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Progress in Planning 62 (2004) 3–65
PROGRESS IN PLANNING
www.elsevier.com/locate/pplann

GIS-based land-use suitability analysis: a critical overview☆

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Abstract

There are three main objectives of this monograph: (i) to provide an introduction to geographical information technology along with an historical perspective on the evolving role of Geographic Information Systems (GIS) in planning, (ii) to overview relevant methods and techniques for GIS-based land-use suitability mapping and modeling, and (iii) to identify the trends, challenges and prospects of GIS-based land-use suitability analysis. The monograph focuses on two perspectives of GIS-based land-use suitability analysis: the techno-positivist perspective and the socio-political, public participation perspectives. It is organized into six chapters. After an introductory setting chapter, which defines the scope of land-use suitability analysis, an overview of relevant GIS technology is provided in Chapter 2. Chapter 3 offers an historical account of the development of GIS. It also discusses the development of GIS in the context of evolving perspectives of planning. Chapter 4 gives an overview of the methods for GIS-based land-use suitability modeling. The overview provides a background against which selected case studies are discussed in Chapter 5. The concluding chapter summarized the main points of the monographs and discusses problems and prospects for GIS-based land-use suitability analysis.

☆ doi of original article 10.1016/S0305-9006(03)00079-5

doi:10.1016/j.progress.2003.09.002

CHAPTER 1

Introduction

1.1. Defining land-use suitability analysis

One of the most useful applications of GIS for planning and management is the land-use suitability mapping and analysis (McHarg, 1969; Hopkins, 1977; Brail and Klosterman, 2001; Collins *et al*., 2001). Broadly defined, land-use suitability analysis aims at identifying the most appropriate spatial pattern for future land uses according to specify requirements, preferences, or predictors of some activity (Hopkins, 1977; Collins *et al*., 2001). The GIS-based land-use suitability analysis has been applied in a wide variety of situations including ecological approaches for defining land suitability/habitant for animal and plant species (Pereira and Duckstein, 1993; Store and Kangas, 2001), geological favorability (Bonham-Carter, 1994), suitability of land for agricultural activities (Cambell *et al*., 1992; Kalogirou, 2002), landscape evaluation and planning (Miller *et al*., 1998), environmental impact assessment (Moreno and Seigel, 1988), selecting the best site for the public and private sector facilities (Eastman *et al*., 1993; Church, 2002), and regional planning (Janssen and Rietveld, 1990). This monograph focuses on land-use suitability analysis as applied to urban/regional/ environmental planning and management rather than agricultural/ecological/geological applications.

The diversity of the types of land-use suitability studies can be attributed to the different ways the term *land use* is defined by various applications and the context of its use. For example, it is likely that the urban planners and the agricultural experts would have different perception of the term. To this end, it is important to make distinction between two notions: land use and land cover (Chapin and Kaiser, 1979; Briassoulis, 2003). Broadly speaking, land cover describes the physical state of the earth's surface and immediate subsurface in terms of the natural environment (such as vegetations, soils, and surfaces and groundwater) and the man-made structures (e.g. buildings). Land use itself is the human employment of a land-cover type. It 'involves both the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation—the purpose for which the land is used' (Turner *et al*., 1995: 20). Furthermore, the term of land use may have different connotations depending on the spatial scale. At the large scales it is typically considered as a resource and consequently land use means resource use. In contrast, at the urban scale it is characterized in terms of the potential use of the land's surface for the location of various activities (Chapin and Kaiser, 1979: 4). This connotation of the term land use is implicit in the context of urban and regional planning. The description of land use, at a given spatial level and for a given area, usually involves specifying the mix of land use types, the particular pattern of these land use types, the areal extent and intensity of use associated with each type.

In the context of land suitability analysis it is important to make distinctions between the site selection problem and the site search problem (Cova and Church, 2000a). The aim of site selection analysis is to identify the best site for some activity given the set of potential (feasible) sites. In this type of analysis all the characteristics (such as location, size, relevant attributes, etc.) of the candidate sites are know. The problem is to rank or rate the alternative sites based on their characteristics so that the best site can be identified. If there is not a pre-determined set of candidate sites, the problem is referred to as site search analysis. The characteristics of the sites (their boundaries) have to be defined by solving the problem. The aim of the site search analysis is to explicitly identify the boundary of the best site. Both the site search problem and land suitability analysis assume that there is a given study area and the area is subdivided into a set of basic unit of observations such as polygons (areal units) or rasters (see Section 3.1.2). The land suitability analysis problem involves classification of the units of observations according to their suitability for a particular activity. The analysis defines an area in which a good site might exist. The explicit site search analysis determines not only the site suitability but also its spatial characteristics such as its shape, contiguity, and/or compactness by aggregating the basic units of observations according to some criteria (Diamond and Wright, 1988; Brookes, 1997; Cova and Church, 2000a; Aerts, 2002; Xiao *et al*., 2002). In this monograph, the term land-use suitability analysis will be used in a broader sense that includes the site search problem.

1.2. GIS-based land-use suitability analysis: trends and challenges

The GIS-based approaches to land-use suitability analysis have their roots in the applications of hand-drawn overlay techniques used by American landscape architects in the late nineteenth and early 20th century (Steinitz *et al*., 1976; Collins *et al*., 2001). McHarg (1969) advanced the overlay techniques by proposing a procedure that involved mapping data on the natural and human-made attributes of the environment of a study area, and then presenting this information on individual, transparent maps using light to dark shading (high suitability to low suitability) and superimposing the individual transparent maps over each other to construct the overall suitability maps for each land use. Although McHarg's approach is widely recognized as a precursor to the classical overlay procedures in GIS, some researches credit Charles Eliot (Miller, 1993; McHarg, 1996) and Jacqueline Tyrwhitt (Steinitz *et al*., 1976) as predecessors of the modern map overlay techniques. Tomlinson (1999) suggests that it was his company, Spartan Air Services of Ottawa, that in 1962 first proposed computerizing the overlay method (Waters, 2002).

The overlay procedures play a central role in many GIS applications (O'Sullivan and Unwin, 2003) including techniques that are in the forefront of the advances in the land-use suitability analysis such as: multicriteria decision analysis (MCDA) (Diamond and Wright, 1988; Carver, 1991; Malczewski, 1999; Thill, 1999), artificial intelligence (AI) (geocomputation) methods (Sui, 1993; Zhou and Civco, 1996; Ligtenberg *et al*., 2001; Xiao *et al*., 2002), visualization methods (Jankowski *et al*., 2001), and Web-GIS (Carver and Peckham, 1999; Zhu and Dale, 2001; Rinner and Malczewski, 2003). Over the last forty years or so GIS-based land-use suitability techniques have increasingly become integral components of urban, regional and environmental planning activities (Brail and Klosterman, 2001; Collins *et al*., 2001). There are several fundamental trends in computer-supported approaches to land-use suitability analysis. These trends can be discussed and analyzed from two interrelated viewpoints: the computer/information science perspective and the social science perspective. Recent advances in information technology especially that of the Internet and AI have urged the development of new approaches to the GIS-based land-use suitability analysis, such as network-based support systems and soft computing-based procedures. These developments are a part of the emerging discipline of geographic information *science* (GISci). GISci is the 'science behind the systems' (Longley *et al*., 1999). Pursuant to GISci is the notion of 'spatial reasoning', defined by Berry (1993) as a situation where the process and procedures of manipulating maps transcend the mere mechanics of GIS interaction (input, display and management), leading the user to think spatially using the 'language' of spatial analysis in GIS. This is how to move beyond mere representation and visualisation of geographic data and information to see an additional or greater value of GIS. There is not however a general consensus about the form of good robust spatial analytic tools which might be added to GIS for supporting planning and decision making processes. This is in part due to the fact that most planning theories are based on different assumptions regarding rationally. Two types of rationality are of particular relevance for understanding the role of information technology in planning: *instrumental* (or functional) rationality and *communicative* (or procedural) rationality.

Most GIS have been developed with theories of spatial representation and of computing in mind, and with strong assumptions about the instrumental rationality underlying planning procedures. Instrumental rationality is based on a positivist ideal, which puts spatial reasoning and scientific analysis at the core of planning. It assumes a direct relationship between the information available and quality of planning and decision making based on this information. On the other hand, communicative rationality postulates an open and inclusive planning process, public participation, dialogue, consensus building, and conflict resolution (Innes, 1995). Klosterman (2001) has characterized the 1990s as the period of 'collective design' in information technology where processes are designed to facilitate social interaction and discourse in the pursuit of collective goals. In this context, GIS is seen as a tool for plan-making *with* the public, rather than *for* the public. While the instrumental and communicative perspectives are often viewed as competing theoretical perspectives, the role of information is relevant to both of them. It is rather the type of data and the way in which the data are processed to obtain information that makes the two perspectives different.

Land-use suitability analysis is more than a GIS-based procedure even if it involves participatory approaches. While databases and spatial information systems are important components of planning activities, planners deal with constituencies, power relationships, and complex urban and regional problems. This calls for socio-political perspectives on the use of GIS as a tool for planning. Harvey and Chrisman (1998) argue that like other technologies, GIS is socially constructed via negotiations between various social groups such as developers, practitioners, planners, decision-makers, special interest groups, citizens, and others who may have interest in the planning and policy making process. To this end, there has been growing criticism of the role of the technology as a tool for planning and decision making. Broadly speaking, the criticism comes from social scientists and it has been focused on the uneven social consequences of the GIS technology, questioning its impact on equity, justice, privacy, accuracy, accessibility, and quality of life (Pickles, 1995; Sheppard, 2001; Thomson and Schmoldt, 2001; Sieber, 2003). It is argued that the advancement of the high-powered microcomputing hardware and the lowering of the costs of desktop GIS software have popularized GIS but achieved limited success in improving the general public's participation in community-based GIS projects. Participation, in this view, is a political rather than a technological issue.

The 'contrast' between the technological and the political perspectives on the societal implications of geographic technologies is evident in a debate between the techno-positivist (proponents) of GIS on the one hand and the social scientists (opponents) on the other (Pickles, 1995; Openshaw, 1999). This debate is exemplified by a series of the US National Center for Geographic Information and Analysis (NCGIA) initiatives including: 'Spatial Decision Support Systems (SDSS)' (Initiative-6), 'Collaborative Spatial Decision Making' (Initiative-17), 'GIS and Society: The Social Implications of How People, Space and Environment are Represented in GIS' (Initiative-19), and the Varenius project on 'Empowerment, Marginalisation and Public Participation GIS' (see http://www.ncgia.ucsb.edu/ncgia.html). While the first two initiatives have focused research efforts on technical/computational aspects of SDSS including participatory/collaborative GIS, the latter initiatives represent the social science perspective by looking at the inter-relationship between GIS and society. Specifically, the Initiative-6 focused on the role of GIS and related techniques in supporting spatial decision making processes. It was organized around the notion that GIS can provide limited support for decision making and that more sophisticated methods of decision support are required. Four research themes emerged from the initiative: (i) optimal schema for decision support in areas of ill-defined spatial problem-solving, (ii) modeling and data requirements for SDSS, (iii) technology and the implementation of SDSS, and (iv) user requirements and organizational issues. The last theme has eventually led to the development of Initiative-17. This initiative extended the conceptual frameworks for SDSS to address the technological needs of collaborative spatial decision making. A specific point of emphasis was placed on integrating SDSS with computer supported cooperative work environments. Such environments enable groups of people to work together by providing a set of generic tools that handle many of the tasks that are required in group enterprises: exchange of data and information; and group evaluation, consensus building and voting (see http://www.ncgia.ucsb.edu/ncgia.html).

The growing interest in examining the societal implication of GIS has brought together the GIS developers and practitioners and social scientists concerned with the nature of GIS. They formed Initiative-19 and identified the following major objectives of the initiative: (i) examining how data availability and visualization techniques influence the ways in which natural resources and society are represented in GIS, (ii) investigating what limits to representation may be intrinsic to the logic of GIS, (iii) determining how the representations of environment and society in GIS influence the questions posed, and solutions proposed in practical applications, (iv) determine whether and how the knowledge, views, and needs of those affected by the application of GIS can be represented adequately in conflictual social situations where GIS is used as a decision making tool, (v) examining to what degree new functionalities of GIS may allow the limits of current representations to be extended, (vi) identifying the degree to which the application of GIS can be democratized by placing the technology in the hands of a broader spectrum of society, and (vii) investigate the ethical and legal implications of related activities.

Finally, the Varenius Project put together all the concerns identified by the previous initiative (Goodchild *et al*., 1999). It has been motivated by scientific, technical, and societal concerns. First, the aim of the project is to develop and refine tools and methods that scientists can use to study geographically distributed phenomena. Second, the project aims at provided better understanding of geographic concepts. Third, it examines the impacts that the geographic information technologies have on individuals, organizations, and society in the context provided by geographic space (see http://www.ncgia.ucsb.edu/ncgia.html).

It is in the context of the debate on the inter-relationship between GIS and society that one can see the potential for advancing the role of information technology in land-use suitability analysis. At the most general term, the GIS-based land-use suitability analysis should be viewed as a process of converting data to information that adds extra values to the original data. At subsequent stages of the process, the original data are interpreted and analyzed to produce information useful to those involved the planning process. The data are progressively converted into information about the planning problem. The problem at hand determines the need and the nature of the information required. To this end, it is useful to make a distinction between 'hard' and 'soft' information used in the land-use suitability analysis as a part of a planning process. The hard and soft information are sometimes referred to as objective and subjective information, respectively. The former are derived from reported facts, quantitative estimates, and systematic opinion surveys; for example, census data, remote sensing data, meteorological surveys, etc. The soft information represents the opinions (preferences, priorities, judgments, etc.) of the interest groups and decision makers, based on intuition, *ad hoc* surveys, questionnaires, comments, and similar sources. This type of information is used in the planning process because social values and political consideration also enter into the calculus of the decision maker. Any planning process must focus on a mix of hard and soft information. Central to the land-use suitability analysis is the way in which these two types of information are combined as well as the right balance between the amount of hard and soft information used in the analysis. This implies that GIS must have the capabilities of incorporating the soft data into the conventional map-based GIS operations to be useful in answering questions related to the land-use suitability analysis. The soft data/information will often be derived from a public discourse between interest groups and individuals affected by development and management activities pursued by the public or private sector. One can suggest that information systems for planning in general and land-use suitability analysis in particular should be constructed with at least two interrelated perspectives in mind: (i) the techno-positivist perspectives on GIS, and (ii) the socio-political, participatory GIS perspectives. This monograph focuses on these two themes.

CHAPTER 2

The history and development of GIS

The evolution of GIS-based land-use suitability modeling has been a function of the development of information technology in general and geographic information technology, in particular. It is also a function of the evolving perspectives of planning and GIS. The modern era in GIS can be divided into three time periods: (i) the GIS research frontier period in the 1950–1970s which can be referred to as the innovation stage, (ii) the development of general-purpose GIS systems in the 1980s or the integration stage, and (iii) the proliferation stage which is characterized by the development of the user-oriented GIS technology in the last decade or so (for a comprehensive overview of the history of GIS see Mark *et al*., 1997; Foresman, 1998; Forrest, 1998; Waters, 1998). The progression in the GIS development corresponds to the likewise evolving perspectives of planning (Table 1). The primary focus has been shifted over time from the scientific, system approaches, through political perspectives to the public participatory and collective design approaches (Brail and Klosterman, 2001). The GIS development and the changing perspective of planning have been influencing the methods and approaches used in the land-use suitability analysis (Collins *et al*., 2001; see Chapter 4 for an overview).

2.1. Innovation: GIS research frontier

Two major factors contributed to the development of GIS in the 1950–1960s: the improvements in computer hardware technology and the theoretical advances in spatial sciences. GIS have been evolving parallel to computer technology. The first 'automatically sequenced high-speed electronic digital computer' was introduced in the 1940s. In the next 10 years or so, the mainframes and computers incorporating integrated circuits were available leading to a significant improvement in the speed of computation. The advances in computer technology in 1950s and 1960s allowed for developing automated systems for storing, manipulating and displaying geographical data. The first systems we now call GIS were emerging in the 1960s, just as computers were becoming accessible to large government and academic institutions (Coppock and Rhind, 1991).

To take full advantage of the improvements in computer hardware technology required advancements in theories of spatial analysis based on computer handling of spatial data. These advancements took place during the 'quantitative revolution' in the spatial sciences

Table 1
Stages in GIS development and changing perspectives of planning

GIS development	Perspectives of planning	Land-use suitability analysis
Invitation (1950s–1970s)	Scientific	Computer-assisted overlay mapping
Integration (1980s)	Political	Cartographic modeling/MCDA
Proliferation (1990s)	Participatory/collective design	MCDA AI/Geocomputation Internet/Multimedia/Visualization

in 1950–1960s. The quantitative approaches for analyzing spatial patterns and processes resulted in the theoretical foundations of spatial concepts such as distance, orientation, and connectivity and geometric representation of geographical entities in the form of rudimentary objects such as points, lines and areas (polygons). The concept of geographical data matrix provided a consistent and comprehensive way of organizing geographical data/information.

It was the combination of the advancements in computer hardware technology and theoretical geography/cartography that lead to development of GIS in the earlier 1960s. Many basic concepts of GIS (map layers, topological structure, TINs) can be traced back to work done in the Land Inventory branch of the Canadian government and the Harvard Lab for Computer Graphics and Spatial Analysis. In 1963 the Development of Canada Geographic Information (CGIS) project was launched. The CGIS system was designed for land inventory and for generating and analyzing information to be used in developing land management plans. The project has pioneered many aspects of GIS by providing a number of conceptual and technical innovations and contributions such as the concept of 'topological' GIS system, the separation of data into attribute and locational files and organizing geographical data themes or layers, the implementation of functions for polygon overlay, and measurement of area (Mark *et al*., 1997). The Harvard Laboratory for Computer Graphics and Spatial Analysis laid its foundation with the development the SYMAP system in the mid-1960s. SYMAP evolved into a family of related systems including CALFORM (late 1960s), SYMVU (late 1960s), GRID (late 1960s), POLYVRT (early 1970s) and ODYSSEY (mid 1970s) (see Section 2.2).

