Henk J. Scholten
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*Editors*

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# Geospatial Technology and the Role of Location in Science

Springer

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# Geospatial Technology and the Role of Location in Science

Springer

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# Foreword

Hundreds of thousands of creative and innovative efforts of users around the world provide evidence of the growing value of Geospatial Technology. Their work is saving resources, helping plan more livable communities, fostering economic development, improving human health and mitigating conflict: Geospatial Technology is creating more sustainable actions throughout the world.

These efforts are part of the long history of the role of location in science. More than 200 years ago Alexander von Humboldt introduced the idea of geography as an integrative science; his holistic view considered the world as a series of interrelated and interdependent processes. Horticulturist and early landscape architect Warren Manning used map overlays as a way to integrate various physical and cultural geographic factors for site and regional planning. Ian McHarg popularized Humboldt's and Manning's ideas in his book *Design with Nature* (1969). Waldo Tobler, the first geographic information scientist, used quantitative methods, computer algorithms and software tools to analytically model geographic processes. In the 1960s Roger Tomlinson conceived and built the first geographic information system (GIS) in Canada. Carl Steinitz, an urban planner at Harvard University, pioneered many of the early ideas about the application of GIS for landscape analysis and urban planning. We stand on the shoulders of these pioneers.

Today a new generation of scientists and researchers are making the history of Geospatial Technology. They are using science-based approaches and the powerful tools of geospatial measurement, data collection, data management, spatial analysis and modeling, and geospatial visualization. They are accelerating the creation of geographic knowledge and its application to nearly every problem confronting society today.

*Geospatial Technology and the Role of Location in Science* is, first of all, a contribution to the history of the current development of Geospatial Technology, documenting how this new generation of workers is using as well as shaping this technology.

Secondly, *Geospatial Technology and the Role of Location in Science* also chronicles the complex process of technology diffusion: how knowledge about Geospatial Technology is spread, how people learn to use it, and why and how it is used. Since technology diffusion is not well understood, any fresh insights into the process are welcome.

But I think the book serves a third important function as well.

We live in a rapidly changing world: population growth and human actions impact our natural world, changing climate, biodiversity and the availability of ecosystem services that support human life. These changes are affecting our economies, our security and challenge sustainability for all of us. Given these challenges, it is not enough just to create the tools of Geospatial Technology: they must also be applied and applied widely. We must understand how to make that happen.

To those of us who believe in the power of this technology and want to see it spread rapidly, *Geospatial Technology and the Role of Location in Science*, by providing numerous examples of why and how Geospatial Technology has been successfully applied, can help make an important difference in meeting the great challenges confronting our world.

For all these reasons the authors deserve our thanks.

Jack Dangermond
President ESRI

# Acknowledgements

In September 2007, a conference was held by the Spatial Information Laboratory of the VU University, Amsterdam. The meeting brought together leading geographic information scientists from a variety of disciplines throughout the world, to discuss the role of location and the use of Geospatial Technology in science. The content of this book reflect many of the themes presented and discussed at the conference.

We wish to acknowledge the valuable input of Professor Guido Martinotti, Professor Hans Kamermans, Dr. Frans van der Wel and Professor Julian Richards in preparing the conference.

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|---|---|
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# Chapter 1
# Geospatial Technology and the Role of Location in Science

**Niels van Manen, Henk J. Scholten and Rob van de Velde**

## 1.1 Introduction

In the last few decades, an increasingly wide range of geospatial tools, geospatial data and geospatial services have become available to a widening body of users. It has become much easier to communicate effectively over vast distances across land, sea, air and space, but the world has also seen much more effective monitoring of social and natural spatial behaviour, partly as a result of the capture of increasing quantities of information. Armies, governments, non-governmental organisations and multinational enterprises have devised new methods of data capture and analysis to satisfy their different requirements. Individual consumers, employees and scientists have enjoyed the advances in data provision and accessibility that have become available, particularly with the development of the internet.

This book is specifically concerned with the use of Geospatial Technology, or Geo-ICT, including geographical information systems (GIS) and modelling as well as spatial data and geospatial services. ICT is an acronym that stands for Information Communications Technology. While there is not a universally accepted definition of ICT, it covers any product that will store, retrieve, manipulate, transmit or receive information electronically in a digital form, including personal computers, digital television, email and robots. Traditional computer-based technologies, such as the activities that we typically perform on a personal computer or using computers at home or at work, can be distinguished from the more recent and fast-growing range of digital communication technologies that allow people and organisations to communicate and share information digitally. In a broader context, ICT is concerned with the use of key applications such as spreadsheets, databases, presentations, graphics and web design software. However, adding the prefix ‘geo’ to the acronym ICT implies that we are particularly interested in the spatial or geographical dimension. In the book we will use both terms Geo-ICT and Geospatial Technology.

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The term ‘location based services’ (LBS) has been commonly used in relation to modern communication technology to describe services that provide information that is fundamentally concerned with the spatial relation between the information receiver and the location of other people, objects or natural phenomena. LBS are information and entertainment services accessible with mobile devices, such as phones, through the mobile network and utilising the ability to make use of the geographical position of the mobile device. LBS include services to identify the location of a person or object, such as discovering the nearest restaurant or the whereabouts of a colleague, parcel tracking and vehicle tracking services, personalised weather services and even location-based games. Here we propose the use of an alternative, more comprehensive concept of ‘geospatial services’ rather than LBS. It is equally concerned with location and spatial relations, but goes beyond providing information to consumers, as in the examples above. We understand it to include services that provide the means to collect, integrate, visualise and analyse georeferenced data. Our particular concern is to understand to what extent Geo-ICT enables scientists to shed light on this more general development: the impact of this technology on the explanation of spatial behaviour, phenomena and processes in the past, present and future.

