DSS-GIS interfaces, interactive visualisation methods, well structured spatial decision-making and AI, administrative responsibility for maintenance, up-dating and back-ups, and interwovenness with decision making agencies etc.
- finware: efficient and inexpensive data mapping techniques, or polyvalent GIS methods.
- ecoware: significant contribution to urban and regional quality of life, balanced conflict resolution/evaluation methodology.

All such factors are of critical importance for a successful implementation and use of the GIS methodology. Lack to overcome the above barriers will inevitably lead to biased or insufficient use of the potential of modern GIS. The intricate synergy between GIS and spatial analysis is one of the crucial developmental factors of spatial informatics and will be discussed in the next section. Next, in the sequel of this paper we will give two interesting examples of successful applications of GIS.

### 3. Spatial Analysis and GIS

There is an increasing need for integrating GIS with spatial analysis in order to design a new policy-relevant strategic framework for effective and balanced decision-making on spatial and environmental systems. Therefore, the linkages between GIS and spatial analysis/modelling deserve closer attention.

Both GIS and spatial analysis serve to systematize a complex reality by focusing in a structured way on key elements under investigation. Thus abstraction and reality breakdown into objects and relationships (either deductively or empirically) serve to assist human comprehension of reality, although a considerable amount of error will always remain. Mapping (by means of GIS) and modelling (by spatial analysis) are essentially two sides of the same coin, but each offers different perspectives and insights. Following Anselin and Getis (1992) we may distinguish four main groups of important functions to be carried out for increasing our knowledge on spatial systems: selection, manipulation, exploration and confirmation. These functionality groups will now concisely be described.

#### 3.1. Selection

Selection is in itself a fairly simple operation. The basic operation is a classification: only units with pre-determined characteristics are selected as



members of a group. This is sometimes an important step in visual interpretation and therefore prone to errors (e.g. Middelkoop 1990), which are not always easy to cope with.

Depending on a value  $x$  of variable  $X$ , a given unit (any spatial object) is a member of the class. Such a dichotomic segmentation can be represented by a Boolean membership. However simple the operation, its result is important, because all subsequent processing will be based on these results. The main problem is clearly the demarcation of the boundaries of relevant sets. For instance, determining whether someone is a teenager is simple: if  $10 \leq x \leq 19$  is true, the person is a teenager. A problem might be the determination whether someone is young or not. The class boundaries are then not very clear. This case may call for a more continuous kind of class boundary, e.g., a fuzzy approach. In general fuzzy classifications are based on recent theories of fuzzy logic and are able to encapsulate statements such as: "a person is fairly young". For an application in the area of land use evaluation we refer to Munda et al. (1992).

In classification and subsequent evaluation, the kind of method used can be very important. Examples of cases where possible errors have not been taken into account causing a disturbing impact on the results are numerous (see e.g. Draaijers et al. 1991).

The previously defined selection or classification is mainly used for attribute data. Spatial selection may also occur in a broader analysis. The best known examples in a GIS are clipping or its complementary form (often related to overlay). If a fuzzy classification is used in a fuzzy selection environment, the result is a set of units similar to an ideal area, where especially locational uncertainty (border errors) is incorporated.

### 3.2 Manipulation

Manipulation functions are the tools usually termed 'analysis' in GIS software. We will not adhere to this practice here, although most GIS tools are part of these functions. Manipulation of the objects stored (as observational units) is usually also related to the next two groups of functions, i.e., exploration and confirmation; it might sometimes even be difficult to separate them. In manipulating the information one may just analyze the data, but more often one will use some kind of hypothetical model of reality, which forms the basis of the analysis. Main techniques in this functionality group (to be elaborated subsequently) are:

- (a) coordinate transformation, like rubber-sheeting, generalization and projecting (although this is very much related to the input stage, it is often necessary to change from, for instance, equal area to equal distance);
- (b) partitioning of observational units (or aggregation to larger ones), while also changes in representation may be made here (e.g., from lines to buffer zones);
- (c) overlay, in order to create new observational units, which in themselves are assumed to be relatively homogeneous;
- (d) interpolation, usually used to change observational units (from points to areas or lines) or to derive information about a unit's variable, which for the

unit is not known, but whose values are known for surrounding objects.

(a) transformation

Coordinate transformation is rather familiar. When all forms remain intact this is done by just recalculating the corners and using the same function for all other points. This may, for instance, be a transformation from rectangle to rectangle, but also from rectangle to parallelogram (resulting in a 'perspective' view).

A more intricate transformation occurs when the transformation function used differs in the map (spatial variation of the function). This is called 'rubber sheeting', which is a mapping technique, that primarily should be used to match edges of different thematic layers in a map; unfortunately it is often used to get the data in the 'right' position, as part of the input stage. Resulting errors are usually discarded.

The transformation best known to cartographers is projection: the problem of mapping a spherical surface on a flat surface with the least distortion (see e.g., Robinson and Snyder 1991). Projections appear in three forms: true to distance (equidistant), true to area (equal area) and true to form (conform). A projection can have only one of these three properties. Obviously, transformation by projection would not be necessary when a true three-dimensional technique is used; however, most techniques are based on classical techniques dealing with flat maps, therefore processing distortion caused by the projection.