The CGIS and Harvard Lab projects influenced the geographic work done at the US government. The development of the GBF-DIME (Geographic Base File using Dual Independent Map Encoding) by the US Census Bureau in the 1960s marked the large-scale adoption of digital mapping by the US government. GBF/DIME system was developed in preparation for the automation of geocoding of the 1970 census. The GBF/DIME data structure was essentially based on the arc structure of CGIS and the internal structure (common denominator format) of POLYVRT. DIME files were very widely distributed and used as the basis for numerous applications in natural resource inventory and land use planning (Mark *et al*., 1997).

As much as the advancements in computer technology brought to life the earlier GIS systems, the changes in the computer technology had made the systems obsolete by the end of the 1970s (Mark *et al*., 1997; Foresman, 1998; Waters, 1998). The most important of the technological changes was the shift from the high-cost mainframe computers to the low-cost mini and PC platforms, which appeared in the 1980s. Most of mainframe GIS computer systems were never transferred to the new platforms. This was primarily related to the underlying limitations of the earlier GIS systems such as limited portability of software and data, the high maintenance cost, the difficulty to update the systems, the lack of distributed access and the complexity of the command line interface. There were also other more inherent reasons why the earlier GIS systems became obsolete. First, the systems were mostly designed as general-purpose databases for performing a very narrow range of functions. Second, the earlier systems were largely developed independently of the organizational setting within which the systems were intended to work. Consequently, the systems failed to integrate the information technology into the organization's information-handling and decision making structures.

2.2. Integration: general-purpose GIS

The most important factors influencing the evolution of the GIS software in the 1980s had been the enormous advances in computer hardware, which led to a dramatic reduction in the cost of processing power (Waters, 1998). Among those advances were: the innovations of large-scale and very large-scale integrated circuits and microprocessors that contained memory, logic, and control circuits (an entire Central Processing Unit) on a single chip. These technological innovations in turn allowed for the development of the home-use personal computers (PCs) like and IBM PC and the Apple (II and Mac) and the MS-DOS (Microsoft Disk Operating System). Following the changes in computer technology, there was a major shift in the GIS industry at the end of the 1980s. The industry was making a transition from the workstation environment to the PC, from computer systems that relied upon command-line systems to software designed around graphical user interfaces (GUI) on the desktop.

Although some of the major commercial GIS software companies have been established at the end of the 1960s, it was not until the 1980s that the numerous commercial GIS systems have been developed. The most notable examples include Environmental Systems Research Institute (ESRI) and Intergraph Corporation (both founded in 1969). Released in early 1980s ARC/INFO from ESRI was the first GIS to take advantage of new super-mini computer hardware. One of the characteristics of the system was a successfully implementation of the separate attribute and locational information concept by combining the standard relational database management system (INFO) to handle attribute tables and specialized software to handle objects stored as arcs (ARC). ARC/INFO was an application-oriented vector-based system with a 'toolbox', command-driven, product-oriented user interface modular design allowing complex applications to be developed on top of the toolbox. Similar design philosophy has subsequently been applied to a number of other GIS companies such as the MapInfo and Caliper corporations. The former supplied a low-cost desktop MapInfo GIS. The latter specialized in transportation GIS (TransCAD GIS).

As computing power increased and hardware prices plummeted in the 1980s, GIS became a viable technology for state and municipal planning and academic departments. In this context, the development of low-cost raster-based GIS was critical. This development was inspired by a work on map algebra at Yale School of Forestry and Environmental Studies that resulted in the Map Analysis Package (MAP) (Tomlin, 1990). Subsequently, a number of raster GIS have been made available including: GRASS (US Army Corps of Engineers, 1993), Idrisi (Eastman, 1997), SPANS GIS (Tydac Resaerch Inc., 1996), and MAP II (Pazner *et al.*, 1992). It is also worth to noting that the development of GIS applications in 1980s has been widened by the range of related commercially available products of information technology including computer assisted drafting (CAD), database management system (DBMS), remote sensing, global positioning system (GPS) as well as an increase of digital data availability to private and public organisations (Coppock and Rhind, 1991).

2.3. Proliferation: the user-oriented GIS

Until the end of the 1980s, GIS had remained a highly specialist professional activity. The 1990s changed it, with the result that GIS is now regarded as a routine software application within the grasp of lay individuals. The Window-based GUI has become a standard for accessing and displaying data in GIS. The common interface tools like on-screen 'buttons' and drop-down menus that can be understood quickly and easily with the result that GIS can tap into the growing market of untrained users. Better awareness of the value of digital spatial data and GIS-based solutions to planning, decision making and management problems have produced a large market for GIS. There are growing areas of application in business and engineering, in addition to the early ones in mapping, environmental management, and land parcel management. The technological progress has been accompanied by an explosion of digital data available to private and public organisations.

Among the most significant trends in the GIS technology in the last decade or so have been the interrelated advancements in the distributed GIS (interoperability), open GIS, multimedia GIS, and Internet-GIS. The concept of distributed GIS is based on the ability for computer systems to link with other computer systems. By using specified protocols, different types of computer platforms can interact and share data with one another. Computers can be linked together in local area networks (LANs), so that a user on one type of machine can access data and applications on another type of machine. With desktop machines and LANs, users can use GIS software and data anywhere on the network from their own desks. The concept of distributed computation has been farther advanced by the implementation of open systems. Open GIS Consortium (OGC) Project (see http://www.opengis.org) established in 1994 has play a key role in advancing the open GIS concept. An open GIS is based not only interoperability between different hardware platforms but between different software applications as well. GIS can interact more freely with other types of applications such as nonspatial databases, statistical packages, spreadsheets and graphics programs. Data and information stored in a spreadsheet, graphics, or statistical program can be incorporated into GIS program and vice versa. This in turn has lead to integrating GIS systems with spatial analysis models, planning and decision making techniques.

The Internet is perhaps the most significant technology influencing current trend in GIS (see Peng and Tsou, 2003). In most general term, the Internet is the world's largest public network. It is a stream of computer serves that supply data and information to multiple clients using the common Internet Protocol. The WWW is an application, which operates over the Internet. The WWW use has been growing an exponential rate and it has become a new standard for many types of GIS application (Longley *et al*., 1999; Laurini, 2001). All major GIS vendors are developing procedures for WWW-based access to data and models developed with their software. Example include: ESRI's ArcView Internet Map Server, Intergraph's GeoMedia Web Map, Autodesk's Map Guide, and MapInfo's Map Xtreme Java. The growth of WWW and on-going improvements made in the different areas of information technology have facilitated the development of multimedia systems and hence the use of multimedia in spatial analysis and modeling. Câmara and Raper (1999) give a review on these technological developments and the spatial applications of multimedia technologies. Batty and Miller (2000) provide an overview of concepts for representing and visualizing physical and virtual information spaces.

2.4. Evolving perspectives of planning and GIS

A look at the role of computer technology in planning as it was viewed in 1960s, and as it is defined today, can tell us a great deal not only about the nature of planning but also about the way computer-based data and models have been used in planning over the last few decades. In 1970 R.L. Creighton wrote: "… during the past two decades … there have been assembled a body of data and a set of procedures by which teams of persons with different skills have been able to prepare long-range plans […]. These plans have not been simply designs based on intuition and judgment, but are based on rigorous process, including computer tests, which demonstrate that the recommended plan maximizations performance in relation to an accepted goal. …Unfortunately, the factual bases for this planning and the planning process themselves, are understood by relatively few people. … A substantial gap exists between the thinking of those with experience in this field and those who *should* know… [including]… political leaders, government executives, businessmen and civic leaders" (Creighton, 1970: XV). This statement contrasts with the arguments put forward 30 years later by Brail and Klosterman (2001: XI). They wrote "… we have moved to the 1990s and beyond with planning as collective design as the defining theme. The rapid development of the Web and of group-based decision tools are two indicators of this focus on the community as a fulcrum around which planning decisions revolve". The contrast between these two perspectives of planning goes along the line between the 'close' and 'open' use of computer technology. It is marked by the difference between planning methodology that is understandable only to experts and the community-based, participatory style of planning.

Fig. 1 illustrates the evolving perspectives of planning and concerns of information technology. Over the last four decades, the planning paradigm shifted from the applied science approaches in the 1960s through the political process-oriented perspective in the 1970s, and a focus on communication in the 1980s to collective-design approaches in the last decade (Klosterman, 2001). The progression of perspectives of planning corresponds to the likewise evolving concerns of information science. The primary focus has been shifted from the data-oriented information systems in 1960s, through information management systems in the 1970s, and knowledge-based and decision support systems in the 1980s to the intelligence-based systems in the 1990s and beyond.

According to the applied science approach, planning is fundamentally a sequence of rational and technical procedures (Hall, 1974). Central to the scientific approach is the instrumental rationality of the positivist paradigm. From this perspective, GIS is seen as a data-centered information technology that provides tools for deriving information from databases to be used in value-free process of rational planning. The underlying assumption—derived from the positivist paradigm—is that there is a direct relationship between the data processing capability and information availability on one hand and the quality of planning on the other. The better data processing capabilities (and more information), the better is the quality of planning.

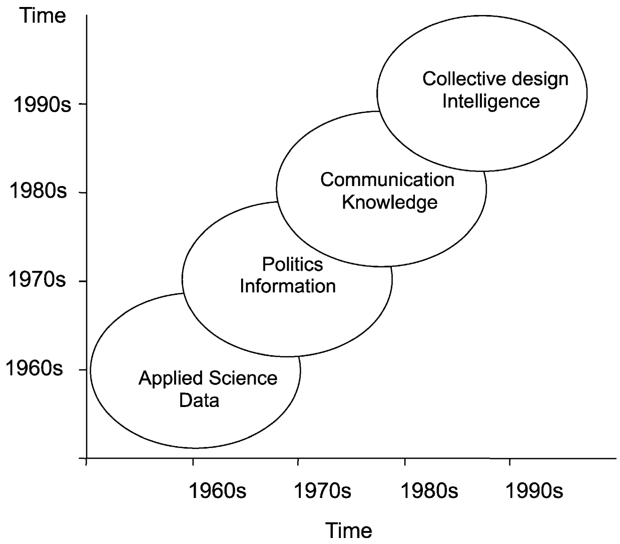

Fig. 1. Evolving perspectives of planning and concerns of information technology.

The late 1970s and the 1980s had been signified by an increasing disappointment in, and questioning of, the applied science model of planning. The criticism was a part of broader critique of positivism. It has been argued that the scientific view of planning is essentially ahistoric and it fails to address the relationship between planning and the society being planned. The criticism of the scientific approaches, focused on its implicit spatial determinism and the logical impossibility of defining spatial variables independent of the context within which they are supposed to operate.

Disillusionment with the applied science model of planning led, in the 1970s, to the adoption of a strong political perspective of planning (Friend and Jessop, 1977; Couclelis, 1991). This perspective recognizes that planning deals with socio-political systems that are composed of interest groups with conflicting values and preferences. The emphasis is put on the importance of the process of development characteristic of the particular societies in which planning is being carried out. Viewing planning in this way the key underlying concepts become public participation, negotiation, compromise, redistribution, consensus building, and conflict management and resolution (Couclelis, 1991). Consequently, the role of information technology is to aid in an open and inclusive planning process. This approach is referred to as the communicative (substantive or procedural) rationality (Nedović-Budić, 2000).

The view of planning as a part of socio-political system was reinforced in the 1980s. A number of empirical studies revealed that planning is more than the collection and provision of information that can improve the policy-making process (Harris, 1989). It involves also a wide range of ‘untangle’ activities such as advice giving, storytelling, myths, and other metaphors and rhetorical devices planners employ to affect the attitudes and values of the community-at-large regarding the benefits and consequences of planning (Klosterman, 2001). The role of planner as a planning agency leader and technical advisor is seen as less important than the ways in which planners convey information to others.

Planning in this view is 'an inherently political and social process of interaction, communication, and social design' (Klosterman, 2001: 10). While some elements of the planning process may be well defined, there are significant components of subjective knowledge, common wisdom, myths, etc. involved in the process. The idea of combining the objective and subjective elements of the planning process in a computer based system lies at the core of the concept of SDSS, Spatial Experts Systems (SES), and Planning Support System (PSS).

DSS is a computer-based system designed specifically for supporting the user in tackling semi-structured problems. Although an application of an SDSS to solve a decision making problem may increase the efficiency of the data and information processing operation, it is not the real aim of the system. More important, a DSS aims to improve the effectiveness of decision making by incorporating judgments and computer-based programs within the decision making process. The system should support a variety of decision making styles that may be present in a particular problem solving process. Consequently, the key feature of any SDSS is that it does not replace a user's judgments. The purpose of such a system is to support a user in achieving 'better' decisions. To improve the decision making, SDSS involves the knowledge, intuition, experience, initiative, creativity, etc. of the users. It provides judgmental information in the form of preferences about the significance of impacts, which cannot be expressed *a priori* in a formal language. The system should help the users to explore the decision problem in an interactive and recursive fashion. To this end, the ability of a GIS to handle judgments involved in the planning process is of critical importance, if the system is to be used as a SDSS. This calls for a representation of the judgments, values, arguments and opinions in the system. One way of doing this is to incorporate decision analytical techniques (e.g. multicriteria analysis), into the GIS-based planning process. While GIS systems can provide a tool for handling the disagreements over facts by providing more and better information, the decision analysis techniques can help in diminishing the disagreements over values among the conflicting interest parties (Feick and Hall, 1999; Jankowski and Nyerges, 2001).

Unlike SDSS, SES is based on an assumption that the system can be used by non-experts to improve their problem-solving capabilities. An SES software can be defined as a computer-based system that employs reasoning methodologies in a particular spatial problem domain in order to transfer expertise and render advice or recommendations, much like a human expert (Kim *et al*., 1990; Waters, 1988; Laurini, 2001). SES is also referred to as a spatial knowledge-based system (SKBS). It aims at imitating the reasoning process of experts in solving specific spatial problems such as land suitability and site selection problems (Han and Kim, 1988; Kim *et al*., 1990; Buis and Vingerhoeds, 1996; Zhu *et al*., 1996). Broadly speaking, an SES consists of a set of rules and user-supplied data which interact through an inference engine. The knowledge and experience of the expert are typically captured in a series of if-then rules which are used to explore and solve problems. During the 1990s there has been a movement away from the traditional knowledge-based approaches toward the development of case-based reasoning (CBR) systems (Clayton and Waters, 1999; Holt and Benwell, 1999). The main idea behind the CBR approach is to use previous cases to interpret or solve a new problem. The advantage of the CBR approach over the traditional rule-based reasoning is that it can record and represent knowledge that is hard to express with explicit rules or is too case-specific (Shi and Yeh, 1999). The SES approaches have been recently influenced by developments in the integration of GIS and AI techniques (see Section 4.3). Yeh and Shi (1999) suggest that the CBR techniques can be consider as an new approach for designing a PSS.

The concept of decision support and knowledge-based systems has evolved in the 1990s from a 'static' system focusing on the combination of objective and subjective knowledge into an 'intelligent' system. Unlike the conventional DSS, the intelligent system is characterized by the ability to handle 'novel situations and new problems, to apply knowledge acquired from experience, and to use the power of reasoning effectively as a guide to behaviour' (Klosterman, 2001). The concept of intelligent system in planning is based on the view of planning as reasoning together or collective design where processes are designed to facilitate social interaction and discourse in the pursuit of collective goals.

This broadened perspective of planning is related to the advancements in information technology. One of the more significant trends in the 1990s has been the evolution from individual stand-alone computers to the highly interconnected telecommunications network environment of today. The Internet and Web created an environment with almost ubiquitous access to a world of information. At the same time, many organizational decisions migrated from individual decisions to ones made by small teams to complex decisions made by large diverse groups of individuals. In this environment, several key technological developments have occurred in the area of decision support. Various tools to support collaboration and group processes have been developed, implemented, evaluated, and refined (Jankowski and Nyerges, 2001). Accordingly, GIS has been applied as a collaborative decision support system allowing interested parties to interact with public or private planning agencies on projected plans. There are some evidence to show that GIS is no longer a tool used by professional planners and consultants but the technology is also increasingly being employed by community groups and non-governmental organizations as part of their planning efforts (Craig *et al*., 2002).

PSS can be considered as an example of collaborative DSS. The PSS concept has been developed in the context of urban and regional planning (Harris, 1989). Well-designed PSS should provide an interactive, integrative, and participatory support for poorly structured planning tasks. It integrates multiple technologies and common interface. Klosterman (2001) suggests that PSS is "an *information framework* that integrates the full range of current (and future) information technologies useful for planning" (p. 15). Although PSS should be organized around the GIS technology, it also should incorporate a full range of planning tools such as economic and population analysis and forecasting, environmental, land use and transportation modeling. In addition, PSS should include other relevant technologies (e.g. expert system, multimedia) and techniques (e.g. optimization models, MCDA) allowing for handling both quantitative and qualitative data and facilitating voting, ranking, public participation and group interaction (Harris, 1989; Bishop, 1999; Klosterman, 2001).

2.5. Concluding comments: synthesis

As demonstrated in Section 2.4 the role of GIS in planning has evolved along with the changing perspectives on planning from scientific approaches through the political process-oriented perspectives and a focus on communication to collective-design approaches. One of the conclusions emerging from the discussion was that the changing nature of planning has been associated with increased involvement of non-experts (public, interest groups, communities, stakeholders, nongovernmental organization, etc.) into planning and decision making processes. This evolution of planning has been paralleled by the increasing accessibility (user-friendliness) of GIS technology. GIS systems have evolved from a close—expert-oriented to an open—user-oriented technology. In short, GIS technology to be useful in planning must evolve in parallel with changing perspectives of planning. To this end, I suggest that the concept of ‘building blocks’ can provide us with an insight into the nature the evolving role of GIS technology in planning as well as it can give us a tool for exploring a path of future evolution of the geoinformation technology as applied to planning.