(b) partitioning and aggregation

Surveys often yield figures for larger units, for instance, population counts or the total area of crops per administrative unit (a municipality, e.g.). The given amount is most certainly not spread evenly in this unit, but is instead concentrated at certain spots within the unit. If possible at all, some partitioning can be performed, in which the total amount is sub-divided by some rule (either deterministic or empirical), while the resulting figures are attributed to smaller units which together form the larger unit we started with. This means that some knowledge about the large unit must exist: where are concentrations to be expected? This technique puts some constraints on the input data: area recalculations may only be performed in equal area projections; densities or fluxes must first be transformed to absolute amounts. And, of course, the error in the result depends largely on the quality of the pre-conceived knowledge or hypothesis about the component areas of the large unit. Sometimes some kind of area interpolation may precede the step of partitioning.

The process can be performed the other way round as well: aggregation. Summations of attribute values are fairly simple; one only has to take care of true area representation (equal area projection).

(c) overlay

Overlay is the best known GIS tool in relation to spatial analysis. Its reputation has two major causes. It is one of the oldest and most commonly used

techniques by cartographers and geographers. Secondly, an overlay in itself is very simple: only coordinates have to be matched and possibly lines intersected. The result is a new map with new observational units with of course different positions from the units in both input maps.

Projection plays an important role in this technique. Any projected map is drawn on a flat piece of paper, upon which a Cartesian coordinate system can be positioned. This allows easy coordinate matching and line intersection. Things would be more difficult on a spherical object (like the earth). The three - dimensional notation (degrees) needs certainly more intricate mathematical transformations than Cartesian coordinates do in an overlay.

An overlay assumes some homogeneity in zones; a condition not often met in reality. Accuracy problems may therefore arise in an overlay.

#### (d) interpolation

Spatial interpolation is another 'old' technique to change from one observational unit to another. The problem can be stated as follows. "Given a set of spatial data either in the form of points or for subareas, find the function that will best represent the whole surface and that will predict values at other points or for other subareas" (Lam 1983).

Choosing the 'right' interpolation method depends largely on the type of information involved and the degree of desired accuracy. Furthermore, some methods will require much computational effort (of either the mapper or the computer). Basic to the method is the assumption that each interpolation method is a sort of hypothesis of the surface, and this hypothesis may or may not be true. Elaborate descriptions will not be given in this paper; some general remarks can be made here.

Point interpolations are used to derive area information from point data (or derive information at an infinite number of points), which can be collected at a point (isometric). Exact methods preserve values of the points. Most functions pass through all points, sometimes totally unconstrained (and therefore sometimes resulting in absurd extremes), or more constrained, but with more assumptions (like distance-weighting). These techniques can easily be used to smooth the data surface, thus introducing some error. Furthermore, assumptions will lead to ambiguity when the actual surface characteristics are unknown, and uneven distributions can distort the method's functioning.

Splines are functions with an appropriate power degree, so that the derivatives of the functions are continuous everywhere. For computing the function, the surface may be divided by drawing lines between points, to form quadrangles or triangles. Especially in choosing the triangles the process is prone to errors. Nevertheless, this technique works piecewise, is very closely related to the value being interpolated and it may be very accurate (depending on the surface modelled). Finite difference methods assume that the desired surface obeys some differential equations, both ordinary and partial. These equations are then approximated by finite differences and solved iteratively. The method is simple, though the solution to a set of difference equations may be time consuming. Interpolation beyond the neighbourhood of the points is usually poor and flat areas may pose serious problems.

Kriging is perhaps the most distinctive type of interpolation method. Kriging is based on some simplifying assumptions, like stationarity in simple Kriging, which means that the probability density function and the autocovariance matrix can be estimated. A variation is needed for most natural phenomena, where this assumption does not hold. The variogram then forms the basis, representing the relationship between the mean-square difference between sample values and their intervening distance. One might also assume that the increments of the regionalized variable have only some properties of stationarity within a neighbourhood and that the trend or drift for a neighbourhood can be described by a polynomial function: this is universal Kriging. It uses a different set of equations for each point estimate in different neighbourhoods. Choosing the size of a neighbourhood and matching a polynomial function with the experimental variogram may pose problems when using Kriging. The advantage is clearly the ability for statistical inference, which also provides an estimate error. Most of the elements described precede the actual Kriging interpolation.

Approximation methods are concerned with determining a function  $f(x,y)$ , which assumes values at the data points approximately but not generally equal to the observed values, therefore resulting in an error or residual at every data point. These errors can be minimized (or optimized), for instance, by least squares polynomials, sometimes added with distance weighting or fitted with splines. Choice of weights or uneven distributions may cause problems with these methods.

The areal interpolation problem is more common to geography than to other fields. Its main use is in isopleth mapping. The change from one set of boundaries to another is not part of the interpolation (like overlay), but is an essential step, which is why overlay is also mentioned here. Most generally, non-volume-preserving methods use point interpolation methods to derive values for small areas (for instance, grid cells), for which the value found is assumed to be a representation. The choice of the control point or the way areas give weights (or even a decisive value) is very important and may have a large effect on the result.

Volume-preserving methods take the topological aspect of areas into account. Overlay is the basic tool for this, since area values of the target zones are determined from sizes of overlapping zones. Derived areas and comparison with input zones may result in weights when attributing a value to a new target zone. This is often accompanied by some regression function of several variables (attributes), of which some may be absent for new target zones. The important assumption of homogeneous zones is in reality often found not to be true.

### 3.3 Explorative data analysis

In exploratory data analysis the data are used in an inductive fashion to gain new insights. The first step in discovering a kind of pattern or cluster in the data available is to derive any information whether patterns exist or not. Pattern indicators have been established with dispersion factors (using nearest-neighbour distances) or, more recently, fractal geometry. The equations will however not yield any spatial result in the form of, for instance, maps (Berry 1991).

A fairly simple approach is to limit the analysis to pure description.

Examples of possible solutions are recently appearing (see e.g., Openshaw 1990; Openshaw and Charlton 1990), where computation intensive routines elicit pattern information from the data, but usually no significant indication or information about the fact that the pattern may be spurious is given. Anselin and Getis (1992) conjecture that this is not really exploratory data analysis, as this be of high dimensionality. Nevertheless, the 'new' routines show examples of univariate and bivariate situations.

Clustering is a fairly old method to group individual data according to similarity or dissimilarity. Most clustering methods use attribute values to discern similarities, but in some cases also distances are be used. There are, depending on the clustering method used, different constraints for this distance aspect in computing clusters. The most simple clustering only looks at distance (or, put in another way, point density). Clustering is getting more difficult if attribute values are also involved in the clustering, mainly because of strict constraints and assumptions.

Typical exploratory analysis is of a statistical nature, while most statistical methods are a-spatial. Spatial aspects might be incorporated in some methods, but this usually means a set of straitjacket constraints on the spatial data. If such conditions are not fully met, wrong or false conclusions may easily result; the best known example is spatial dependence (and/or heterogeneity).

Interactivity between maps and other (statistical) exploratory information offers interesting insights into the relationships within the data. Examples of this approach developed in a computer environment are interactive graphics (Haslett et al. 1990a,b and c; Bradley and Haslett 1990; Unwin et al. 1990).

Explorations will most certainly elicit some pattern or structural relationship in the data. Such results should be considered with caution, because causal relations may very well be absent. Therefore, after an exploratory analysis there will be a need for further research into the nature of these relations and processes.

### 3.4 Confirmatory analysis

Anselin and Getis (1992) point out that very little has been achieved in the field of automating confirmatory analysis, which can be seen as the main functionality for predictions, forecasts and filtering tests. Most applications are non-spatial, like regression analysis, which fail to make use of the spatial aspect of the information (topology). Some links with pure statistical methods can be made, but it proves difficult to work with the space component. Some model-based techniques may use spatial elements, such as Kriging and Kalman filtering when they are explicitly concerned with space (see e.g., Christensen 1991).

A well developed field of spatial analysis is that of spatial interaction or, in a broader sense, any kind of spatial dynamic modelling (e.g., diffusion). Spatial interaction and gravity ('potential mapping') are pure models, which are tested after formulation. The test contains both comparisons with observations and statistical features. Unfortunately, the fact that the model is only an approximation of (part of) reality means that statistical tools are indispensable (see for details amongst others Nijkamp and Reggiani 1992; Scholten and Stillwell 1990)

In cases of space-time clustering it is often necessary to apply some pre-conceived notion (model) to the data, for instance, by stratifying the data (a kind of classification problem). The result is a clear mix of both exploratory and confirmatory techniques (see e.g., Melse 1991).

After this rather lengthy discussion about the connections between GIS and spatial analysis (including modelling), we will in the next sections offer a presentation of two recent applications of GIS modelling so as to illustrate the power of GIS modelling in a regional and urban planning content.

#### 4. A Case Study on Greek Islands

Here a concise description of a GIS-based regional model will be given which serves to analyze sustainable development (SD) for the Greek Sporades Islands, with particular emphasis on the island of Alonnisos (see for details Giaoutzi and Nijkamp 1993). The study deals with conflicts between regional economic development and environmental protection for an island economy dominated by tourism and fishery. Especially the seasonal peaks in tourism exceed the carrying capacity of the islands and may result in abrupt high resource demands (e.g., water, food, etc.). This may in turn cause irreversible processes in the resource stocks. This means that the SD conflicts on the study area are dynamic phenomena. Some of these conflicts can be also expressed in spatial dimensions directly (e.g., the expansion of urban land at the expense of forest areas). But only through the use of a spatio-temporal hybrid GIS-SD dynamic model we can satisfactorily describe and simulate the mechanics of our ecosystem SD conflicts. For such a purpose, the model concerned should focus on dynamic simulations in space and time rather than being an optimization model; should assist planners in examining the dynamic economic and ecological conflicts of the study area in their physical dimensions (three dimensions for the spatial reference together with one dimension for the dynamic reference over time); and should provide alternative strategic solutions by scenarios which should be based on SD constraints for the development of the region at hand.

The data requirements for such a GIS-SD hybrid model are determined by (1) the spatio-temporal resolutions selected (i.e., 100m x 100m ground pixel size, and a simulation period of 1 year), and (2) the data needs for a successful GIS-SD model calibration. The data supply may not necessarily be in one-to-one correspondence with the data demand. This means that (1) some digital data may have been collected and processed which finally are not all used as an input to the GIS-SD model, but rather form an integrated digital data base and (2) necessary digital data for the GIS-SD model may not have been available for the period the model was developed and tested. The data collection process focused mainly on obtaining as much information as possible about the socio-economic and natural environment of the study area. The necessary data input to both our GIS-SD model and the digital data base constructed included amongst others:

##### **Non-spatial data**

- socio-economic data of the region (productivity and income per economic sector, tourism, fishery, houses, energy used per household, etc.)