The concept of building blocks is derived from a general theory of evolving systems suggested in biological sciences (Dawkins, 1976; Blackmore, 1999). Dawkins (1976) proposed the term ‘meme’ as a cultural analog of the gene. A meme is a concept or idea that reproduces by spreading from one individual’s mind to others. This process of self-reproduction, leading to spreading over a growing group of individuals, defines the meme as a replicator. Memes ‘work’ essentially like genes in that they can replicate themselves and the ones that prove to be beneficial will last in the culture or ‘meme pool’. They can mutate, evolve or become extinct as they are passed from generation to generation. A meme’s success is a matter of survival of the fittest. Therefore, the most successful memes are not necessarily those with the greatest merit, but those with characteristics that help them get distributed to a great number of ‘hosts’. The concept of meme has been has been extended to decision science (Savage, 1995) and computer science (Tanaka, 2003). Tanaka (2003) implemented the concept in his IntelligentPad technology and suggested how the IntelegentPad technology and GIS might be developed together (Waters, 1995, 2003).

The concept of evolutionary building blocks is base on three principles: *aggregation, ergonomics*, and *standardization* (Savage, 1995). The aggregation principle states that evolving systems are often comprised of building blocks which were once at the evolutionary forefront of the systems themselves. The components of electronics: resistors, capacitors, coils and vacuum tubes, were the building blocks of early computers in the 1940s. The transistor led to the aggregation of far more electronic components into the computers of the 1960s. An innovation of integrated circuitry has raised the level of aggregation to millions of components per square inch, and led to the development of PCs in the earlier 1980s. Thus, the changes in computer technology can be described as an evolutionary process of aggregation of simple building blocks into more complex building blocks.

GIS technology has evolved in similar way. The GIS systems developed at the Harvard Laboratory for Computer Graphics and Spatial Analysis provide a good illustration of the evolving system (see Section 2.1). SYMAP was developed first as general-purpose mapping package with the output capabilities exclusively on a line printer. The system had a limited functionality of mapping isolines, choropleths and proximal maps. CALFORM improved the output capabilities of SYMAP by replacing the line printer output by a plotter output. SYMVU added the 3D perspective views to the SYMAP output. GRID pioneered the concept of the raster GIS. It allowed multiple input layers of raster cells to be stored in the system and then processed using the McHarg's concept of map overlay. POLYVRT was a 'mutation' of the capabilities of SYMAP and CALFORM. The development of the system was motivated by need of computer mapping packages for flexible input, transfer of boundary files between systems, growing supply of data in digital form, e.g. from Bureau of the Census. POLYVRT has evolved into ODYSSEY by extending its capabilities beyond format conversion to a comprehensive analysis package based on vector data. The Harvard Laboratory's systems have become, eventually, 'extinct' as a new generation of GIS systems (e.g. ESRI products) have moved into the forefront of GIS technology. However, the elements of the Harvard Laboratory's systems were building blocks for the new generation of GIS technology (e.g. ARC/INFO and ArcView). In short, according to the aggregation principle today's systems are often tomorrow's subsystems.

The principle of aggregation can also be applied to the role of GIS in planning. At first, the support of planning activities was limited to very routine digital tasks such as mapping and querying spatial data. These fundamental GIS functionalities had been considerably increased by introducing map algebra, which in turn provided the building blocks for more advance GIS-based modeling such as MCDA. Successively, there has been a considerable activity aiming at extending GIS operations to statistical, optimization, simulation, and related modeling functions to increase the GIS capability for exploratory, explanatory and predictive analysis. These advanced GIS functionalities have been in some way developed around the simple building blocks of GIS such as measurement, querying, buffering, proximity, aggregation, combination, interpolation, etc. The basic GIS functions have in turn became building blocks for the new generation of GIS functions included Participatory-GIS, Web-GIS, Multimedia-GIS, and a wide range decision and planning supporting technologies. Thus, the development of GIS and related technologies can be viewed as an evolutionary process of aggregating simple building blocks into more complex structures.

One of the main objectives of the computer industry in general and the geoinformation industry in particular is to supply the markets with easy-to-use products. This can be referred to as the ergonomic principle. Specifically, the principle says the complex systems are often easier to use than their simpler ancestors. My lap-top computer is much more complex than the first 'automatically sequenced high-speed electronic digital computer'. Yet, it is much easier to use than the first computer. Similarly, today's GIS systems (such as ArcGIS 8.0 or Idrisi for Windows) are far more complex than those of the Harvard Laboratory (e.g. SYMAP or ODYSSEY). Yet the former are much easier to use than the latter. In short, as GIS systems have gradually become more complex they have also become more user-friendly and more accessible to the public.

During the era of the scientific approaches to planning, the laws of arithmetic formed the basis of planning techniques such as linear programming and spatial interaction models. Computer systems designed to support planning were built on algebra and probability, and provided the building blocks of modern planning and decision making. This type of planning was strongly associated with the instrumental (functional) rationality, which put scientific analysis at its core. Because most planners and decision makers let alone the public do not view planning processes in algebraic and probabilistic terms, and their views on planning do not conform to the functional rationality approach, there has traditionally been a serious ergonomic problem with the scientific approach. One can refer to this as an 'algebraic curtain' separating the experts (academics and planners) from the decision makers and public (Savage, 1995). It can be argued that it was the ergonomic principle at work when the focus of planning shifted from the functional rationality to the communicative (substantive or procedural) rationality approach, which is centred on open and inclusive planning process, public participation, consensus building, and conflict resolution (Harris, 1989; Klosterman, 2001). This shift has accordingly found its reflection in the changing role of models in the planning process.

Another important factor in technological evolution is the establishment of standards. The standardization principle of the evolving systems is a prerequisite to successful proliferation of a given technology. Increasing standardization results not only in increased accessibility of a system but it also makes the system less expensive and therefore available to more people. Today's computer hardware and software products are far more standardized than those available a few decades ago.

The variety of data structures used in different GIS and the growing use of GIS are accompanied by intense efforts for standardization of data structures and methods for the interchange of spatial data. Especially in planning, management and decision making tasks the integration of data from different sources is a central requirement, which is only partially met by the current state-of-the-art GIS. Metadata provide a platform for standardization. They provide a summary with detailed information pertaining to a particular GIS dataset (Decker, 2001). Since the first standardized content was released by the Federal Geographic Data Committee (FGDC) in 1994, there has been considerable movement towards harmonizing the FGDC metadata standards with the International Organization for Standardization (ISO) metadata standard. The major contribution of the metadata standards to GIS-based analysis and planning is that the users can now use a wide range of publicly available files (datasets) which once had to be scanned or digitize from scratch.

Similarly to the meta-data standards, it would be useful to have meta-models. Broadly speaking, the idea behind the meta-models in planning is to develop an application from 'standardized software' containing a set of standardized modules that can be used under different planning and decision situations. Such perspective on the role of computer-based modeling differs from the traditional approach to model building in planning. Instead of formulating a model from scratch, the user merely transform existing ones, which may be combined (recombinant) to form larger and customized applications. The systems provide a set of simple, standardized building blocks that can be used for constructing an appropriate model in a give situation. Such systems consist of a software planning/decision support that is built on the top of conventional GIS software. There is a wide spread agreement that PSS and related technologies should be built around GIS (see Section 2.4). One may suggest that standardization would provide for the proliferation of the GIS/PSS technologies. Increasing standardization results not only in increased accessibility of a system but it also makes the system less expensive and therefore available to more people and democratization of GIS technology is enhanced.

CHAPTER 3

GIS: components, software and operations

3.1. Components of a GIS

3.1.1. GIS functions

There have been a number of attempts to define a Geographic Information System (GIS) (Cowen, 1987; Longley *et al*., 1999; Heywood *et al*., 2002). On careful scrutiny, most definitions of GIS focus on two aspects of the system: technology and/or problem-solving. GIS is conventionally seen as a set of tools for the input, storage and retrieval, manipulation and analysis, and output of spatial data. Accordingly, the technological perspective on GIS identifies four components of the system: data input, data storage and management, and data manipulation and analysis, and data output. Data input refers to the process of identifying and gathering the data required for a specific application. The process involves acquisition, reformatting, georeferencing, compiling and documenting the data. The data input component converts data from their raw or existing form into one that can be used by a GIS. The systems typically provide alternative methods of data input including: keyboard entry for non-spatial attributes and occasionally locational data, manual locating devices (e.g. digitizers and computer mouse), automated devices (e.g. scanning), or the importation of existing data files.

The data storage and management component of a GIS includes those functions needed to store and retrieve data from the database. The methods used to implement these functions affect how efficiently the system performs operations with the data. Most GIS systems are database oriented. The database can be defined as a collection of non-redundant data in a computer organized so that it can be expanded, updated, retrieved and shared by various uses (see Section 3.2).

The distinguishing feature of a GIS is its capability of performing an integrated analysis of spatial and attribute data. The data are manipulated and analyzed to obtain information useful for a particular application. There is an enormously wide range of analytical operations available to the GIS users and a number of classifications of those operations have been suggested (see Section 3.3).

The data output component of a GIS provides a way to see the data/information in the form of maps, tables, diagrams, etc. The output subsystem displays the results of GIS data processing and analysis to the users. The results may be generated in the hardcopy, softcopy or electronic format. Maps are the most standard output format, but frequently are accompanied by tabular display. A variety of output devices are used, including display monitors, pen plotters, electrostatic plotters, laser printers, line printers, dot matrix printers/plotters. Results, particularly in the map forms, are often modified or enhanced interactively through cartographic map composition functions to add elements such as legends, titles, north arrows, scale bars, color modification, and symbology adjustments. Output functions are determined by the user's needs, and so user involvement is important in specifying the output requirements. In addition, two forms of data output from GIS can be distinguished: display and transfer. The former presents the information to the GIS user in some form (e.g. maps and tables). The latter transmits the information into another computer-based system for further processing and analysis. Digital data can be output directly to disk, tapes, or a network and than input into another computer-based system.

3.1.2. Data models

Most GIS systems are database oriented. The relational data base management system (RDBMS) is the most often applied approach for storing and managing data in GIS (Rigaux *et al*., 2002). In a relational model, the database is a group of relations. A 'matrix of tables' is used to store the data. The tables are also referred to as relations. Each table contains a data item (or a column of data), that is the same as at least one other table containing additional data. In other words, each table contains data relevant to a particular object and is linked to other tables by a common value. For example, two attribute tables can be linked to a spatial data table via the postal code. This common data item provides a relationship between two or more tables. Advantages of the relational model include: easy access and minimal technical training for users, flexibility for unforeseen inquiries, easy modification and addition of new relationships, data, and records, and physical storage of data can change without affecting the relationships between records. This type of database is particularly suited to structured query language (SQL).

Spatial data are typically arranged in a GIS using one of two models: *raster* and *vector*. Data in a raster model are stored in a two-dimensional matrix of uniform grid cells (pixels or rasters), usually squares, on a regular grid. Each cell is supposedly homogeneous; that is, the map is incapable of providing information at any resolution finer than the individual cell. Areas are made up of contiguous pixels with the same value. Lines are made by connecting cells into a one-pixel thick line. Points are single cells. All spatial objects have location information inherent to where they lie in the grid. The map shows exactly one value (land use, elevation, political division) for each cell. The size of the grid can vary from sub-meter to many kilometers and therefore the spatial resolution of the data is determined by the grid size. The higher the level of resolution, the greater the detail one can distinguish on an image.

Entities in vector format are represented by strings of co-ordinates. A point is one co-ordinate; that is, points on a map are stored in the computer with their 'exact' (to the precision of the original map and the storage capacity of the computer) coordinates. Points can be connected to form lines (straight or described by some other parametric function) or chains. Thus, a line is represented as a number of co-ordinates along its length. Chains can be connected back to the starting point to enclose polygons or areas. A polygon is represented as a set of co-ordinates at its corners. For example, a point which represents a village or town may have a database entry for its name, size, services, etc. A line which represents a road may have a database entry for its route number, traffic capacity, emergency route, etc. A polygon which represents an administrative unit may have a database entry for the various socio-economic, environmental, and population characteristics. Each of these spatial objects may have an identifier which is a key to an attached database containing the attributes (tabular data) of the entity. In the vector representation, the various objects (points, lines and polygons) have a definite spatial relation called topology.

The most common approach for structuring the geography of the real world in the GIS raster or vector system is to use a layered structure (Longley *et al*., 1999; Heywood *et al*., 2002). The layered approach can be conceptualized as vertical layering of the characteristics of the earth's surface. To build up a realistic representation of a study area a variety of layers are used. The terminology may differ between GIS software, but the approach is the same. For example a DTM may be used to model the relief of an area, a raster surface to model its land-use, a point layer used to represent buildings of interest, a line layer to represent rivers, a network layer to represent the transport system, and polygon layers to represent field patterns and administrative boundaries. All of these contain the relevant attributes.

From the perspective of land-use suitability analysis it is important to note that the layered approach involving the idea of breaking the geography of a real world (landscape) into a series of attribute layers was used to develop the first map overlay technique. The layers are the bases for combining a set of maps displaying land suitability for different land uses (McHarg, 1969; see Section 1.1). In general, the raster data model has traditionally be recognized as the more appropriate approach for land-use suitability applications. This is because the raster data structure is area-oriented (the contents of areas are important rather than the boundaries between them). Consequently, such functionality as Boolean operations, proximity analysis, buffer operations, and overlays can be more easily implemented in the raster model (see Section 3.3). If a set of data layers contains both data in the raster and vector format, the vector data are usually rasterized and the land-use suitability analysis is performed in the raster environment. It is important to stress that any given real world situation can be represented by both raster and vector models and that data modeled in one system can be converted into the other; that is, raster data can be vectorized and vector maps can be rasterized. Most common GIS software packages can handle both types of data although the majority will concentrate on one of them.

3.1.3. Data sources

In undertaking any GIS-based work the most common sources of spatial data are comprised of one or more of the following: (i) mapsheets and plans, (iii) aerial photographs and remotely sensed images, (ii) surveys and/or (iv) digital data products (Table 2). Mapsheets comprise one of the most widely available and familiar sources of spatial data. Scanning and digitizing are two fundamental methods for integrating mapsheets into a GIS database. A survey is an alternative method for collecting spatial data. The data may be obtained directly from survey instruments, usually in the form of co-ordinate pairs (or 3D triples) often with attached attribute(s). Often survey data will be in the form of CAD drawings, which may have thematic (layer) structure or complex block-attribute structure themselves. An important technology that has simplified surveying is the GPS.

Arial photography/remote sensing is an increasingly popular way to gather spatial data (Treitz, 2003). Spatial data (such as area photos, satellite images, and census data) which are already in digital form may be purchased from public and private mapping agencies. An increasing amount of spatial information can also be downloaded from the Internet (in both vector and raster formats). A list of selected digital data sources can be found in Table 2. The list includes the major gateways to geographical data for the USA, the UK, Canada and Europe. The gateways offer access to geographical data on physical environment (area photos, satellite imageries) and socio-economic datasets (census data).

Table 2
Selected sources of spatial data

Organization/data provider URL address	Comments (type of data)
GeoCommunity—GIS Data Depot www.data.geocomm.com	A collection of geographical data sources arranged by country offers free data from all over the world, or you can pay a fee for a custom-cut CD; some datasets are available for free download
Geography network clearinghouse www.geographynetwork.com	A global network of geographic information users and providers provides the infrastructure needed to support the sharing of geographic information among data providers, service providers, and users around the world
NASA: Committee on Earth Observation Satellites (CEOS) www.gcmd.gsfc.nasa.gov/ceosidn	Satellite imagery worldwide
Census Watch www.esri.com/industries/localgov/censuswatch/datares.html	A portal providing immediate access to the most recent information on the US Census Bureau geographical data
GeoConnections www.geoconnexions.org	Canada's geospatial databases; aerial photography remotely sensed data
European Space Agency earth.esa.int	Satellite imagery world-wide
Statistics Canada www.statcan.ca/start.html	Canada's census data
USGS Geospatial Data Clearinghouse www.nsdi.usgs.gov	A pathway to find information about spatially referenced data available from USGS; the information is in the form of metadata. Metadata are used to organize and maintain investments in data, to provide information to data. Catalogs and clearinghouses; aerial photography and remotely sensed data
Ordnance Survey www.ordsvy.gov.uk	Maps of all parts of the UK
The National Mapping Agencies of Britain and Ireland www.osmaps.org/digital-maps.htm	Gateway to National Mapping Agencies responsible for mapping Britain and Ireland
National Statistics: StatBase www.statistics.gov.uk	StatBase is an on-line database which holds a large selection of the UK Government statistics (census data); it also provides detailed descriptions of all the UK Government Statistical Service's data sources
GIgateway www.gigateway.org.uk	Gateway for the UK data; aerial photography remotely sensed data

The variety of data sources and data structures used in different GIS and the growing use of GIS are accompanied by intense efforts for standardization of data structures and methods for the interchange of spatial data. Current standards aim at providing mechanisms for data interchange and communication between different systems, data producers and users. Due to the large number of institutions and methods involved in data collection, it is often very difficult to locate a specific data set. This problem has been greatly helped by data clearinghouses that allow a user to query the region, type, and date of the specific data they are looking for (see Table 2).

From the perspective of the land-use suitability analysis, one should note that when acquiring off-the-shelf GIS software one gets hardly any useful maps. Typically one can get such digital data as a map of the US showing the interstate highways, a three-digit ZipCode map, and some demographic data by region, state, county. The data will be in most cases of little use for a land-use suitability analysis. A set of data for a specific application (specific study area) will most likely be locally available or have to be digitized from paper maps. If a parcel of land is the basic unit of analysis for land-use suitability modeling, then digitalizing may be the only option for inputting the data into GIS. Census tract and block group maps, traffic analysis zone maps, city limits lines, street networks, and even block maps, can be purchased from private or government agencies (for a comprehensive overview of GIS data sources see Decker, 2001; Walford, 2002).

3.2. Geographic information software

3.2.1. GIS software

There is an enormous range of software which is labeled GIS and which is available for almost every computer platform. GIS software can run on the whole spectrum of computer systems ranging from laptops to multi-users supercomputers. The available GIS software can be categorized according to their intended application area into three categories: GIS data viewers, desktop GIS, high-end GIS (see Table 3).

Table 3
Different types of GIS software

	GIS data viewers	Desktop GIS	High-end GIS
Computer hardware required	Desktop PC	Desktop PC	Workstation and often a separate database server
Approximate cost	Free or low cost	US$100–$15,000	US$15,000 +
Primary users	The general public, non-experts	Full- or part-time GIS experts	Full-time GIS experts
Major uses	Displaying and querying a specified data set provided by a public agency or other organization, usually cannot be further customized by users, or accept additional data	Database management, queries, and display, often at a project level	Full-fledged data and application development, statistical analysis, and high-quality map production, often enterprise-wide or over a network
Examples	ArcExplorer, GeoMedia Viewer, MapInfo ProViewer	ArcView, Autodesk World, Maptitude, Idrisi, GeoMedia, MapInfo Professional	ArcGIS, GIS + GeoMedia Pro, MapInfo Professional

Broadly speaking, a GIS data viewer application allows for browsing spatial data without or with a very limited ability to perform spatial analytical operations. Typically, they support a limited number of data formats. For example, ArcExplorer is a GIS data viewer—freely available from ESRI—which offers an easy way to perform basic GIS operations such as display, query, and data retrieval applications. It can be used on its own with local data sets or as a client to Internet data and map servers.

Desktop GIS is the traditional software application that is thought of when software is labeled a GIS. As the name suggests, desktop packages are designed to run on desktop PCs usually using a windows and mouse-based interface. A full featured desktop GIS includes built-in ability to input, store, manipulate and analyze, and output spatial data (see Section 3.1). Many desktop GIS software offer a framework for implementing customizations either through a proprietary or third generation programming language. ArcView, GeoMedia, and MapInfo are examples of desktop mapping software packages. While they are gradually increasing in power, they still do not offer the full range of analysis capabilities of the full-featured GIS packages. For example, in many desktop systems, there is no way to digitize map information and the user must rely on data already in a pre-defined digital format. Analysis operations may also be limited. Desktop GIS are usually much more user-friendly then the high-end systems.

The high-end GIS systems are fully functional GIS toolkits which often require powerful UNIX-based workstations. In a sense, a high-end GIS is a set of programs and it often requires customization for a particular application. Customization may include the development of Graphic User Interfaces (GUI) and also the development of specialized tools relating to a particular application. Developments in software engineering such as object-oriented programming languages and the availability of Dynamically Linked Libraries (DLL) have enabled the increased reuse and improved modularity of code written for GIS software. These developments coupled with the GIS user's demand for increasingly specialized applications have prompted GIS vendors to offer the technology used to rebuild their own software as component technology. Components allow for building standalone GIS applications.

It is in the context of the 'enterprise computing' that the high-end GIS systems have recently become popular. The 'enterprise computing' involves a situation where all the users of an organization or enterprise have access to a central information resource. In GIS terms, this might mean the vast majority of users using desktop GIS to query a central data set over a network. The central database would be maintained and updated by specialists using high-end GIS toolkits. The high-end GIS includes the Internet GIS or Web-GIS technology, which is designed to integrate the Internet/Web and GIS in order to display, manipulate, visualize, and analyze GIS data using a Web browser or other Internet-based client programs (Peng and Tsou, 2003). Early development looked at the Internet as a way to disseminate spatial data. More recently an effort has been made to link existing GIS programs with the Web server to provide users some limited GIS functionality on the Web. This approach takes advantage of existing GIS programs and their functions and delivers them to users through Web browsers. Recent advances explore distributed components system architecture. The distributed component approach adopts the client-server model to distribute data and GIS processing components from the server to the Web client.

3.2.2. GIS related technologies

The term GIS is sometimes applied loosely to geographic information related technologies that provide tools for three main functions. First, GIS can be considered as a special-purpose digital database in which a common spatial coordinate system is the primary means of storing and accessing data and information (see Section 3.1). GI systems have the ability to perform numerous tasks utilizing both the spatial and attribute data stored within them. These functions distinguish GIS from other management information systems. Second, GIS is an integrated technology. It allows for integrating a variety of geographical technologies such as Remote Sensing (RS), GPS, Computer Aided Design (CAD), Automated Mapping and Facilities Management (AM/FM) and other related technologies. These geographic information technologies can in turn be integrated with analytical and decision making techniques (see Table 4). Third, the ultimate aim of GIS is to provide support for making decisions. GIS can be thought of "as a decision support system involving the integration of spatially referenced data in a problem solving environment" (Cowen, 1988). The way in which data are entered, stored, and analyzed within a GIS must mirror the way information will be used for a specific analysis, planning

Table 4
GIS related technologies

Technology	Role of the technology in enhancing GIS capabilities
DBMS	Storing attributes for display in GIS; Data querying, sorting, joining, appending, updating, restructuring, relating tables and fields.
CAD	Extending 2D GIS geometry into 3D; Enabling appropriate rendering.
Land Information System (LIS)	Extending GIS capabilities to land surveys and land records for legal, administrative and an aid for planning and development.
Automated Mapping/Facilities Mapping (AM/FM)	Enhancing GIS functions by automated mapping and map maintenance for public utilities such as waterworks, drainage, gas and electricity.
GPS	Enhancing location accuracy of objects and verifying accuracy of attributes in GIS; Enabling navigation and tracking.
Remote sensing and Photogrammetry (RSP)	Integrating GIS functions and image processing and analysis; Source of raster data;
Statistical Software (SS)	Integrating GIS and statistical procedures
SDSS	Extending GIS functions for spatial decision making
SES	Integrating expert knowledge and GIS functions
PSS	Extending GIS functions for planning
Multimedia Systems (MS)	Enhancing visualization of geography information by use of sound, videos, images, hypertext and hot links
Internet-based Systems (IS)	Enhancing communication, data sharing, joint task operation and online GIS service delivery
Groupware Systems (GW)	Enabling multiple users in different locations to commit tasks related to planning and decision making

or decision making task. GIS should be viewed as a process rather than as merely software or hardware. The system contains a set of procedures that facilitate the data input, data storage, data manipulation and analysis, and data output for both spatial and attribute data to support decision making activities. It is important to realize however that the set of functionalities available in proprietary GIS for modeling, planning, and decision making is still quite limited. Most functions need to be added through specifically designed add-ins such as statistical, optimization, simulation, and decision analysis software. In the response to the needs for extending the standard GIS functions, a considerable effort has been made to conceptualize, design, and implement such GIS related technologies as SDSS, Group and Collaborative SDSS, Spatial Expert Systems (SES), Planning Support Systems (PSS), Web-GIS, Multimedia-GIS (see Table 4).

3.3. GIS operations for land-use suitability modeling

3.3.1. Basic and advance operations

The distinguishing feature of GIS is its capability to perform an integrated analysis of spatial and attributes data. GIS can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multisource datasets such as data on land use, population, topography, hydrology, climate, vegetation, transportation network, public infrastructure, etc. The data are manipulated and analyzed to obtain information useful for a particular application such as land-use suitability analysis. The aim of a GIS analysis is to help a user to answer questions concerned with geographical patterns and processes.

There is an enormously wide range of analytical operations available to the GIS users and a number of classifications of those operations have been suggested (Goodchild, 1987; Tomlin, 1990; Burrough, 1992). From the land-use suitability analysis perspective it is useful to make distinction between two broad categories of GIS operations: basic (or fundamental) and advanced operations. This distinction is based on the extent to which these operations can be used in a variety of spatial analyses including land-use suitability analysis. The operations considered to be useful for a wide range of applications are referred to as fundamental ones. They are more generic than the advanced functions in the sense that they are available in a wide variety of GIS systems for different data structures. The fundamental operations include: measurement, (re)classification, scalar and overlay operations, neighborhood operations, and connectivity operations. Many popular GIS systems, such as ArcGIS (Booth and Mitchell, 1999), Idrisi (Eastman, 1997), GRASS (US Army Corps of Engineers, 1993), GeoMedia (Intergraph, 1998), MapInfo (MapInfo Corporation, 1995), SPANS (Tydac Research Inc., 1996), and TransCAD (Caliper Corporation, 1996) have the capability to perform most, if not all, of the basic operations. A comprehensive overview of GIS operations can be found in introductory GIS textbooks (Heywood *et al*., 2002).

The basic operations can be considered as the spatial data handling ‘primitives’ or ‘building blocks’ for advance analysis (Berry, 1993). They are invariably low level geometric operations and could be thought of as tools that build relationships among and between spatial objects. To be useful for spatial decision making and planning, GIS should also provide the capabilities of data manipulation and analysis based on theoretical models. These capabilities are referred to as advanced or ‘compound’ GIS operations. Cartographic modeling is an example of advanced operations.

3.3.2. Cartographic modeling

Arguably, land-use suitability modeling is the most fundamental and most often used type of spatial analysis in GIS. Central to the land-use suitability analysis is the concept of cartographic modeling. The concept was developed to model land use planning alternatives, and applications that require the integrated analysis of multiple geographically distributed factors (Tomlin, 1990; see Chapter 4). Broadly defined, cartographic modeling involves a set of related, ordered map operations that act on raw data, as well as derived and intermediate data, to simulate a spatial modelling process (Tomlin, 1990; Berry, 1993; DeMers, 1997: 353). It is a generic method for organizing the basic GIS operations into a complex spatial model.

In the most general term, a cartographic modeling approach to land-use suitability analysis involves three steps: (i) preprocessing of spatial data sets relevant to a particular land-use suitability analysis (ii) developing a flowchart to represent graphically the land-use suitability model (the flowchart represents a process of moving from the data available to a solution or a land suitability map), and (iii) executing the model using GIS operations. The preprocessing stage is required because of the data for land-use suitability applications typically come from a variety of sources. They are often derived from different mediums (e.g. scanned and digitized maps) and they are stored in different formats (e.g. raster and vector models). When combining and integrating information from a variety of sources the following points should be kept in mind: (i) all spatial data must be recorded in the same co-ordinate system (data which are recorded to some other system must be transformed/projected to the required co-ordinate system), and (ii) all spatial data should be to the same spatial resolution, or scale (it is not possible to get meaningful results from the combination of spatial data recorded to a scale of 1:250 and 1:250,000; in the former example 1 mm represents 25 cm, and in the latter example represents 250 m).

The preprocessing stage involves the geometrical transformation. In the vector data environment the geometrical transformation requires a composite topological structure. First, all the intersections for the input map layers are identified, and then the new polygons are labeled with unique identifiers, and assigned new attribute values corresponding to that of a given input layer. The output layer is a new topological structure that preserves all the input features plus those portions of the polygons that overlap the input layers. The maps obtained by performing geometric transformation are the input data layers to the land-use suitability modeling. If the input maps are in raster format of different resolutions, then the preprocessing stages involves transforming the input data to grid system (the same size and shape of raters). This can be achieved by re-sampling operation which registers the data in one grid system to a different grid system covering the same area.

Once the GIS raster or vector database has been organized into a number of map layers of the same geometric framework, the land-use suitability procedure can be represented as a flowchart and executed using GIS operations. The concept that underpins land-use suitability modeling (and cartographic modeling in general) is map algebra. Map algebra processes maps (spatial data layers) as variables in algebraic equations. While in algebra variables are represented by symbols such as x and y, in map algebra the entire maps represent the variables (that is, attribute values associated a set of map objects such as rasters or polygons represent a variable in map algebra). In similar way to conventional algebra, the primitive map algebra operations (add, subtract, multiply, divide, exponentiate, etc.) are organized in a logical sequence to solve complex spatial problems. Specifically, the GIS overlay procedure generates a new layer (output layer) as a function of two or more input layers; the attribute value assigned to every location (e.g. raster or polygon) on the output layer is a function of the independent values associated with that location on the input layers (Tomlin, 1990; Berry, 1993). Typically, the logical sequencing of analytic operations is expressed in flow charts (see Fig. 2a). This may involve a cyclical processing which similar to evaluating nested parentheticals in conventional algebra. For example, given three input map layers X, Y, and V, and the following relationships $V(X - Y) = Z$, the map Y is first subtracted from map X and then the resulting map is multiplied by V to obtain the output map layer Z.

There are two commonly used classes of map combination (overlay) operations in GIS: Boolean overlay (such as AND and OR) and weighted linear combination (WLC). Given a set of suitability maps and corresponding threshold values, the Boolean intersection (AND operation) results in classifying areas as suitable for a particular land use if each suitability map meets its threshold. Conversely, the Boolean union (OR operation) identifies suitable areas as those that meet at least one suitability threshold value. The WLC approach involves standardization of the suitability maps, assigning the weights of relative importance to the suitability's maps, and then combining the weights and standardized suitability maps to obtain an overall suitability score. Unlike the Boolean operations, WLC is a compensatory method in the sense that a low score on one suitability criterion can be compensated by a high suitability one another (see Section 4.1 for a overview of the applications of these approaches to the land-use suitability analysis). The WLC method is employed in a number of DSS under the generic title of Simple Additive Weighting. A review of these is offered in Massam (1988).

3.3.3. Using off-the-shelf GIS for land-use suitability analysis

In general, land-use suitability analysis can be performed in any GIS having the basic GIS operations. One can distinguish two main types of approaches to land-use suitability modeling in the commercial-off-the-shelf (COTS) GIS: the script/macro language-based methods and the flowchart-based methods. Many GIS provide a simple programming language called a macro language or script that allows the user to express the basic spatial operations and cartographic modeling. Using map algebra, equations can be written with maps as variables to allow the development of land-use suitability model. Same GIS systems such as ArcView GIS and Idrisi provide a calculator-like environment for performing operations involved in spatial modeling. A map calculator is an interactive expression-building dialog and aids in the creation of an expression that produces a new map layer. The map calculator interface is similar to that of a hand-held calculator. This provides a user-friendly environment for building logical and algebraic expressions. However, the macro language and map calculator based approaches are rather difficult to use for a complex spatial models.

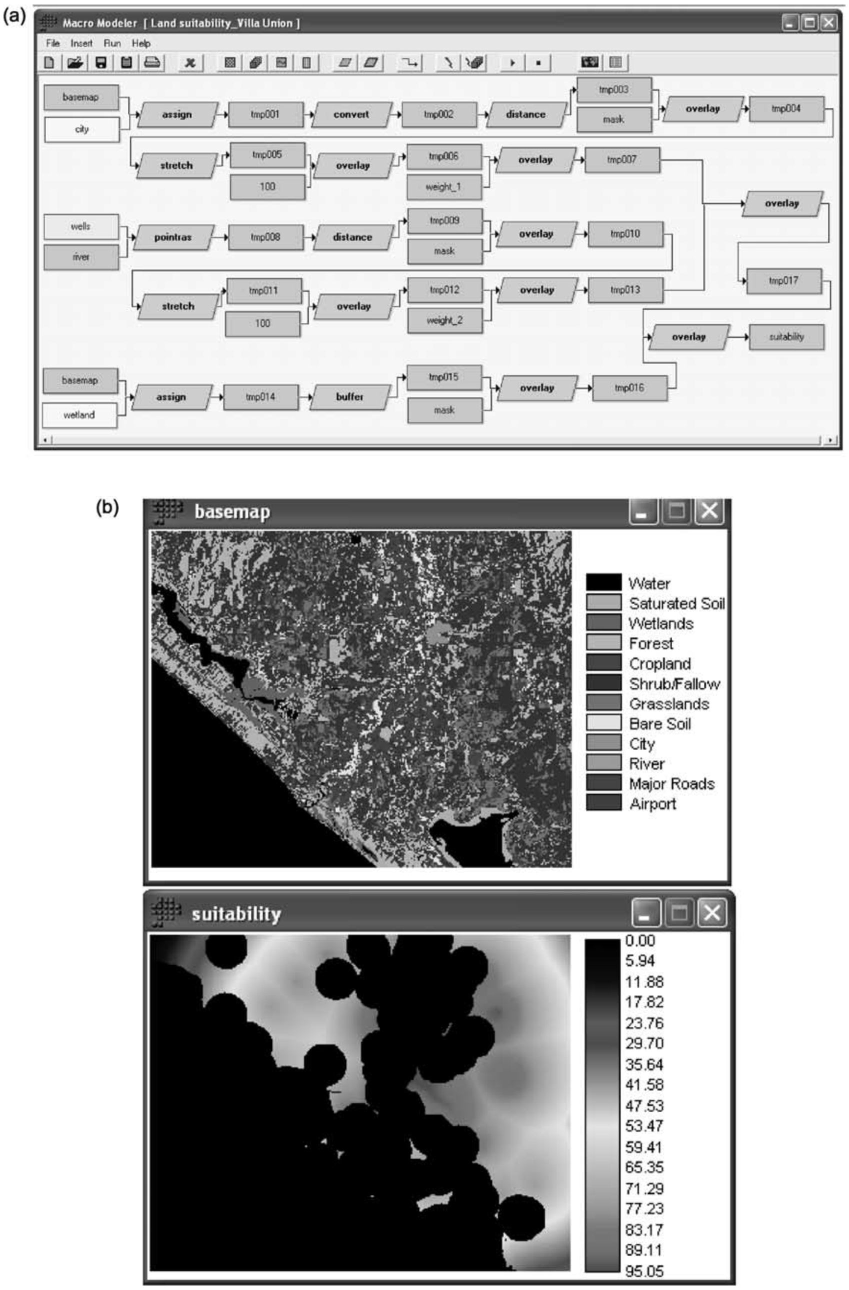

Fig. 2. A hypothetical example of land-use suitability analysis in the Villa Union region, Mexico: (a) the Idrisi Macro Modeler interface; (b) the base map of the study area and the overall suitability map.