- demographic data (population, age pyramid etc.)
- ecological data (ground water, sea water quality, forest fires, wild life data etc.)

#### **Spatial data**

- terrain elevation and sea depth data
- land use data
- distance data from important land uses such as urban land, forests etc.
- road transportation network data etc.

After the necessary spatial and non-spatial data requirements were set, the relevant data were collected from the various (mainly Greek) sources: National Statistical Service, Greek Military Geographic Service, Ministry of Environment, Planning and Technical Works etc. Based on these selected data, a complete GIS-SD model was designed and used as follows. Various scenarios on the future development of the island were developed. The main focus was on land use/transportation scenarios, and on two scenario runs generated by successively excluding and including road transportation on Alonnisos island in order to demonstrate the efficient use of the GIS-SD system for monitoring land changes under different urban attractiveness conditions. It was assumed that urban land use development was strongly dependent on the presence of transportation infrastructure. This was reflected in so-called attraction layers. Using these attraction layers the system was run for a simulation period of 15 years, starting with the year 1985 and ending with the year 2000 for a five year period. The results can be represented by means of systematic colour maps (see Despotakis 1991). Here we will only describe some results based on the policy options of "absence" and "presence" of transportation, respectively.

The effects on urban expansion as a result of road transportation are clearly depicted in the above two figures. For the "no transportation" scenario the urban expansion takes place mainly along the sea shore and the already existing urban areas of the island; for the "transportation" scenario the urban expansion presents clusters spread along the roads of the island, thus eliminating the amount of urban area to be spread along the sea shore. This GIS-SD system provides these results in the form of raster images which may also be used for animation applications, so that more intuitive information may be extracted from the simulation results. These two scenario results can be inserted into a DSS. The evaluation by means of a DSS for the Sporades contains four relevant policy criteria, viz. tourism, nature, landscape and transportation. In addition, the impacts of possible development scenario's on each of these criteria have to be assessed. Based on policy trade-off analysis, in particular multi-criteria analysis, the most desirable scenario can then be identified.

For each criterion (e.g., nature, tourism, etc.) an evaluation map can be generated which corresponds to the selected alternative development scenario for a specific year. Multi-criteria analysis is then used to rank the selected alternatives. Based on the above methodology, five spatial scenario runs generated by assuming certain policies with respect to urban expansion over the island of Alonnisos were carried out. The purpose of selecting these scenarios was to use the GIS-SD model for evaluating the effects of various spatial policies on

urban development. These scenarios can be developed for both the 'transportation' and 'no transportation' policy. In the sequel of our analysis only scenarios related to the 'transportation' option will be further illustrated.

- Scenario 1:** the first spatial scenario encourages urban growth within 200m of the sea. The beaches themselves may be changed to urban areas.
- Scenario 2:** the second spatial scenario encourages urban growth in the middle of the island. The beaches and a zone of 500m from the sea may not be changed to urban areas.
- Scenario 3:** the third spatial scenario allows the urban area to expand in the southern part of the island only. The northern part of the island remains untouched.
- Scenario 4:** the fourth spatial scenario allows urban to expand only in the eastern part of the island. Beach areas are allowed to change to urban functions in the eastern part of the island only. The western part of the island remains untouched.
- Scenario 5:** the fifth spatial scenario allows urban areas to expand only in the existing urban areas of the island. This means that any type of urban growth is strictly prohibited in horizontal direction, and only urban growth in a vertical direction is allowed.

The effect table for these five scenarios is shown in Table 1. The scoring units are non-dimensional relative units. High scores mean 'good' results, whereas low scores indicate 'poor' results. We may observe from the above table that:

(1) Scenario 2 (urban growth in the middle of the island) has a very low relative score for the 'tourism' criterion, whereas scenario 5 (no urban expansion) has the highest score for the same criterion. This results from the fact that the urban distances to the sea - which determine the "happy tourist" in this scenario - are maximal for the case of scenario 2 and minimal for the case of scenario 5.

(2) The 'best' sustainable scenario for nature, determined by land use changes, is scenario 5. This is due to the fact that, for scenario 5, the natural area for the year 2005 remains almost the same as the natural area for the year 1985. The 'worst' scenario from the point of view of natural sustainability in this case is scenario 2; according to this scenario the scarce natural areas of the middle of the island are destroyed and changed to urban areas. We also observe here that the third scenario (urban expansion at the southern half of the island) results in a lower burden to nature than the fourth scenario (urban expansion at the eastern half of the island). This happens because the existing urban area for year 1985 is already located at the southern half of the island; therefore, a scenario according to which additional urban expansion at the eastern half of the island takes place, will destroy the natural areas more than the southern (already disturbed) areas.



CRITERIA	ALTERNATIVE SCENARIOS				
	1	2	3	4	5
tourism	6.219	3.761	6.242	6.543	6.817
nature	4.128	3.841	3.906	3.879	5.516
landscape	4.663	5.742	4.575	4.427	4.353
transportation	6.299	5.635	6.945	5.168	8.691

Table 1: The effect table in the GIS-SD-DSS system for the Sporades

(3) Scenario 2 is the 'best' in terms of preserving the original landscape of the island: the urban expansion takes place in the middle of the island and therefore the urban areas are not visible from either the sea or other parts of the island. This non-visibility results in high scores for the landscape criterion.

(4) Scenario 5 is the 'best' in terms of road transportation; in other words, this scenario results in the minimum transportation burden required for the local people or tourists to move on the island. The 'worst' scenario in terms of road transportation load is scenario 4 (urban expansion only at the eastern half of the island). This is due to the fact that the distances from harbour, located at the southern part of the island, are taken into account for the computation of road transportation load. The effect table was next evaluated by a multi-criteria analysis, based on a regime method (see Nijkamp et al. 1990).

The ranking results, given the four selected criteria, are as follows (see Table 2).

Alternative scenario	1	2	3	4	5
Rank	3	5	2	4	1

Table 2: Optimal ranking for the five spatial alternatives in the Sporades

We may thus conclude that based on the above assumptions and ranking methods, scenario 5 is to be regarded as a 'sustainable' scenario, to be preferred to the others. The term 'sustainable' here refers to a development (till the year 2005) which 'best' combines the four sustainability criteria selected: (1) the tourist sector activities are favoured and enhanced; (2) the natural areas are as little as possible destroyed and/or changed to urban areas; (3) the landscape values are preserved, and (4) the road transportation load becomes minimal. Clearly, such a conclusion is expected from development scenarios of the type

of scenario 5: if the urban areas are to be restricted to their original locations, then this is the 'best' sustainable scenario, at least in an ecocentric sense. Since such 'no expansion' policies often tend to be unrealistic (and much more difficult to apply and control), one might, alternatively, select scenario 3, i.e., the scenario which was ranked as the second 'best'. All results - including all detailed GIS maps - are documented more extensively in Despotakis (1991) and Giaoutzi and Nijkamp (1993). This illustration has shown the potential of combining GIS with spatial modelling for policy evaluation purposes.

## 5. A Case Study on Elderly Housing and Neighbourhoods in Amsterdam

The population in Europe, and even more so in the Netherlands, is aging rapidly. An increase in life expectancy and a decrease in birth rates are leading to an explosive increase of persons 55 years of age and older, generally regarded as "the elderly". Within this group of elderly, "double aging" also takes place, and the population of the "old" elderly within the total elderly population increases even more rapidly. Concurrently the Dutch government's elderly care service policy has decreased the number and capacity of elderly care services, such as old peoples' homes and nursing homes.

The consequence of this national policy, with regard to housing, is that elderly need to remain independent in their own residential neighbourhood for more years than they did in the past. However in the urban and suburban areas, elderly who live independently face an increasing number and range of problems. A notable shortage of suitable dwellings exists, especially in older urban areas in Amsterdam. There the quality of dwellings is often insufficient: poor technical quality, poor accessibility due to steep and narrow staircases, and lack of amenities like a shower or bath. Furthermore, a decent residential environment often is lacking. The gradual disappearance of small neighbourhood shops and post offices has a negative impact, especially for less-mobile inhabitants who often are nearby-oriented. Increasing fear of crime, threatening behaviour and violence in the streets diminish the interaction possibilities of the elderly and devalue their daily living environment.

Over the past decades, planning concepts of elderly housing in The Netherlands shifted from the planning of institutional housing - old peoples' homes and nursing homes - towards planning concepts of independent housing with a focus on the design of buildings and dwellings. This new policy emphasised the neighbourhood as the geographical unit to study and monitor the living environment of elderly and ensure continuity of the individual life-styles.

Recently, Dutch planners have developed a planning concept, called "residential zoning for elderly", which includes a framework to monitor and guarantee the possibility for elderly to live independently in a 'friendly' residential neighbourhood. GIS offers promising possibilities to integrate data to measure the physical and social qualities of a neighbourhood for elderly housing. GIS applications in the urban area of Amsterdam already illustrate the potential of GIS technology to monitor housing and neighbourhood quality for older residents and to support planners in local housing policy development.

Originally, residential areas for elderly were defined as "areas with suitable and affordable dwellings, situated within 500 meters walking distance - or 400 meters as the crow flies - of services for elderly: shops, public transport, medical facilities, post offices and green areas. At the same time, these areas have by no means a homogeneous population of elderly, but are built up heterogeneously". Consequently, in considering housing for the elderly, planners need to focus their attention on both physical and social characteristics of elderly residences (Burby and Rohe 1990). Residential zoning for the elderly addresses this need because it is adapted to the local circumstances and qualifies areas according to their suitability for elderly housing based on both physical and social characteristics.

Physical characteristics of the neighbourhood are measured by means of indicators of accessibility to several important shopping facilities, care services centres and recreational facilities. The availability of suitable dwellings - defined and selected on their physical characteristics such as ground floor accessibility, availability of an elevator, amount of floor space, number of rooms, availability of amenities, rent level, house ownership etc - is the other important objective policy variable for measurement of elderly housing. Social variables include neighbourhood livability and satisfaction, fear of crime and potential for social interaction, which are linked with the location, design and management of housing for the elderly. The actual use of neighbourhood facilities and services, the patterns of social interaction and the perception and fear of crime are indicators of housing satisfaction for elderly who are economically and physically often restricted, more vulnerable and less mobile. Interviews among the elderly population are necessary for planners in order to obtain insight into:

- the actual behaviour of the elderly and their perceptions concerning the use of services; and
- their existing and preferred housing situations.