Some GIS systems provide a graphical environment (the flowchart approach) for building and executing land-use suitability models. ModelBuilder for ArcView/Spatial Analyst (ESRI, 2000) and Idrisi Macro Modeler (Eastman, 2001) are two examples of such the flowchart approach. In the flowchart approach a land-use suitability model is constructed of individual processes from input data, basic GIS operations, and derived data which are then linked together. The creation of the model takes place in a user friendly GUI with the help of drag-and-drop capabilities. For example, in the Idrisi Macro Modeler a spatial model is built from three basic types of component: data, commands and links. Data elements include raster and vector layers, attribute values files and collections (raster group files and time series files). Command elements include modules and submodels. Modules are analytical modules available in Idrisi, such as overlay, buffer, distance, etc. Submodels are user-created models that are saved in a manner that allows them to become new analytical elements equivalent to modules. Links establish the sequence of processing. A special form of link, known as a DynaLink is used for dynamic modeling. It provides a feedback loop where outputs are substituted for inputs on successive iterations.

Fig. 2a shows an example of a hypothetical land-use suitability modeling in the Idrisi Macro Modeler. The example involves identifying the land suitability for housing development in the Villa Union region, Mexico. Two factors and one constrain are considered. The factors are: the proximity to the main city (Villa Union) of the study area and the proximity to sources of water (river and wells). The constraint map is a buffer around the wetlands. The input data have been derived from the base map (a raster data—see Fig. 2b) and a set of vector data representing location of water sources (wells) as points. The base map of the study area was derived from LANDSAT TM Satellite image dated 1993. The image covers 500 km^2 (20 by 25 km^2) of land (each cell of the image covers 625 m^2 (25 by 25 m^2). It contains 800 000 cells and each cell is considered an alternative to be classified according to its suitability for the land development. The flowchart shows the procedure for deriving the suitability maps for the three input date layers and for combining the suitability maps by the weighted liner combination. The overall suitability map is shown in Fig. 2b.

3.4. Concluding comments

Although there are many definitions of GIS, most identify a GIS as a database in which every object has a precise geographic location, together with software to perform functions of input, management, analysis, and output. However, over the last decade or so GIS systems have increasingly been seen as tools for decision making. It is the capability of GIS for supporting decision making processes that is of particular importance for the land-use suitability mapping and modeling. It is beyond the scope of this monograph to provide a comprehensive overview of the GIS technologies. This chapter offered an outline of GIS as applied to the land-use suitability analysis. The aim of Chapters 4 and 5 is to provide an overview of GIS-based land-use suitability studies (Chapter 4) and illustrate the applicability of GIS for this type of analysis by looking at a collection of case studies (Chapter 5).

CHAPTER 4

An overview of methods for GIS-based land-use suitability analysis

The GIS-based approaches to land-use suitability analysis have their roots in the applications of hand-drawn overlay techniques used by American landscape architects in the late nineteenth and early twentieth century. McHarg (1969) advanced the overlay techniques by proposing a manual overlay cartographic procedure. The method is widely recognized as a precursor to the classical overlay procedures in GIS (see Sections 1.1 and 2.1). One can distinguish three major groups of approaches to GIS-based land-use suitability analysis: (i) computer-assisted overlay mapping, (ii) multicriteria evaluation methods, and (iii) AI (soft computing or geocomputation) methods (see Collins *et al.*, 2001).

4.1. Computer-assisted overlay mapping

The computer-assisted overlay techniques were developed as a response to the manual method's limitations of mapping and combining large datasets (MacDougall, 1975; Steinitz *et al.*, 1976). Rather than manually mapping the values of a series of suitability factors in gray—or color scales, the models are stored in numerical form as matrices in the computer. The individual suitability maps can then be analyzed and combined to obtain an overall suitability map. The development of computer-assisted mapping techniques in the Harvard Laboratory (see Chapter 2) was instrumental for advancing the land-use suitability analysis (Lyle and Stutz, 1983). The Harvard's SYMAP and GRID systems included a set of modules allowing for performing land-use suitability analysis. One of the early applications the Harvard's systems focused on evaluating a proposed flood-control reservoir and parkway for their suitability for recreation and other land uses (Murray *et al.*, 1971). Miller and Niemann (1972) employed GRID-based overlay analysis for developing alternative interstate corridors. Similarly, Turner and Miles (1971) proposed a computer system for identifying the transportation corridor selection based on the suitability map overlay technique. Massam (1980) provides an overview of the earlier applications of computer-assisted overlay mapping approaches to the corridor location analysis. Lyle and Stutz (1983) demonstrated the application the land suitability analysis for developing an urban land use plan.

The introduction of cartographic modeling and map algebra techniques into computer-assisted mapping was an important advancement of the land-use suitability methods (Tomlin, 1990). Central to the map algebra approach for handling land-use suitability problems is overlay analysis (see Section 3.3). The map overlay approach has been typically applied to land-use suitability in the form of Boolean operations and weighed linear combination (WLC). The primary reason for the popularity of these methods is that they are easy to implement within the GIS environment using map algebra operations. The methods are also easy-to-understand and intuitively appealing to decision makers. However, GIS implementations of WLC are often used without full understanding of the assumptions underlying this approach. The method is often applied without any insight into the meanings of two critical elements of WLC: the weights assigned to attribute maps and the procedures for deriving commensurate attribute maps. The major criticism of the conventional map overlay approach is related to the inappropriate methods for standardizing suitability maps and untested or unverified assumptions of independence among suitability criteria (Hopkins, 1977; Pereira and Duckstein, 1993). In many case studies the overlay land-use suitability models have been applied incorrectly and with dubious results because analysts (decision makers) have ignored or been unaware of these the underlying assumptions. Hobbs (1980), Lai and Hopkins (1989), Heywood *et al*. (1995) and Malczewski (2000) provide discussions on some aspects of the incorrect use of the methods. It is suggested that the classical Boolean operations and WLC methods oversimplify the complexity of the process underlying land use planning problems by focusing on the facts (that can be effectively represented in GIS) rather than a right combination of facts and value judgments (that are difficult to represent in a computer environment in general and in GIS in particular). This limitation can be removed by integrating GIS and multicriteria decision making (MCDM) methods.

4.2. Multicriteria decision making methods

The integration of MCDM techniques with GIS has considerably advanced the conventional map overlay approaches to the land-use suitability analysis (Carver, 1991; Banai, 1993; Eastman, 1997; Malczewski, 1999; Thill, 1999). GIS-based MCDA can be thought of as a process that combines and transforms spatial and aspatial data (input) into a resultant decision (output). The MCDM procedures (or decision rules) define a relationship between the input maps and the output map. The procedures involve the utilization of geographical data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules. Accordingly, two considerations are of critical importance for spatial MCDA: (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the MCDM capabilities for combining the geographical data and the decision maker's preferences into unidimensional values of alternative decisions. A number of multicriteria decision rules have been implemented in the GIS environment for tackling land-use suitability problems. The decision rules can be classified into *multiobjective* and *multiattribute* decision making methods (Malczewski, 1999). The multiobjective approaches are mathematical programming model oriented methods, while multiattribute decision making methods are data-oriented. Multiattribute techniques are also referred to as the discrete methods because they assume that the number of alternatives (plans) is given explicitly, while in the multiobjective methods the alternatives must be generated (they are identified by solving a multiobjective mathematical programming problem).

4.2.1. Multiobjective methods

Multiobjective methods define the set of alternatives in terms of a decision model consisting of two or more objective functions and a set of constraints imposed on the decision variables. The model implicitly defines the alternatives in terms of decision variables. The multiobjective models are often tackled by converting them to single objective problems and then by solving the problem using the standard linear/integer programming methods (Diamond and Wright, 1988; Aerts, 2002). Cambell *et al*. (1992), Chuvieco (1993) Cromley and Hanink (1999) have demonstrated the potential of integrating linear programming, as a tool for GIS-based land-use suitability analysis. They show how linear programming can be used to optimize spatial pattern of land use, generate different planning scenarios, and analyze the relationships between decision variables and the problem constraints. The rapidly increasing problem size, particularly if the allocation decisions are defined as the integer variables, is perhaps the major barrier blocking more rapid integration of optimization techniques with GIS. One possible solution to this problem is to use heuristic algorithms. Eastman *et al*. (1993) have developed such an algorithm. The algorithm is useful for solving very large land allocation decision problems. While the heuristic does not guarantee an optimal solution, in most cases the suggested allocation is near optimal, and much larger problems can be handled effectively than is possible in the formal linear/integer programming format. Cromley and Hanink (1999) suggest that heuristic approaches are appropriate only if they generate near optimal solutions and if an exact method cannot be developed to work within the existing limitation of computing technology. They also proposed a generalized assignment model for land-use suitability analysis in the raster GIS environment. An advantage of the model (and the linear programming approaches in general) is the ability to map the patterns of location rent and opportunity costs in addition to the optimal land suitability pattern. This added information can be used for evaluating the robustness of land suitability patterns and identifying areas were modifications could be made without significant impacts (Cromley, 1994; Cromley and Hanink, 1999).

One problem with the traditional multicriteria approaches to land use suitability analysis is that they do not assure a spatial pattern with contiguity or compactness in land allocations for different land use types. Several solutions to this problem have been proposed including heuristic approaches (Diamond and Wright, 1988; Brookes, 1997; Cova and Church, 2000a,b; Aerts, 2002) and AI techniques such as genetic algorithms (GA) (see Section 4.3.3). It should be noted that additional constraints guaranteeing contiguity and compactness further exacerbate the computational complexity of the land use suitability models. The computation complexity is one of the reasons that multiobjective optimization methods are difficult to implement in the GIS environment. They required a considerable effort in terms of developing mathematical programming algorithms or integrating commercially available optimization packages (solvers) and GIS. The multiattribute approaches are much easier to implement in GIS (especially, for the raster data model). Consequently, there are a considerable number of GIS-multiattribute applications to land-use suitability analysis.

4.2.2. Multiattribute methods

Over the last decade or so, a number of multiattribute (or multicriteria) evaluation methods have been implemented in the GIS environment including WLC and its variants (Carver, 1991; Eastman, 1997), ideal point methods (Jankowski, 1995; Pereira and Duckstein, 1996), concordance analysis (Carver, 1991; Joerin *et al*., 2001), and analytic hierarchy process (Banai, 1993). Among these procedures, the WLC and Boolean overlay operations, such as intersection (AND) and union (OR), are considered the most straightforward and the most often employed (see Section 3.3). WLC (or simple additive weighting) is based on the concept of a weighted average. The decision maker directly assigns the weights of 'relative importance' to each attribute map layer. A total score is then obtained for each alternative by multiplying the importance weight assigned for each attribute by the scaled value given to the alternative on that attribute, and summing the products over all attributes. When the overall scores are calculated for all of the alternatives, the alternative with the highest overall score is chosen. The method can be operationalized using any GIS system having overlay capabilities. The overlay techniques allow the evaluation criterion map layers (input maps) to be combined in order to determine the composite map layer (output map). The methods can be implemented in both raster and vector GIS environments. Some GIS systems have built-in routines for the WLC method (see Section 3.3.3). There are, however, some fundamental limitations associated with the use of these procedures in a decision making process. Jiang and Eastman (2000) give a comprehensive discussion of those limitations and suggest that the Ordered Weighted Averaging (OWA) approach provides an extension to and generalization of the conventional map combination methods in GIS.

OWA is a class of multicriteria operators (Yager, 1988; see Section 5.3). It involves two sets of weights: criterion importance weights and order weights. An importance weight is assigned to a given criterion (attribute) for all locations in a study area to indicate its relative importance (according to the decision-maker's preferences) in the set of criteria under consideration. The order weights are associated with the criterion values on a location-by-location (object-by-object) basis. They are assigned to a location's attribute values in decreasing order without considering which attribute the value comes from. The order weights are central to the OWA combination procedures. They are associated with the degree of ORness, which indicates the degree to which an OWA operator is similar to the logical connective OR in terms of its combination behaviour. The parameter is also associated with a trade-off measure indicating the degree of compensation between criteria. The parameters associated with the OWA operations serves as a mechanism for guiding the GIS-based land-use suitability analysis. The ORness measure allows for interpreting the results of OWA in the context of the behavioral theory of decision making. The OWA operations make it possible to develop a variety of land use strategies ranging from an extremity pessimistic (the minimum-type strategy based of the logical AND combination) through all intermediate the neutral-towards-risk strategy (corresponding to the conventional WLC) to an extremely pessimistic strategy (the maximum-type strategy based on the logical OR combination). Thus, OWA can be considered as an extension and a generalization of the conventional combination procedures in GIS (Jiang and Eastman, 2000; see Sections 3.3.3).

Another multiattribute technique, which has been incorporated into the GIS-based land-use suitability procedures, is the Analytical Hierarchy Analysis (AHP) method (Saaty, 1980). It can be used in two distinctive ways within the GIS environment. First, it can be employed to derive the weights associated with suitability (attribute) map layers. Then, the weights can be combined with the attribute map layers in way similar to the linear additive combination methods. This approach is of particular importance for problems involving large number of alternatives represented by means of the raster data model, when it is impossible to perform a pairwise comparison of the alternatives (Eastman *et al*., 1993). Second, the AHP principle can be used to aggregate the priority for all level of the hierarchy structure including the level representing alternatives. In this case, a relatively small number of alternatives can be evaluated (Banai, 1993; Jankowski and Richard, 1994). This approach is also more appropriate for implementation in the vector-based GIS (Jankowski, 1995). It should be noted that AHP can be used as a consensus building tool in situations involving a committee or group decision making (Saaty, 1980). Despite the widespread use of AHP, some researchers question the theoretical functions of the method (Belton and Gear, 1983; Barzilai, 1998).

One of the difficulties associated with the multiattribute methods is the independence-among-attributes assumption underlying those methods. The ideal point methods avoid some of the difficulties (Pereira and Duckstein, 1993). These approaches order a set of alternatives on the basis of their separation from an ideal point. This point represents a hypothetical alternative (decision outcome) that consists of the most desirable levels of each criterion across the alternatives under consideration. The alternative which is closest to the ideal point is the best alternative. The separation is measured in terms of a distance metric. A wide range of decision rules can be developed that combine the different definitions of separation measures. Although the ideal point methods can be implemented in both the raster and vector GIS environment (Carver, 1991; Jankowski and Ewart, 1996) the technique is especially suitable for the raster GIS (Pereira and Duckstein, 1993; Malczewski, 1996).

There are several problems associated with implementing the MCDM methods in GIS (Zhou and Civco, 1996). First, it is well-known that the input-data to the GIS-multicriteria evaluation procedures usually have the property of inaccuracy, imprecision, and ambiguity. In spite of this knowledge the methods typically assume that the input data are precise and accurate. Some efforts have been made to deal with this problem by combining the GIS-multicriteria procedures with sensitivity analysis (Lodwick *et al*., 1990) and error propagation analysis (Hevelink *et al*., 1989). Another approach to deal with impression and ambiguity in the input data (attribute values and decision maker's preferences) is to use fuzzy logic methods (see Section 4.3.1).

The second problem is related to standardization of non-commensurate criteria. There are many different standardization methods that can be used in GIS-based multiattribute analysis. To this end, it is important to note that different standardization methods may lead to different land-use suitability patterns. The most common approach to criterion standardization is the linear transformation method. However, there is no good theoretical and empirical justification for using this method (Jiang and Eastman, 2000). Given that evaluation criteria (attributes) act as proxy measures of the decision maker's utility, the different criterion values reflect different levels of utility for the decision maker. If the values are changed or distorted by the transformation process, the intra-attribute and inter-attribute preference structure can be affected.

Third, given the wide variety of MCDM rule there is a question which of the methods is the best one to be used in particular situation. This is a largely unsolved problem in decision analysis. Several studies demonstrate that the different multicriteria evaluation rules generate considerably different land use suitability patterns (Carver, 1991; Heywood *et al*., 1995). For example, Heywood *et al*. (1995) used the multicriteria procedures available in Idrisi and SPANS to evaluate housing suitability and concluded that the amount of agreement between the results of the two systems was only 34.8%. It is suggested that two or more methods should be applied to dilute the effect of technique bias

(Carver, 1991). Another solution to this problem is to integrate MCDA and AI techniques (see Section 4.3) to develop the knowledge-based or 'intelligent' multicriteria decision support.

4.3. Artificial intelligence methods

Recent developments in spatial analysis show that AI (computational intelligence) offers new opportunities to the land-use suitability analysis and planning (Openshaw and Abrahart, 2000). Broadly defined, AI includes the modern computational techniques that can help in modeling and describing complex systems for inference and decision making. The major area of AI is soft computing. From this perspective, AI seeks to develop systems that attempt to mimic human intelligence without claiming an understanding of the underlying processes. The common denominator of these methods is that, unlike conventional approaches, they are tolerant of imprecision, ambiguity, uncertainty, and partial truth. AI is a general term covering a number of methods such as evolutionary algorithms (EAs), genetic programming, artificial neural networks, cellular automata (CA) and fuzzy systems. The term of geocomputation is sometimes used to cover these new computer-based techniques for analysis and modeling geographic data and solving spatial problems (Longley *et al*., 1998; Openshaw and Abrahart, 2000). During the past decade many advanced paradigms integrating individual components of AI and GIS have emerged. Prominent research areas in developing hybrid systems include the integration of GIS and AI approaches such as fuzzy logic techniques (Wang *et al*., 1990; Burrough and McDonnell, 1998), artificial neural networks (Sui, 1993; Zhou and Civco, 1996), evolutionary (genetic) algorithms (Krzanowski and Raper, 2001) and CA (Batty and Xie, 1994).

4.3.1. Fuzzy logic techniques

One of the criticisms leveled at the conventional land-use suitability analysis is that the underlying assumptions of precise (crisp) input data are unrealistic. In a complex land-use suitability analysis, it is difficult (or even impossible) to provide the precise numerical information required by the conventional methods based on the Boolean algebra. For example, for some activity, there may exist natural dividing boundaries between suitable and unsuitable areas (e.g. in the case of legal requirements). However, in many situations attributes associated with the land uses lack natural cut-offs (constraints or thresholds). In conventional approaches a cut-off is defined as 'the acceptable site must be located within 1 km of a river', for example. Such a cut-off is not a natural one. Why would a site within 0.99 km be acceptable and a site located 1.01 km away from a river would be categorized as an unacceptable one? There is usually an ambiguity and imprecision involved in defining such constraints. In addition, the conventional methods often assume that the criterion weights are given in a numerical form. Contrary to these assumptions the weights of importance are often specified by means of some linguistic statements that provide an ordering of the criteria for land suitability from the most important to the least important one. Therefore, issues related to vagueness, imprecision and ambiguity should find a proper place in the land-use suitability procedures. They can be addressed by the fuzzy set theory and fuzzy logic (Zadeh, 1965; Fisher, 2000).