The decisive factor for the perceived housing situation and actual interaction pattern is the household situation. Differences in household situation, in terms of age, mobility, cultural/ethnic background and socio-economic characteristics, cause individual households to perceive the housing environment differently and to weight objective policy criteria differently. This difference in perspectives demonstrates that residential zoning is a relative concept: a range of friendly to unfriendly zones, related to the demographic and socio-economic characteristics of the elderly population, exists. The analytical framework can be found in Figure 3. The objective policy variables are weighted, using interview results, and combined with other variables for the development of local housing policy.

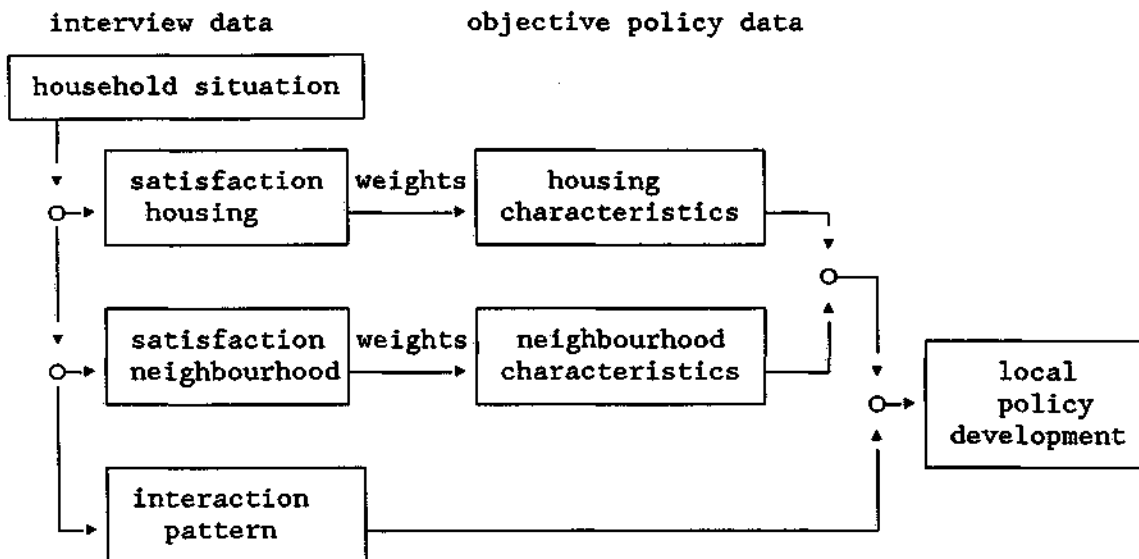


Figure 3. Analysis framework for analyzing elderly housing and neighbourhoods

In several pilot studies conducted in residential districts of the Amsterdam urban area, GIS has been used to define residential areas for the elderly to support policy development for elderly housing. GIS is applied in all aspects of the research framework:

- qualification of neighbourhood areas, based on accessibility of facilities and services;
- selection and display of suitable dwellings; and
- integration of data on elderly social interaction and attractiveness of collective areas, based on the occurrence of crime.

Data about physical and social variables have been collected, processed and stored using statistical software in combination with GIS. Objective policy indicators for measuring of elderly residential situations in the Netherlands were applied as well. Two types of questions concerning the neighbourhood and housing characteristics had to be answered by the elderly:

1. Which retail facilities and care services are important to the elderly and how is accessibility defined?
2. Which type of dwellings are suitable for the elderly?

From the viewpoint of accessibility, the following retail and recreational facilities and care services appear to be important to the elderly, according to Dutch planning objectives (in descending order of importance):

- daily-visited retail facilities (bakery, green-grocery, butcher's shop, dairy, supermarket and daily market);
- public transport (bus, tram and metro);
- financial services (post office or bank);
- recreational facilities (parks and green areas); and
- care/welfare service centres.

Accessibility for the elderly has been defined as a walking distance of 250 meters for less-mobile elderly and 500 meters for mobile elderly. Suitable elderly housing was defined as:

- being on the ground floor, first floor or in a building with an elevator; and
- dwellings with 3 or 4 rooms, more than 32 square meters of floor space and a low rent level.

Data about the location and type of facilities and care service centres, and the location and characteristics of the housing supply have been collected and stored as point data. A transportation network is used for distance calculations between all residential locations and every single retail facility and care service centre. Using policy variables and weights, this information can be processed and displayed in suitability maps (see Grothe and Blom 1992). GIS analysis and mapping functions produced suitability maps based on the accessibility of several types of facilities and care service centres (in declining planning priority) in the district "de Baarsjes" in Amsterdam.

On the basis of interviews among elderly residents, the weighting was adapted to local circumstances. Elderly expressed their preference and the frequency of use of the different types of facilities and service centres. Using different weighting methods and the weighted summation method of multiple criteria analysis, a classification was derived, based on the product of weights and the distance between residential location and facility location. Shopping and recreation facilities available to elderly in their neighbourhood were measured by counting the number and type of shops within variable distance zones from the residents' dwellings. Using the average distance, a qualification of dwellings according to the neighbourhood service level was generated.