Fuzzy logic represents an extension of the classic binary logic, with the possibility of defining sets without clear boundaries or partial memberships of elements belonging to a given set (Zadeh, 1965). Essentially, a fuzzy set is a set whose members may have degrees of membership between 0 and 1, as oppose to classical set where each element must have either 0 or 1 as the membership degree. The central concept of fuzzy set theory is the membership function, which numerically represents the degree to which a given element belongs to the set. It provides a framework for representing and treating uncertainty in the sense of vagueness, imprecision, lack of information, and partial truth. There are three approaches for defining fuzzy membership: the semantic import model, the similarity relation model, and an experimental analysis (Burrough and McDonnell, 1998; Fisher, 2000). In the semantic import model some form of expert knowledge is used to assign a membership on the basis of the measurement of some property. The similarity relation approach is based on a pattern recognition algorithm which searches the data for fuzzy membership. The membership function can also be identified empirically by an experiment involving human subjects.

The definition of membership function (fuzzy set) provides a natural basis for the theory of possibility, playing a role which is similar to that of measure theory in relation to the theory of probability (Zadeh, 1965). It is important to realize that possibility theory is an alternative information theory to that based on probability. Although possibility theory is logically independent of probability theory, they are related: both arise in the Dempster-Shafer evidence theory as fuzzy measures defined on random sets (Shafer, 1976). Furthermore, possibility theory directly generalizes both nondeterministic process theory and interval analysis (see Eastman (1997) for a discussion on spatial aspects of the possibility theory).

The concept of membership function has been employed in a number of GIS-based studies (Burrough and McDonnell, 1998). The studies are mostly focusing on land classification and land evaluation rather than land-use suitability analysis as defined in Section 1.1. However, many aspects of fuzzy logic approaches to the land classification and evaluation are relevant to the land-use suitability modeling. For example, Wang *et al*. (1990) described a method of fuzzy information representation and processing in a GIS context, which lead to the development of a fuzzy suitability rating method (see also Hall *et al*., 1992). Several studies use the concept of fuzzy membership function in conjunction with MCDA to develop GIS-based land-use suitability procedures (Banai, 1993; Jiang and Eastman, 2000). Banai (1993) discussed the AHP based method for representing fuzziness in the land suitability analysis using GIS. Jiang and Eastman (2000) proposed fuzzy measures for multicriteria evaluation using the OWA concept as a framework for GIS-based land suitability analysis (see Section 5.3). Eastman (1997) and Alexander *et al*. (2003) demonstrated the Dempster-Shafer weight-of-evidence modeling in the GIS environment.

The application of fuzzy logic to spatial problems in general and land suitability modeling in particular has several advantages over the conventional methods (Hall *et al*., 1992; Burrough and McDonnell, 1998; Fisher, 2000). Given the continuous variation in the geographical phenomena such as soil or vegetation classes, Burrough and McDonnell (1998) suggested that fuzzy membership approach is appropriate in defining the boundaries between different land-use suitability classes. They also demonstrated how the conventional approaches lose information and increase the chance of errors when a spatial problem involves data corrupted by inexactness. The fuzzy set methods retain the complete information of partial memberships giving due consideration to the uncertainty involved. Although the fuzzy logic approach to land-use suitability modeling is shown to have fewer limitations than conventional techniques, the approach is not without problems. The main difficulties associated with applying the fuzzy logic approach to land-use suitability modeling is the lack of a definite method for determining the membership function.

4.3.2. Neural networks

The neural network model is derived from a simulation of the human brain. It has its origin in the attempt to simulate an idealized form of the elementary processing units in the brain and of their interconnections, signal processing, and self-organization capabilities. The basic structure of a neural network resembles that of a simplified human brain; that is, many individual processing elements (artificial neutrons) are joined by a series of interconnected weights. It is convenient to think of neural networks in terms of the following three steps: input (e.g. data for land use analysis), model (e.g. model of land use), and output (e.g. the best pattern of land use). In a neural network procedure, each input is presented to the network during a training phase, where the network is told the correct output for each given set of inputs. The network is presented with many of these input and output sets, and it begins identifying the relationships between in the data. Like a brain, the memory or 'knowledge' of the resulting network is stored in the overall pattern of connections that determine the network's structure. Among many training procedures, the back-propagation learning method is by far the most common learning mechanism (Sui, 1993; Hewitson and Crane, 1994). Back-propagation neural network processes the errors created by propagating the input forward through the hidden layer to the output layer. Error is determined at the output layer, and then the errors are propagated back through the network from the output layer to the input layer. After training, the network model is 'tested' by taking a set of new input data (datasets that were not a part of training data), and feeding it through the network to see which output it will produce. The resulting output 'guess' is then compared to the know answer, and an accuracy rating can be assigned. This allows us to determine how well the neural network has 'learned' to place the correct dependencies and weights to the various inputs to produce an output. When a neural network works well, it 'learns' which inputs are influential to the output, which are not important at all, and what complex relationships exist (Gimblett *et al*., 1994).

A wide variety of research has been conducted to explore the potential applicability of neural networks for spatial data analysis including land-use suitability analysis (Sui, 1993; Gimblett *et al*., 1994; Zhou and Civeco, 1996). Sui (1993) utilized a back-propagation network to analyze the suitability of a number of land parcels for development. He compared the neural net-based approach to more traditional cartographic modeling based techniques (see Section 4.1.1). Wang (1992) applied a neural network in a similar application to determine land suitability. Both Wang (1992) and Sui (1993) found the neural networks to be an effective tool for suitability analysis in a GIS environment. Gimblett *et al*. (1994) stressed the adaptive autonomous rule generation capability of a neural network technique for handling a large number of different combinations of interdependent land suitability factors. Zhou and Civeco (1996) used a neural network approach in which the learning algorithm is a genetic (see Section 4.3.3) rather than the traditional back-propagation algorithm. Their experiment shows that the traditional GIS methods of overlay and multicriteria combination can be replicated with neural network.

Neural networks approximate solutions to complex land-use suitability problems rather than provide deterministic solutions (Fischer, 1994). A neural network can be seen as an adaptive system that progressively self-organizes itself in order to arrive at an approximate solution. It has the capability to progressively improve its performance on a given task by somehow 'learning' how to do the task better. Thus, the approach does not require the analyst to specify accurately and unambiguously the steps towards solutions. This problem-solving philosophy can be seen as either an advantage or a drawback. It all depends on the application and the objectives. An advantage of neural network methods is that a user can focus on the problems themselves rather than on the details of the techniques. The neural network approaches are best suited for tacking planning tasks in which there is little or incomplete understanding of the problem structure. Also, the techniques are data-driven so that they work best for problems involving very large datasets.

The problem with neural networks is that it is not clear what constitute the optimal structure of the network (i.e. how many hidden layers and how many neurons in each layers should be used). This structural problem leads to another problem with applying the neural network to land-use suitability analysis; namely, the internal workings of the approach are intentionally hidden from the analysts (and decision-makers). There are many parameters to set when developing a neural network, all of which can affect its accuracy. The specification of such parameters requires the user to have a basic understanding of a complex algorithm or data set, yet this is often prohibitive thus leading to less than optimal performance. Another drawback is overtraining, where the network seems to perform well in training, but is just memorizing solutions specifically for the training data, and will perform poorly on the real data. The 'black box' nature of the neural network methods is a limitation as far as real-world applications are concerned. It is likely that decision makers and interest groups would be reluctant to recommend solutions to land-use suitability problem obtained by the technique which they cannot 'see' and understand (O'Sullivan and Unwin, 2003).

4.3.3. Evolutionary (genetic) algorithms

EAs are search methods that mimic the metaphor of natural biological evolution. EAs differ from the conventional optimization techniques in that they involve a search from a 'population' of solutions. Each iteration of an EA involves a competitive selection that successively eliminates poor solutions. The solutions with high 'fitness' are 'recombined' with other solutions by swapping parts of a solution with another. Solutions are also 'mutated' by making a small change to a single element of the solution. Recombination and mutation are used to generate new solutions that are biased towards regions of the solution space for which good solutions have already been identified. Several different types of evolutionary search methods have been developed independently (for an overview see Krzanowski and Raper, 2001). One group of those algorithms is known as the GA. GAs are especially well suited for combinatorial problems involving large search space such as complex multi-objective land-use suitability problems (see Section 4.2.1). In its general form, the basic operation of a GA is simple. First, a population of possible solutions to a problem (e.g. a population of potential spatial patterns of land use) is developed. Next, the better solutions are recombined with each other to form some new solutions. Finally, the new solutions are used to replace the poorer of the original solutions and the process is repeated. Every time a new solution is proposed by GA, an objective function (e.g. minimization cost of land acquisition, maximization accessibility to public facilities, etc.) is evaluated and a ranking of the individuals (solutions) in the current population is dynamically updated, based on their fitness values. This ranking is used in the selection procedure which is performed in such a way that in the long run the best individuals will have a greater probability to be selected as parents, in resemblance to the natural principles of the 'survival of the fittest'. Similarly, the ranking is used in the replacement procedures to decide who, among the parents and the children should survive in the next population. Only the high scoring members preserve and propagate their worthy characteristics from generations to generation and thereby help in continuing the search for an optimal solution. Individuals (solutions) with a good performance may be chosen for replication several times whereas poorly performing structures may not be chosen at all. Such a selective process causes the best-performing individuals in the population to occupy an increasingly larger proportion of the population over time.

The applications of GA to GIS-based land-use suitability analysis have gained popularity in recent years (Krzanowski and Raper, 2001). Notable examples include Zhou and Civco (1996), Brookes (1997), Guimarães Pereira (1998), Matthews *et al*. (1999), Bennett *et al*. (1996), Manson (2000), Xiao *et al*. (2002) and Stewart *et al*. (2003). Zhou and Civco (1996) used a combination of neural network and GA as a method for GIS-based land-use suitability analysis. Brooks (1997) demonstrated that generic algorithm can improve the conventional land-use suitability approaches by its capability to identify a specific site for locating activities. Matthews *et al*. (1999) suggested that a GA can be a key component of the land-use planning and management support system. Bennett *et al*. (1996) and Manson (2000) combine an agent-based approach (see Section 4.3.4) and GA in the GIS environment. Examining land use/cover changes, Manson (2000) demonstrated that the evolutionary based-model generally fairs better than the conventional approaches such as WLC. Bennett *et al*. (1996); Guimarães Pereira (1998) used a GA in conjunction with GIS-based multicriteria evaluation methods (see Section 4.2). Bennett *et al*. (1996) emphasized that a land-use suitability problem should be analyzed both in the criterion space (land attribute space) and geographical space (location of land attributes) and suggested that a GA-based approach is an effective way of constructing a link between the two spaces.

GAs are especially useful in situations when conventional multicriteria optimization methods for land use modeling are inadequate, the decision problem is very complex (large and poorly understood) and the possible solution space is very large (Stewart *et al*., 2003). Also, the algorithms are particularly suitable in situations when the additional information available to guide the search is absent or not sufficient so that the use of conventional methods is not practical (Krzanowski and Raper, 2001). While GAs cannot be guaranteed to find an optimum solution, it is an efficient method for finding a set of solutions that are 'good enough' (they are near the global optimum). A disadvantage of

GA is that one never can be sure whether the global optimum is identified sufficiently precise. O'Sullivan and Unwin (2003) note that one of the main problems in using GA for tacking spatial problems is the difficulty associated with applying the abstract framework of GA to a particular problem and identifying fitness criteria for the problem at hand. They argue that if one knows how to describe a good solution, then it is likely that one can be able to find it without applying GA.

4.3.4. Cellular automata

A CA is a discrete dynamic system composed of a set of cells in a one-or multi-dimensional lattice. The state of each cell in the regular spatial lattice depends on its previous state and the state of the cells in its neighborhood. The states of the cells are updated according a set of deterministic or probabilistic local rules. Specifically, the state of a cell at a given time depends only on its own state in the previous time period and the states of its nearby neighbors at the previous time. All cells of an automaton are updated synchronously in parallel. Thus, the state of the entire automaton advances in discrete time steps. The global behavior of the system is determined by the evolution of the states of all cells as a result of multiple interactions (Batty and Xie, 1994; Couclelis, 1997; Li and Yeh, 2000). The locality of the interactions between a cell and its neighbors is a defining characteristic of CA. Because CA models are explicitly spatial, they have been used for simulating urban development, as well as for other applications such as simulating change in land use, freeway traffic, or the spread of fires (Batty and Xie, 1994; Clarke and Gaydos, 1998).

The rational of CA is not to try to describe a complex system from a global point of view, but modeling the system starting from the elementary dynamics of its interacting and letting the system complexity to emerge by interaction of simple individuals following simple rules. In this way, a physical process may be naturally represented as a computational process and directly simulated on computer. A relaxation of CA based upon the discrete event simulation theory widens the applicability of CA to describe non-autonomous geographical processes. Such relaxed CA can be applied in multi-model approaches, like the constrained CA approach (Engelen *et al*., 1999) or the integration of CA with GIS and multi-criteria evaluation (Wu, 1998).

More recently, the CA method has been extended by incorporating more agent-like behavior or non-local search (Batty *et al*., 1999; Ligtenberg *et al*., 2001; O'Sullivan and Unwin, 2003). The agent technology deploys agents in the real world of a database or searching for materials on the Internet. In an agent-based model the agents represent human or other actors in a simulated real world environment (O'Sullivan and Unwin, 2003). Agent-based systems can be defined as a set of agents interacting in a common environment, able to modify themselves and their environment (Ferrand, 1996). For example, the environment might represent an urban area and agents might represent the interest groups involved in land use planning. From this perspective, the agent-based approach provides a new kind of modeling paradigm that allows a closer resemblance to the reality to be modeled (Ligtenberg *et al*., 2001). Specifically, the spatial agent-based models acknowledge the fact that land use emerges from decentralized human decisions. Accordingly, the models attempt to capture essential features of human–environment interaction by providing means to include human decision making without losing the strength of the concept of self-organization. Bennett *et al*. (1996) and Manson (2000) provide examples of using the agent-based modeling in conjunction with other AI techniques in the GIS environment (see also a case study in Section 5.4). It is suggested that GIS-based integrated agent models will become a powerful tool for land-use suitability analysis (Ferrand, 1996; Ligtenberg *et al*., 2001).

In summary, applications which merge the GIS and AI promise to provide us with new automated knowledge-based decision support capabilities. It is argued that the AI techniques could examine complex spatial decision making problems. Specifically, the AI approaches are generally superior to traditional methods in situations involving: (i) large sets of data with unpredictable non-linearity, (ii) hidden patterns important to the decision making tasks, and (iii) human opinions and ill-defined components of the decision situation (Gimblett *et al*., 1994; Openshaw and Abrahart, 2000).

The integration of AI and GIS is a relatively new area of research and software development and currently, AI systems are not easily set up to be interfaced with a GIS. Those exploring AI-GIS applications are frequently required to create their own interface links. The current lack of easily utilized connections between GIS and AI presents a formidable barrier to planners and decision makers without the necessary computer programming skills. Overall, the advanced concepts of neural networks and the work required to link current AI systems to GIS, render these approaches inaccessible to most planners, mangers, and decision makers. Also, it is important to note that the AI technology does not guarantee more accurate decision making, although one can expect that it should provide for more informed decisions (Gimblett *et al*., 1994).

Unfortunately, the internal workings in the AI approaches are in many cases intentionally hidden from the analysts (and decision makers). Arguably, this 'black box' style spatial analysis is the major limitation in applying the AI-GIS approaches real-world land-use suitability analysis. It is unlikely that a solution or a set of solutions obtained by AI-GIS techniques will be acceptable to those who make decisions regarding land use and the public, if it is difficult or even impossible to clearly present and explain to them the internal workings of the AI models. One needs a better answer then 'because my AI model says so' when faced with questions regarding a recommended land-use plan (O'Sullivan and Unwin, 2003).

4.4. Concluding comments

The development of GIS-based methods for land-use suitability analysis has evolved over the last 30 years or so from the map overlay modeling through MCDM techniques to a wide range of AI approaches. It is important to point out that many case studies use a combination of these methods; e.g. multicriteria evaluation methods can be used in conjunction with AI techniques. In addition, the classical overlay modeling is present, in one way or another, in most, if not all, of the methods.

The classical overlay mapping and modeling approaches are the most commonly used methods for land-use suitability analysis in the GIS environment. The major limitation of these approaches is the lack of well defined mechanize for incorporating value judgments (e.g. the decision-makers preferences) into the GIS-based procedures. This limitation can be removed by integrating GIS and MCDM methods. Multicriteria analysis is not, however, without its problem. The main problems are related to the choice of method for combining different evaluation criteria, standardization of criterion maps, and the specification of criterion wrights. Different methods may produce different results. There is no commonly acceptable method for assigning the weights of relative importance to the criterion maps. Again, it is likely that different weighting methods would result in different overall land-use suitability patterns. Some researchers suggest that these problems can be, at least partially, resolved by using the AI based methods. However, there is not enough real world applications using the AI methods to verify their usefulness for tackling complex land use planning problems. Arguably, the major limitation of these methods is their 'black box' style of analyzing spatial problems.