Next, the relationship between the household situation and the spatial component of activities of older individuals was examined based on a behavioural analysis of elderly social interaction. Data about places that elderly regularly visit, so-called "habitats", have been collected from individual elderly in order to identify commonly visited areas in the neighbourhood. Data concerning spatial and social interaction by type (shopping, visiting friends etc), origin-destination and frequency were collected, stored and analyzed in ARC/INFO (see also Shalaby 1991). Using map overlay operations, the interaction maps were combined and collective areas of interaction have been defined and differentiated for the household situation (age, mobility etc). Measuring the habitat of the elderly is important to understand the actual interaction which was used to correct policy variables of accessibility to the local circumstances. Residential zoning areas were defined based on collective areas of interaction differentiated by age. At the same time, this information is combined with information about "attractive" and "less attractive" areas gathered during

interviews among governmental, care and welfare institutions and elderly inhabitants.

As a result, maps of attractive and less attractive areas, based on the perception and occurrence of crime, can be compiled and stored. These maps reflect the mental and social perceptions of elderly individuals and indicate the parts of the neighbourhood they perceive as decent living environments. In combination with objective policy variables, these maps aid in the development of new local plans for improving the housing environment of the elderly. (see for further details Grothe and Blom 1992)

To apply the concept of residential zoning in a Dutch - or in a broader European - urban planning practice, several integrative elements need to be distinguished:

- a framework for new housing, housing renovation and allocation;
- a structure for the integration and adjustment of housing, care and service facilities to the needs of elderly;
- procedures to handle the flows of elderly residents from large to small(er) dwellings; and
- a system for the management of the residential environment.

Although the concept of friendly residential zoning for elderly is still in a development stage, the Amsterdam applications have clearly illustrated the potential of GIS technology for residential zoning, behavioural analysis and policy development and support. Not only local government authorities but also care service institutions, housing corporations and real estate owners appeared to benefit from this concept and to gain support for their elderly housing policies. GIS use in this regard appeared to be inevitable.

## 6. Concluding Remarks

The combination of the availability of large numbers of digitised maps with abundant software which allows a wide spectrum of data to be presented by these maps has increased the interest in GIS enormously. One can even speak of an explosion of geographic data that is unprecedented in history (Rhind et al. 1989). The users of such GIS systems are extremely diverse and originate from various scientific disciplines. The increased use of such systems can be explained simply by the need expressed by many planners to attach a spatial dimension to the presentation of their data. Besides, the discovery that the spatial component offers the possibility of integrating data is another reason for the world wide penetration of GIS.

This penetration however, has not yet reached its full benefits to the user, as there are in the operationalization stage still many elements of GIS and spatial analysis to be improved, in particular:

- improvement of models (e.g., the combination of descriptive and evaluative or predictive models)
- orientation towards DSS and AI environments, based on realistic policy information

- improvement of spatial analytical tools (e.g., spatio-temporal autocorrelation, cellular automata methods, neural networks methods and bio-computing techniques)
- integration with remote sensing data (especially multi-spectral and multi-temporal raster data)
- improvement of error analyses dealing with the quality of the data used (including fuzzy set methods for imprecise spatial information or demarcation)
- enhancement of user-friendliness of GIS-based methods (e.g., provisions of source programme documentation, detailed model-base description, presentation of graphical sampling results, menu-driven applications, help-files retrieval etc.).

In a GIS environment the following characteristics can be regarded as important in the determination of relevant spatial analysis techniques, which may favour a further use of GIS models and techniques:

- a. The techniques must be explicitly spatial, meaning that they must utilize the specific characteristics of spatial data as distinct from non-spatial data
- b. The techniques must be able to deal with large data bases (e.g., more than 10.000 objects)
- c. The techniques must be oriented towards the field which are regarded as important and should focus on problem resolution
- d. The techniques must be able to have an interface with GIS systems
- e. Attention needs to be devoted to the way in which uncertainty is managed in spatial data
- f. Attention is also necessary, if possible, for dealing with temporal dynamics in data
- g. The techniques must be subject to advanced automation in order to make optimal use of the current technical possibilities and in order to reduce the dependence on the knowledge of the user
- h. The techniques need to be oriented in particular towards exploration and simulation instead of hypothesis testing. For this reason it is important that the present use of already available power of computers will be optimised.
- i. It is important to focus on issues which allow transferability to results and methods, so that methodological and technical knowledge can be further disseminated .

In conclusion: the penetration, implementation and utilization of GIS in combination with spatial analysis requires both methodological/conceptual progress and applied field work. The critical success factors for a successful introduction of GIS (see Section 2) may offer a meaningful guideline for policy and research strategies in this field.