It is important to note that some of the methods overviewed in this chapter have been implemented using a variety of computer technologies including the Internet-GIS and Web-GIS (Carver and Peckham, 1999), multimedia-GIS (Câmara and Raper, 1999; Allen, 2001), and GIS-based visualization techniques (Jankowski *et al*., 2001). Like many GIS applications, the land-use suitability analysis has recently been influenced by the development of the Internet (Carver and Peckham, 1999). The multimedia-GIS provide a platform for extending the traditional approaches by using modern technologies such as video, audio, virtual reality, etc. The use of GIS and web-based multimedia technologies has considerable potential as visualization tools for adaptation in the land use planning. The ability to view data from many perspectives and to conduct many 'what-if' scenarios can lead to better-informed decision making (Allen, 2001; Klosterman, 2001). As the software visualization tools become more widely available on the Web, the potential exists to undertake networked GIS-based land-use satiability analysis, which may be particularly applicable to widening public participation approach to land use planning (see Section 5.5).

CHAPTER 5

Case studies

This chapter provides a selection of case studies on GIS-based land-use suitability analysis. The case studies illustrate the methods discussed in the previous chapter. They have been selected to demonstrate that the methods are applicable in a variety of land-use planning situations. It is suggested that these case studies cover a number of issues associated with the land-use suitability analysis which are currently being addressed in the GIS and planning literature.

5.1. Classical landscape architecture approach: GIS-based greenway suitability analysis in the town of Prescott Valley, Arizona, USA

This case study presents a GIS-based land suitability analysis for identifying and measuring the suitability of potential sites for greenway development in the town of Prescott Valley, AZ, USA (Miller *et al*., 1998). The analysis involved five major steps: (i) identifying land-use functions, (ii) collecting spatial data, (iii) identifying preferences (weighting values), (iv) integrating and analyzing GIS data by overlay techniques, and (v) evaluating the output.

Three land-use functions were identified: wildlife habitat, recreation, and riparian corridor. For each of these functions, four or five primary factors were determined. Additionally, for each factor, a land capability rating was established. Land capability values for attributes within factors were set as high, moderate, low, and no capability. For each greenway function, three experts were identified as sources for individual factor-ranking information. Each expert was asked to rank the greenway functions in order of importance. In order to provide community-wide involvement in the planning process, it was necessary to collect a significant sampling of the general population. This was accomplished through the circulation of the function-based questionnaires to the town council, and among all town of Prescott Valley employees who lived in the area. This sampling technique proved successful in distributing the questionnaires to over 60 Prescott Valley citizens.

All spatial data were integrated into a vector-based GIS software. The polygon was adopted as the primary entity-type for this analysis. The greenway function value for each polygon was calculated as the sum of the normalized integrated score of all factors within a function. This value was derived by overlaying all map layers within a function and calculating the normalized integrated score. Finally, the three greenway function map layers were combined to generate a greenway suitability values. The values were than classified into composite (or overall) greenway suitability scores to form an overall greenway suitability map. Large portions of the study area were found unsuitable for greenway development. This was a direct result of the growing conflict between developmental pressures and the natural environment.

The final analysis was then evaluated by a panel of experts to determine its accuracy and potential for use in a greenway development plan. All experts suggested that the process appeared to produce a valid and credible greenway suitability result. One expert expressed concern on the process of normalization and its potential to obscure the relationships among the individual factor variables. Miller *et al*. (1998) discussed some drawbacks of their method. First, the evaluation criteria within the process were not independent of each other. Based on the results reported in Miller *et al*. (1998), it is hard to say to what extent the dependence of criteria might undermine the results. Second, the researchers also recognized the problems of adding ratio to ordinal values. At the technical level, this GIS-based greenway suitability model is seem to be capable of integrating physical, environmental, and social geographic data with human knowledge. It allows for a variety of information from experts and citizens to be used in the weighting process. Miller *et al*. (1998) stress the participatory approach to the GIS-based greenway suitability procedure. The use of GIS technology brings people together, including planners, scientists, engineers, and landscape architects. The high level of cooperation and involvement creates a broad-based approach to greenway suitability analysis.

5.2. GIS versus public participation: land suitability modeling for transmission line in southern West Virginia, USA

Towers (1997) provides a detail discussion of a case study on the political nature of the GIS-based land-use suitability analysis. He demonstrates the controversy surrounding a GIS study commissioned by the US Forest Service to determine the suitability (sensitivity) of parts of southern West Virginia and Virginia to the American Electric Power Company's (AEPC) proposal of a high-voltage transmission line from Oceana, West Virginia to Cloverdale, Virginia. The preferred corridor was identified based on a GIS study. It goes through the rural, agricultural land of Monroe County. Because the preferred corridor is located on federal lands administered by the Forest Service, the National Park Service and the US Army Corps of Engineers, these federal agencies are empowered to decide if and where the power line will cross federal lands. The Forest Service has been designated as the lead agency in the decision making process. They applied the GIS-based land suitability modeling to identify sensitivity to the power line. Specifically, the simple weighted additive scoring method (or WLC) and the cartographic modeling approach were used (see Section 4.1). A set of evaluation factors was identified and the different levels of each factor were subjectively assigned scores. The results of the modeling were made public.

The methodology and the results of the Forest Service's GIS modeling have generated a criticism of the Monroe County interest groups such as the Border Conservancy and Common Ground which have formed to oppose the transmission line. Other citizen groups, most prominently the National Committee for the New River (NCNR), which operates in North Carolina, Virginia and West Virginia, have also criticized the power-line route through Monroe County. The criticism focused on three elements of the study: the data collection, methodology and presentation of the results.

First, the citizens groups found these maps of the potential social and environmental impacts of the power line route to be incomplete. Specifically, the Border Conservancy undertook a community cartography project, developing counterparts to each of the Forest Service's maps. Using fieldwork and first-hand knowledge of the landscape, the community produced separate maps of population clusters, water supplies, noise levels, visibility, recreational facilities, and cultural and historic sites. This exercise revealed that many essential features were missing from the Forest Service's maps. Consequently, the citizens objected to the Forest Service's failure to incorporate comprehensive, field-checked geographic data/information.

Second, the interest groups have attacked the methodology applied by the Forest Service. They argued that GIS modeling is inherently subjective and therefore should include all concerned parties' subjective judgments. Since the Forest Service did not consult the public in its methodological deliberations, the rating of factors and weighting scheme have been found questionable and lacking credibility. The citizen groups have also suggested that the methodology was deliberately designed to generate predetermined results. For example, the use of population density was an important part of the GIS study. It was used to measure visual and non-visual impacts on residents. The citizen groups argued, however, that by measuring population density by census block, the Forest Service has corrupted its study. The rural population of Monroe County is clustered, rather than spread evenly across the landscape. Therefore, assigning a uniform population density to a census block was an oversimplification that resulted in assigning disproportional high and low scores to unpopulated and populated areas respectively. In addition, the Forest Service was accused of intentionally using population density to increase scores for public lands and lower scores for private lands. Public lands, which are generally sparsely populated, were combined with private lands in census blocks. Therefore, scoring population density by census tract resulted in an increase of public lands' scores and in reducing the scores assigned to private lands. There was also a criticism leveled at the way the weights have been identified. Specifically, the citizen groups found it suspicion that the Forest Service's study was lacking an adequate explanation of the reasoning behind the weighting schemes. They believed that the Forest Service's approach to assigning the weights of importance systematically undervalued private land and overvalued the National Forest.

Third, there was criticism of the way the Forest Service's composite suitability (sensitivity) map was presented to the public. It was argued that the map represented 'an exercise in cartography's essentially understated political power. More than the sum of its parts, the map transcends the Forest Service's comprehensively criticized GIS methodology. Independently persuasive, the composite sensitivity map suggests that West Virginia is a better place for a power line than Virginia' (Towers, 1997: 123). He has also argued that the map had a rhetorical role. Since the map was created according to the rigorous scientific methodology, its authority was to be accepted and proposed solution was assumed to be undisputable.

Based on this case study one can suggest that if a participatory GIS approach to land suitability analysis was applied in the Forest Service study, then the results could have been acceptable to the public. The participatory GIS approach does not, however, directly translate into a democratic decision making. Towers (1997) suggest that "participation can end in co-option and the eventual implementation of the dominant institutions' original objectives" (p. 124).

5.3. GIS-multicriteria evaluation: developing management strategies for the Cedar Creek watershed, Ontario, Canada

This case study illustrates the use of multicriteria evaluation methods in the context of land-use suitability analysis for identifying the priority areas for rehabilitation and enhancement projects in the Cedar Creek watershed, Ontario, Canada (Malczewski *et al*., 2003). It focuses on an application of the GIS-OWA method. It also demonstrates a participatory approach to developing land-use suitability scenarios. The Woodstock Environmental Advisory Committee (WEAC) and the Upper Thames River Conservation Authority (UTRCA, 1998) initiated the process of developing alternative scenarios for land use management. At the same time, the Cedar Creek Watershed Technical Subcommittee (CCWTC) was established to supervise the process. The Subcommittee identified a set of 10 evaluation criteria for assessing potential project sites in the watershed. The criteria reflect opinions and concerns raised by the community at open houses, community days and public meetings. The set of evaluation criteria includes: (i) protection of groundwater recharge areas, (ii) distance to city well heads, (iii) erosion-prone area protection, (iv) wetland protection, (v) forest interior protection, (vi) proximity to surface water, (vii) proximity to natural areas, (viii) land use protection, (ix) protection of property ownership, and (x) visibility (the criterion maps were provided by the UTRCA, Ontario Ministry of Natural Resources and Oxford County). Each criterion map displays land suitability measured on an ordinal scale; that is, parcels of land were assigned value of high, medium, or low suitability depending of land attributes. The maps are the input data to the GIS-OWA-based decision making procedure. Given the criterion maps the problem is to combine the maps so that one can identify the 'most suitable' sites for rehabilitation and enhancement projects. The combination procedure follows the conventional scheme for GIS-based MCDA (Malczewski, 1999). It involves three main steps, which correspond to the three main components of the GIS-OWA module in the GIS-MCDA) system developed within the ArcView 3.2 environment (see Fig. 3):

(i) standardizing criterion map; since the criterion maps contain the ordinal values (high, medium, and low) that indicate the degree of land suitability with respect to a particular criterion, the maps were standardized using the pairwise comparison method (Saaty, 1980) in GIS-OWA; the pairwise comparisons were undertaken by the Technical Subcommittee;
(ii) identifying the weights of criterion importance; the weights of relative criterion importance have been derived using the pairwise comparison method; this approach required the Technical Subcommittee to provide its best judgment as to the importance of evaluation criteria. After debate and careful analysis of the set of evaluation criteria, the Subcommittee made all the pairwise comparisons for the set of the ten criteria. The criterion weights are automatically calculated once the pairwise comparison matrix is entered in the GIS-OWA module; and
(iii) combining (aggregating) the criterion weights and the standardized criterion maps by means of the OWA operations. Central to the OWA operations order weights associated with the degree of ORness (the alpha parameter—see Fig. 3).

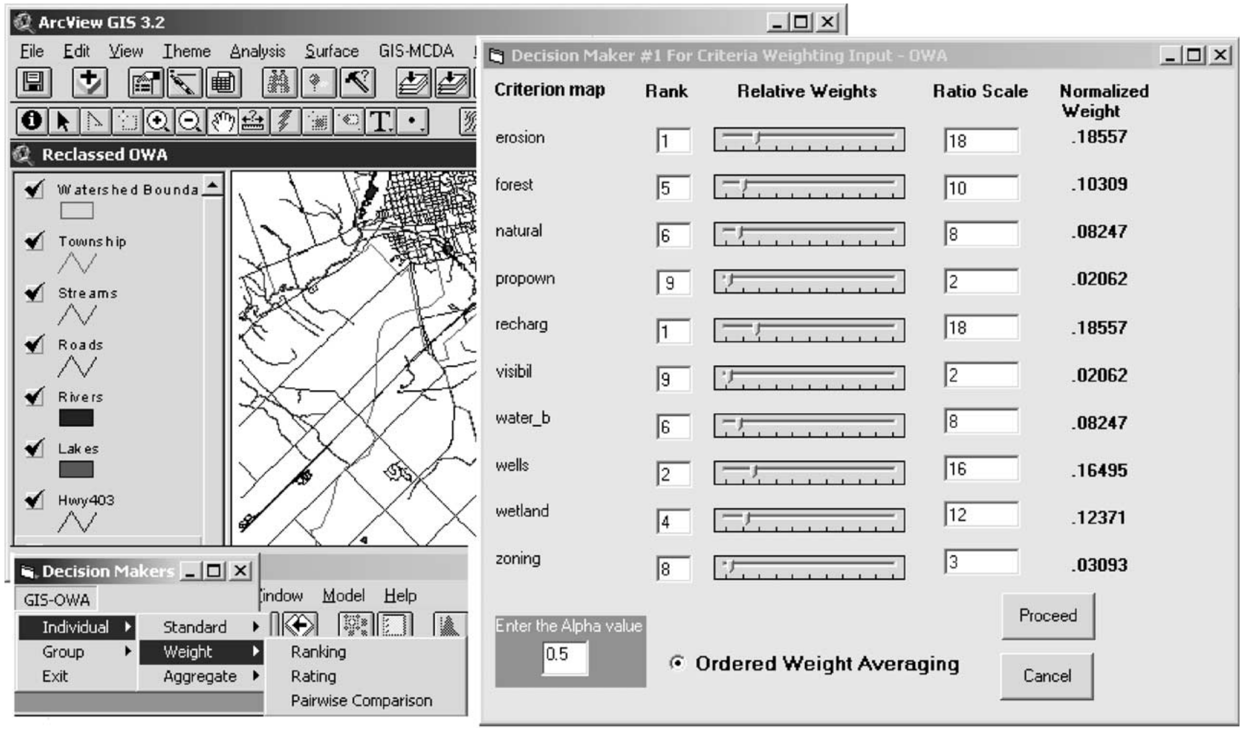

Fig. 3. The GIS-OWA interface in the GIS-MCDA support in ArcView GIS 3.2.

The parameter ranges from 0 to 1. The alpha (α) parameter is also associated with a trade-off measure which indicates the degree of compensation between criteria.

Using the GIS-OWA method a number of alternative strategies for rehabilitation and enhancement projects were generated and evaluated. The different strategies were obtained by changing the order weights (the α parameter). The analysis was focused on developing various decision strategies in the context of the decision maker's degree of optimism (the attitudes towards risk). This was achieved by varying the alpha parameter using the GIS-OWA module. The parameter guides the user (the Technical Subcommittee) along the continuum ranging from the pessimistic to optimistic decision strategies. Theoretically, one can obtain an infinite number of alternative decision strategies by continuously varying the α parameter. Fig. 4 shows a selection of five decision strategies for $\alpha = 0.0$, 0.3, 0.5, 0.7, and 1.0.

The strategy associated with $\alpha = 0$ is referred to as an extremely pessimistic strategy. Interpreting the strategy from probabilistic perspective it is a situation in which a probability of 1 is assigned to the worst case scenario (the lowest value is assigned to each location). Also, this strategy is characterized by a trade-off measure of 0. This implies no trade-off between evaluation criteria. The map representing this strategy indicates that

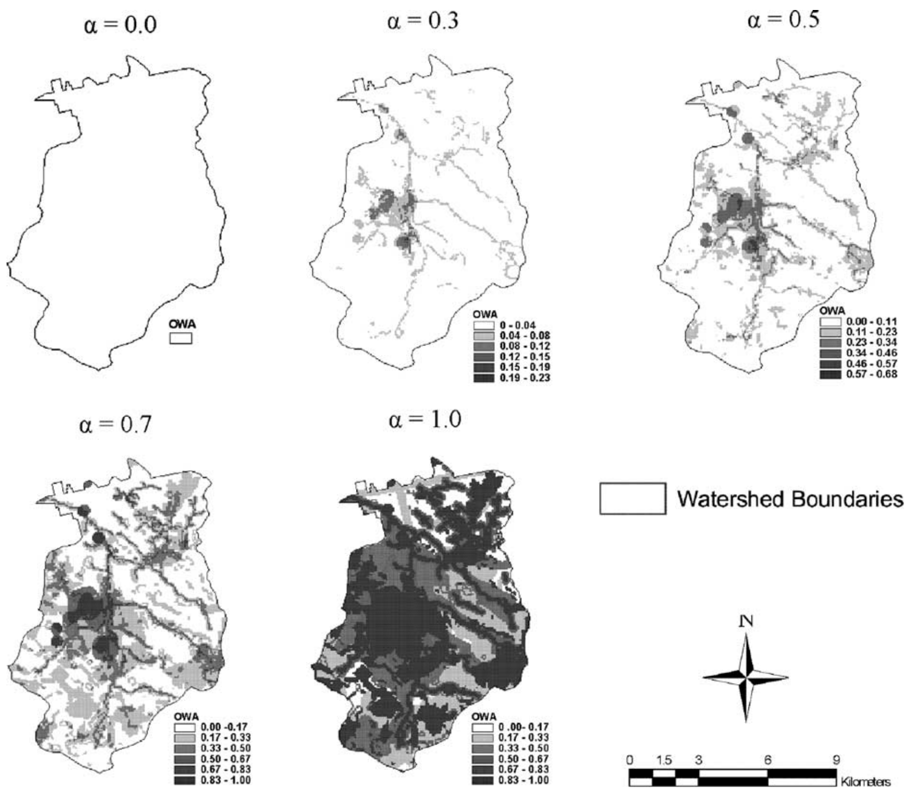

Fig. 4. Alternative decision strategies for the Cedar Creek watershed management.

each location within the watershed has been assigned a value of 0 (there is at least one criterion value (suitability) of 0 at each location). This means that under the extreme pessimistic strategy no action should be taken. Increasing the value of α from 0.0 to 0.5 corresponds to the increasing the degree of optimism as well as the increasing trade-off between evaluation criteria. This implies that gradually higher and higher probabilities are assigned to the higher-ranking criterion values at a given location at the expense of assigning smaller probabilities to the lower-ranking criterion values for that location. As a result, the size of the areas that could be recommended for rehabilitation and enhancement gets gradually larger (Fig. 4).

The strategy for $\alpha = 0.5$ represents a decision maker characterized by neutral attitudes. It is also a strategy resulting in a full trade-off between criteria. Assigning an order weight of 0.1 to each criterion value at a given location implies a situation in which an equal probability is associated with all possible outcomes at that location.

Increasing the value of α from 0.5 to 1.0 represents increasing degree of optimism and decreasing level of the trade-off among criteria. The strategy for $\alpha = 1.0$ represents an extremely optimistic strategy. This strategy assigns a probability (order weight) of 1.0 to the highest value at each location in the watershed. In other words, the decision maker is characterized by optimistic attitudes represented by the best possible outcome (that is, the highest possible value is selected at each location). Under this strategy, most of the watershed area should be considered for rehabilitation and enhancement (see Fig. 4). However, an implementation of the extremely optimistic strategy would be beyond the limited resources available for rehabilitation and enhancement projects. Consequently, the strategy selected for implementation was associated with the parameter $\alpha = 0.7$. It is a moderately optimistic strategy. This strategy is also characterized by a moderate trade-off between criteria. It recommends that the rehabilitation and enhancement projects should be undertaken at locations of the existing natural areas. The areas of highest priorities are situated near Cedar Creek Swamp and around woodlots and wetlands. Also, sections along watercourses are identified as high or medium priority.

A workshop was conducted to discuss the application of the GIS-OWA module within Cedar Creek. At that time, the decision makers (UTRCA) found the module user-friendly and a valuable tool for visualizing decision strategies. In comparison to the conventional GIS-based combination approaches, OWA provided more flexibility for analysing land-use management strategies. The capability of the GIS-OWA to generate and visualize a range of decision strategies was particularly useful.

5.4. Multi-agent/cellular automata modeling: land use conflict management in the City of Nijmegen, the Netherlands

This case study presents an application of an AI approach to land-use suitability modeling in an area located west of Nijmegen in the eastern part of the Netherlands (Ligtenberg *et al.*, 2001). The region has been experienced a high pressure of urban expansion due to the growth of the City of Nijmegen and the construction of a freight railway. The aim of this study was to develop alternative scenarios for land uses in the region based on preferences of interest groups/stakeholders (or agents in the AI terminology). There are two stakeholders involved in the planning process. They are referred to as: ‘Municipality of Nijmegen’ and ‘The New Rich’. The actors differ in their definitions of the spatial preference functions. The ‘Municipality of Nijmegen’ prefers a clustering of new land developments near the existing urbanized areas, while ‘The New Rich’ group prefers locations near to existing small villages, natural areas or along the shores of water bodies. In addition, the environment is considered as an agent called ‘Nature and Environment’.

The study combines the CA and multi-agent system (MAS) techniques to build a spatial multi-actor model that simulates land use change as result of actor-based decision making (see Section 4.3.4). The actors evaluate suitability of land for competing uses such as urban development, agriculture, conservation, etc. The framework for implementing the CA and MAS methods is based on the assumption that the actors involved in the planning process: (i) interpret the environment and define a land use pattern (spatial organization) based of their own interpretations, (ii) compare the definition of the spatial organizations with their own future objectives and determine the differences between them, (iii) prioritize their preferences, (iv) adopt the current spatial organization in order to narrow the gap between the desired and the existing land use pattern, and (v) communicate and synchronize the agents actions in order to reach a final decision.

The agents-based decision making process consists of two main steps: individual and group decision making tasks. The individual decision making tasks involve constructing the agent-specific image (map) of the land use pattern. To this end, the agent evaluates its spatial organization and assigns a ranking indicator to every AgentCell object that represents the aggregated land use potential of each object. CA serves as an engine to carry out this evaluation efficiently. By using CA, a simple ranking indicator is generated for a transition according to the distance-based weighted sum approach. The distance-based weights are calculated using spatial preference functions. Once each agent has made up its construct of a desired future spatial organization, a group decision making procedure is needed to allocate the new land use classes. A planning agent accomplishes this task. The ‘Municipality of Nijmegen’ has played the role of planning agent. A planning agent is similar to the other agents in the model, but has the additional ability to ‘ask’ for the ‘opinions’ of the other agents. The final assignment is performed in four steps. The planning agent asks every agent in the model to hand over its set of AgentCells. The agent then determines the locations that are agreed upon by all agents, meaning that for these locations all individual agents intend the same land use class to be assigned. The evaluation is done by simply comparing the land use proposed by an agent with the land uses suggested by other agents. If the proposed land use is not identical for all the agents, a reference to its location is stored in a conflict list. Each agent has voting power depending on its position in a hierarchy of agents and conflicts over allocating land uses are resolved by a progressive voting procedure.

The MAS framework was implemented as a pilot model using JAVA and the SWARM agent modeling toolkit. The software was loosely coupled with Arc/Info GIS system. GIS serves as a tool for visualizing different land use patterns. Using the system, two scenarios have been developed in the 30 year planning horizon. In the first scenario, the Municipality of Nijmegen was characterized by a decisive power to influence the land use pattern, while the other agents were assigned equal decision power. In the second scenario, all agents can influence the land use pattern equally. Given the power of the Municipality of Nijmegen to influence the assignment of urban areas into line with this agent's objectives, the other agents were forced to conform to the special preferences of the planner. As a result the spatial patterns of land uses were similar at the end of the simulations. Interestingly enough, the results of the simulation suggest that it was impossible to resolve the conflict in the second scenario when there was an equal importance assigned to all agents.

The advantage of the AI based approach is that it provides a tool for developing dynamic models that combine explicit spatial processes using the CA techniques and actor (stakeholders) interactions by applying the multi-agent technology. This type of approach seems to be better suited for modeling the open-ended and complex planning problems. It has the potential to provide a better understanding of the complexity of multi-actor land-use planning. However, the approach is not without its problems. First, the AI technology does not guarantee more accurate decision making, although one can expect that it should provide for more informed decisions. Second, the technology is large inaccessible to non-experts. Third, the technology can be criticized for its black box style of spatial analysis (see Section 4.3). The difficulties associated with a clear presentation of the internal workings of the GIS-based MAS models make them of limited applicability in a public participatory GIS approach to land-use suitability analysis.

5.5. Public participation and democratization: web-GIS for nuclear waste disposal in Britain

One of the first examples of a participatory land suitability analysis using the Internet technology has been the Open Spatial Decision making (OSDM) system (Carver, 1996; Carver and Peckham, 1999). A detailed discussion of this work can be found at the following URL address: http://www.ccg.leeds.ac.uk/mce/mce-home.htm. OSDM and the website were designed to create a transparent and open environment for public to learn, understand and contribute to the decision making process. The project allows the users to access GIS datasets (maps) and information about these data and use them to identify suitable sites according to their own individual preferences as to what evaluation criteria are important in the site suitability analysis. Specifically, the process of identifying the suitable areas for the location of radioactive waste disposal facilities in Britain involves three basic stages: (i) a data viewer menu which gives access to the GIS data and information, (ii) a data selection and criterion weighting menu which allows users to select a set of constraint and criterion maps, weigh individual criterion maps and then submit a site search request, and (iii) a results display menu which allows users to view the resulting site search image and provide feedback; in addition, a final menu gives the user a chance to provide feedback both on the system and on their own views regarding the radioactive waste disposal problem.

The data component consists of two sets of maps: constraint maps and evaluation criterion (suitability) maps. These are the input data to the site suitability analysis. The set of constraint maps include: (i) a deep geology constraint, (ii) a surface clay geology constraint (iii) a conservation areas constraint, (iv) a coastal location constraint, (v) a high population density constraint. The constraint maps are used to limit the geographical area (suitable location alternatives). Each constraint is represented as a binary map; if a location is considered suitable, then it is assigned a value of 1, otherwise it is assigned a value of 0.

The data on evaluation criteria consist of six criterion maps: (i) population density, (ii) access to population, (iii) strategic access, (iv) local road access, (v) local rail access, and (vi) distance from conservation areas. The first two criteria are to be minimized (that is, the lower the population density and access to population, the better), while the remaining four criteria are to be maximized. Each criterion map has been standardized to a 0–255 scale. In addition the user of OSDM can express his/her preferences in the form of weights indicating the relative importance to the evaluation criteria.

Given the input data, the process of searching for the suitable areas for storing nuclear waste follows a multicriteria evaluation method. The method evaluates each alternative (pixel in GIS data layer) by using the simple additive weighting formula; that is, a overall suitability score is obtained for each location by multiplying the weight assigned to a particular criterion map by the scaled value given to the alternative on that criterion, and summing the products over all criteria. The higher the value of the total score, the more suitable is the area for locating a nuclear waste facility.

OSDM provides an example of how the GIS-based land suitability analysis can be made available for the public use via the Internet. It adopts an open approach to public information, consultation and participation in the complex decision making process of locating public facilities. It is important to note that the conflict among different interest groups is central to the process of locating such facilities as landfills, incinerators, nuclear waste disposal sites, etc. On the one hand there is a strong national interest argument in favor of finding the best available site for disposing nuclear waste, for example; on the other, the NIMBY (not in my backyard) syndrome leads to a strong opposition from local communities toward sitting a nuclear waste facility. It is argued that by making the relevant data and information available over the Internet, the GIS technology improves public consultation and participation in spatial decisions of national importance (Carver and Peckham, 1999). Although the system has not been used for implementing a real world scenario, one can argue that it can provide a platform for more democratic and open site selection process.

5.6. Concluding comments

This chapter offered a selection of case studies to illustrate the different techniques and approaches to land-use suitability analysis overviewed in Chapter 4. Based on the overview and the discussion of the case studies two main trends in the GIS-based land-use suitability analysis can be identified. On one hand, there is a wide range of techniques such as multicriteria and geocomputational (AI) methods that are moving into the mainstream of GIS-base spatial analysis and planning including the land-use suitability modeling. The modern techniques, with their strong flavor of the system approaches to planning, are drawing much of their philosophical background from the instrumental or functional rationality and the techno-positivist perspectives on GIS (see Sections 1.2 and 2.4). On the other hand, there is a strong movement in the GIS community towards using the technology to increase the democratization of planning process via public participation. These two are apparently contradictory trends. One can argued that the modern modeling techniques of multicriteria and geocomputation create yet another barrier between the GIS experts/planners and the public and therefore they decreases rather then increases the potential of GIS-based analysis as a tool for public participation. This tension between the techno-positivist perspectives on GIS and the socio-political, participatory GIS perspectives is central to the advancement of the land-use suitability analysis and its potential as a tool for the land use planning and management. This issue will be taken up in Chapter 6.

CHAPTER 6

Conclusions: problems and prospects

The role of GIS in land-use suitability analysis has evolved along with the changing perspectives of planning from scientific approaches through the political process-oriented perspectives and a focus on communication to collective-design approaches. One of the conclusions emerging from this monograph is that the changing nature of planning has been associated with increased involvement of non-experts (public, interest groups, communities, stakeholders, nongovernmental organization, etc.) into planning and decision making processes. The evolution of planning has been paralleled by the increasing accessibility of GIS technology. GIS systems have evolved from a 'close'-expert-oriented to an 'open'-user-oriented technology (see Chapters 2). This trend has stimulated a movement in the GIS community towards using the technology to increase the democratization of planning process via public participation (see Chapter 5). The monograph has argued that it is in the context of the debate on the inter-relationship between GIS and society that one can see the potential for advancing the role of information technology in the land-use suitability mapping and modeling. Specifically, GIS-based land-use suitability analysis should be constructed with two perspectives in mind: (i) the techno-positivist perspective on GIS, and (ii) the socio-political, participatory GIS perspective. These two perspectives are often perceived as opposite viewpoints of the debate on GIS and society. I suggest that the two viewpoints can be reconciled by giving a proper consideration to ethical issues in the process of GIS design and development of GIS applications for land-use suitability analysis.

GIS is a part of information technology with which it shares ethical dilemmas (Pickles, 1995; Sheppard, 2001). Like any information technology, GIS can be a tool for good or harm. The responsibility of computer professionals including GIS experts is to maximize the good consequences of 'computerization', and minimized the bad ones. This requires not only technical skill (an aspect which is emphasized by the technocratic perspective on GIS), but also skill in recognizing and handling moral dilemmas (as postulated by the social critics of GIS). While there has bean a significant progress in advancing the GIS technical skills among land-use planners and managers, our ethical standards and social institutions have not yet adapted, it seems, to the moral dilemmas that result from the use of GIS technology in the land-use planning process. These dilemmas are related to such issues as *accuracy*, *accessibility*, *accountability and shared responsibility* (Massam, 1993; Thomson and Schmoldt, 2001; Ball, 2002). Choosing a particular approach to GIS design and application development can either hinder or facilitate addressing these issues in an ethical manner.

6.1. Accuracy

The use of GIS in the land-use suitability modeling involves a question about the accuracy of representing the real-world situation in a GIS database. The notion of representational accuracy has two elements: an accurate representation of geographical objects (the 'hard' data) and accuracy in representing social, economic, cultural, political elements (the 'soft' data) of the environment within which land-use planning is made (see Section 1.2). GIS is focused on representation and visualization which is structured towards seeing the world as composed of geographic layers containing objects (pixels, points, lines, and polygons) along with associated attributes. At the fundamental level, GIS systems are based on certain conceptualization of space (particularly a geometric and relative space) and certain forms of reasoning (particularly Boolean logic) (see Chapter 3). Such conceptualization provides the impression of a value free and rigorous view of the world. According to the critics of GIS, there is a danger, however, that the users of GIS will be misled into thinking it is entirely objective and value free technology. In fact, GIS represents the world in the form of maps which reflect the value systems of the map makers. However, in my opinion, the central issue is not related to the objectivity in representing of the word. It is the accuracy of the world represented in GIS which is of critical importance rather then objectivity. In order to correctly represent a particular land-use planning problem one has to focus on the right combination of both objective and subjective data/information (see Chapter 1). It is not only the geo-referenced objects (e.g. parcels of land) and their relevant attributes that are important. It is also data/information representing the values, opinions, preferences, priorities, judgments, etc. of these involved in planning process and the public at large that are of critical importance in planning. Some of the issues related to accurate representation of land-use planning problems have recently been addressed by public participatory GIS (Jankowski and Nyerges, 2001; Ball, 2002; Craig *et al*., 2002) and PSS (Brail and Klosterman, 2001) (see Chapters 2 and 4). It is expected that the trend towards advancing public participatory approach to system design and application development will be of critical importance for a successful use of GIS in the land-use planning process. Also, one should indicate that some of the developments underway in geocomputation technologies (see Section 4.3) have the potential to be relevant in developing new types of GIS orientated towards social rather than map spaces (Openshaw, 1999; Openshaw and Abrahart, 2000).

6.2. Accessibility

Appropriate access to GI technologies involves a number of both technical and social issues (Thomson and Schmoldt, 2001). To use GIS, an individual or organization must have access to the GI technology, must be able to provide any required input, and must be able to comprehend the information presented. Accessibility to a system is also limited if results are presented using language and concepts beyond the end-user's understanding. As demonstrated in Chapter 2, there has been a considerable increased in availability of powerful, low cost, and easy-to-use GIS software and hardware over the last decade or so. Accordingly, GIS technology promises to improve public access to information and facilitate public participation in the land-use planning (Nedović-Budić, 2000). Contrary to the expectation that GIS provides for enhancing democracy and empowering disadvantaged groups, social critics of GIS argue that the technology has been yet another tool in the hands of the government agencies and corporations leading to a formation of GIS technocratic elite and an increased in current social and geographical inequalities (Pickles, 1995). The premise of the 'digital divide' is that there is differential access to computer technology and information in society. This differential access is typically correlated with such variables as income/poverty, education, race, age, etc. Give the fact that social actors have differential access to GIS, the technology has been seen "as facilitating practices of surveillance, social engineering, opinion formation, and warfare by those with access to the technology" (Sheppard, 2001).

A considerable effort has been made towards developing public participation GIS that empowers communities involved in the land-use planning (Craig *et al*., 2002). While researchers increasingly recognize the importance of public participation in land-use planning, there is less agreement about how to involve the public. It is often suggested that the Internet has features making it especially useful to advance the public participation GIS concept (Carver and Peckham, 1999). They include: low costs of entry, efficient data transfer, connectivity and interactivity. These properties provide a platform for developing GIS applications that encourage public participation and have the potential to empower the public in the land-use planning process. Using the Internet, however, cannot resolve all the conceptual, practical, and ethical problems of public participation GIS including the issues related to under-representation, trivialization of the planning process, bias in system authorage and control, political intransigence, and spatial cognition and interface design (Carver and Peckham, 1999).

6.3. Accountability and shared responsibility

'The thorny question of how to balance the impossible conflicting cases will always result in some being dissatisfied in the outcome'. The GIS-based methods for land-use suitability analysis 'can never solve all the problems. Decision making is seldom (if ever) a science. Nor is it objective and value free'. What we can hope for is 'that the decisions should be fair, reflect community choice, be based on evidence and facts that are correct, and be subject to *post hoc* scrutiny with penalties attached to those who deliberately abuse people's rights ' (Openshaw, 1999: 435–436). This calls for a public participation GIS that would be a part of a procedure organized around the concepts of accountability and shared responsibility (Massam, 1993). Such public participation GIS-based procedure should aim at establishing and maintaining a high degree of trust, transparency, and a sense of shared responsibility for all involved in the land-use planning process (Ball, 2002).

Accountability requires that one group or individual (e.g. GIS experts and land-use planers) provides a professional account (or justification) of its activity to another stockholding group or individual (e.g. public, interest groups, non-government organizations). It presupposes that an organization or institution involved in land-use planning has a clear policy on who is accountable to whom and for what. It involves the expectation that the GIS-experts, land-use planners, and decision-makers will be willing to accept advice and criticism and to modify their practices in the light of that advice and criticism.

Acknowledgements

This research was supported under a GEOIDE grant project (Res. # 31) from the Network of Centres of Excellence (a program jointly administered by the Natural Sciences and Engineering Research Council, the Canadian Institutes of Health Research and the Social Sciences and Humanities Research Council of Canada) and a University Research Grant (University of Western Ontario). I would like to thank Bryan H. Massam of York University, Ontario, for his encouragement and advice as I was preparing and writing this monograph. The author is grateful for helpful comments from two anonymous reviewers.

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