## REFERENCES

- Anselin, L. and A. Getis, 1992. Spatial Statistical Analysis and Geographic Information Systems. Annals of Regional Science, vol. 28, no. 1, pp. 19-34
- Armstrong, M.P., and P.J. Densham, 1990. Database Organization Alternatives for Spatial Decision Support Systems, International Journal of GIS, vol. 4, no. 1, pp. 3-20
- Berry, J.K., 1991. Discovering Feature Patterns; Everything Has its Place, Everything in its Place. GIS World, October 1991, pp. 42-46
- Beurden. A.U.C.J. van & H.J. Scholten, 1990. The Environmental GIS Of The Netherlands and its Organizational Implications. Proceedings 1<sup>st</sup> EGIS Conference, Amsterdam, April 10-13, EGIS Foundation, Utrecht, pp. 59-67
- Bradley, R. & J. Haslett, 1990. Interactive Graphics for the Exploratory Analysis of Spatial Data - the Interactive Ariogram Cloud. Department of Statistics, Trinity College, Dublin.
- Burby, R.J. and W.M. Rohe, 1990. Providing for the Housing Needs of the Elderly. Journal of the American Planning Association, vol. 65, no. 3, pp. 324-40.
- Burrough, P.A., 1986. Principles of Geographic Information Systems for Land Resources Assessment. Clarendon Press, Oxford.
- Christensen, R., 1991. Linear Models for Multivariate, Time Series, and Spatial Data. Springer-Verlag, New York.
- Despotakis, V., 1991. Sustainable Development Planning Using Geographic Information Systems, Ph.D. Dissertation, Dept of Economics, Free University, Amsterdam
- Douven, W. and H.J. Scholten, 1993. Spatial Analysis in Health Research. In: H.J. Scholten (ed.), The Added Value of Geographical Information Systems in Public and Environmental Health, (forthcomming)
- Draaijers, G.P.J., W. Bleuten, N.H.S.M. de Wit, W. Hoogendoorn & A.U.C.J. van Beurden, 1991. Bodembeschermingsgebieden: Selectie en Bescherming van Abiotisch Waardevolle Gebieden. Milieu, vol. 6, no. 2, pp. 42-29
- Fischer, M.M. and P. Nijkamp (eds.), 1993. Geographic Information Systems, Spatial Analysis and Policy Evaluation, Springer Verlag, Berlin
- Fisher, P.F., 1991. Modelling Soil Map-unit Inclusions by Monte Carlo Simulation. International Journal of Geographical Information Systems, vol.5, no.2, pp.193-208



- Giaoutzi, M. and P. Nijkamp, 1993. Decision Support for Regional Sustainable Development, Avebury, Aldershot, UK, 1993
- Haslett, J., G. Wills & A.R. Unwin, 1990a. SPIDER - An Interactive Statistical Tool for the Analysis of Spatially Distributed Data. Department of Statistics, Trinity College, Dublin.
- Haslett, J., R. Bradley, P.S. Craig, G. Wills and A.R. Unwin, 1990b. Dynamic Graphics for Exploring Spatial Data, With Application to Locating Global and Local Anomalies, American Statistician (to appear).
- Haslett, J., R. Bradley, M. Dillon and G. Wills, 1990c. Interactive Graphics for the Exploratory Analysis of Spatial Data - Applications to Data of Different Support. Department of Statistics, Trinity College, Dublin.
- Grothe, M.J.N. and W. Blom, 1992. GIS Measures Elderly Housing and Neighbourhood, GIS Europe, vol. 1, no. 7, pp. 20-24
- Lam, N.S., 1983. Spatial Interpolation Methods: a Review. The American Cartographer, vol. 10, no. 2, pp. 129-149
- Maggi, R., I. Masser and P. Nijkamp, 1992. Missing Networks in European Transport and Communications, Transport Reviews, vol. 12, no. 4, pp. 311-321
- Melse, J.M., 1991. Literatuuronderzoek Betreffende het Gebruik op een Gezondheidsdienst van Statistische Methoden Voor Ziekteclustering in Relatie tot Milieuverontreiging. Gemeenschappelijke Gezondheidsdienst Zuid-Kennemerland, Haarlem.
- Middelkoop, H., 1990. Uncertainty in a GIS: a Test for Quantifying Interpretation Output. ITC Journal, 1990-3, pp.225-232.
- Munda, G., P. Nijkamp and P. Rietveld, 1992. Multicriteria Evaluation and Fuzzy Set Theory, Research Paper, Dept of Economics, Free University, Amsterdam
- Nijkamp, P., P. Rietveld and H. Voogd, 1990. Multicriteria Analysis in Physical Planning, Elsevier, Amsterdam
- Nijkamp, P. and A. Reggiani, 1992. Spatial Interaction, Chaos and Evolution in Space, Springer Verlag, Berlin
- Openshaw, S., 1990. Spatial Analysis and Geographical Information Systems: a Review of Progress and Possibilities. GIS for Urban and Regional Planning, edited by H.J. Scholten & J.C.H. Stillwell, Kluwer Academic, Dordrecht, pp. 153-164

- Openshaw, S. & M. Charlton, 1990. Applying GIS to a Small Area Health Statistics System. Paper presented at SAHSU meeting London, (June 22, 1990)
- Openshaw, S., C. Brunsdon and M. Charlton (1991). A Spatial Analysis Toolkit for GIS. Proceedings of the EGIS'91 Conference, EGIS Foundation, Utrecht, The Netherlands
- Rhind, D., Openshaw, S. and N. Green, 1989. The Analysis of Geographical Data: Data Rich Technology Adequate, Proceedings of the IV International Working Conference on Statistical and Scientific Data Base Management
- Robinson, A.H. & J.P. Snyder (eds.), 1991. Matching the Map Projection to the Need. Committee on Map Projections of the American Cartographic Association, Bethesda.
- Scholten, H.J. & J.C.H. Stillwell (eds.), 1990. GIS for Urban and Regional Planning. Kluwer, Dordrecht.
- Shalaby, M.T., 1991. GIS in Behavioural Analysis and Activity Systems. In: Proceedings Second European Conference on Geographical Information Systems, (J.J. Harts, H.F.L. Ottens, H.J. Scholten eds.) EGIS Foundation, Utrecht
- Unwin, A., G. Wills & J. Haslett, 1990. REGARD - Graphical Analysis of Regional Data. Department of Statistics, Trinity College, Dublin.