While the spatial dimension is the core dimension in the discipline of geography, with its prime focus on the spatial distributions of phenomena, much other scientific investigation has a spatial or location aspect – the ‘where’ question. To explore these location dimensions adequately, tools are needed to collect, integrate, analyse and visualise georeferenced information that relates raster (grid) cells or vector (line, point, polygon) elements to a specified coordinate system or map projection. Geo-ICT is one of the most rapidly developing fields within ICT. A range of increasingly sophisticated tools has come onto the market over the last 40 years, facilitating the work of scientific research. While geography researchers have embraced the technology and used the tools of GIS and modelling in a range of human and physical contexts, there is also evidence of a growth of geographically-oriented subdisciplines such as spatial economics, spatial demographics, geohistory and spatial sociology in the social sciences. The emergence of interdisciplinary spatial centres of excellence also demonstrates a growing interest in location. Moreover, there are strong indications that scientists in other disciplines are increasingly turning to Geospatial Technology to explore their location issues. Sales by Intergraph and Environmental Systems Research Institute (ESRI), major developers of proprietary GIS software systems in this field, suggest that researchers and students in over one hundred scientific disciplines use their software.

Despite the evidence of widening usage and a burgeoning literature on concepts, developments and applications of GIS (e.g. De Lepper et al. 1995, Fischer, Scholten and Unwin 1997, Longley et al. 1999, 2001, Stillwell and Clarke 2004, Lo and Yeung 2007), very little is known about exactly how and why scientists use Geo-ICT across the different disciplines, nor about the ways the use of such systems affects their research and has influenced developments in different disciplines. This book aims to bridge this gap. Bringing together the views of prominent scholars, each of whom is an authority on location-based approaches within their own discipline, it seeks to explore the past, present and future significance of Geospatial Technology for scientific research. Why, in the first instance, did scientists decide to use Geo-ICT systems in their specialist fields? To what extent has the nature of their use changed over the course of time? How has the use of Geo-ICT affected their approach to and understanding of location-based issues? And how have the systems enriched or restricted their research in other ways?

The impact of developments in Geo-ICT has not been restricted to the academic world, of course, and applications can be found in many other areas of society, including public sector activities such as policing, health service provision, transport and land use planning, and private sector activities such as retailing. Urban and regional planning is an activity that has adopted national, regional and local applications of GIS across the world in different contexts (Scholten and Stillwell 1990, Stillwell and Scholten 2001). These include customised planning support systems with Geo-ICT tools integrated into an automated system to support a specific planning function, sometimes for enhanced participation in the planning process by key stakeholders or the general public (Geertman and Stillwell 2003, 2009). New global-scale products, such as Google Earth and Virtual Earth (Microsoft), for example, have increased public awareness of the possibilities of digital maps for gathering knowledge about their neighbourhood, region or country, but also their destinations for tourism or business purposes. This has led to the growth of interest in both participatory GIS (P-GIS) and public participation GIS (PPGIS). New Geo-ICT technologies like onboard navigation systems (e.g. Garmin and TOMTOM) have demonstrated that Geo-ICT is able to support decision making on a very basic routine level, such as finding your way around. It has now become possible for the public to play with these systems, gather information and enrich them – by adding Points of Interests (POI) from Google Earth into their TOMTOM system, for example, or by adding the locations to pictures and thereby creating a ‘geotagged picasa’.

These apparently new non-scientific applications have their origin in scientific understanding. The success of the navigation systems as a user-friendly device depends on five components:

- the development of intelligent digital road databases;
- methods to analyse the available data quickly and accurately (shortest path algorithms);
- the ability to locate vehicles in space at any moment (global positioning systems, GPS);
- developments in smart user interfaces;
- developments to integrate actual traffic information into planning.

All these components have their roots in scientific research. Conversely, the application and successful adoption and use of these systems also stimulate academics to raise new questions: some may be about legal issues, such as who is responsible for ensuring or maintaining the quality of the data; others may be economic in nature, such as how to optimise fleet vehicle management based on the new possibilities of Geo-ICT; or they may be psychological questions, such as how these tools and the information they generate will influence people's behaviour. There are always many different kinds of technological questions, such as how we can further improve Geo-ICT instruments. Better understanding of these issues and questions has continued to stimulate businesses to engineer and market new devices, such as radio-frequency identification (RFID), which now makes it possible to track the location of objects within buildings where GPS become inoperable. RFID is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or 'transponders', objects that can be applied to or incorporated into an object, such as a person, for the purpose of identification using radio waves.

One section of society in which Geo-ICT is starting to make a considerable impact and has much potential is primary and secondary education. The global impact of climate change, international conflict and economic downturn currently dominate political and public debate. Each of these issues has important geographical components – interactions between natural, social, political and economic circumstances in a particular place. Spatial topics like these are destined to become an important part of the school curriculum in a number of subjects. Geo-ICT initiatives in several countries indicate the possible role that new technology can play in assisting students to understand these phenomena. Modules are being developed that not only stimulate students to approach issues from a geographical perspective, emphasising the importance of place, but also enhance their spatial thinking skills. These skills can also be applied in other subjects and outside the classroom, highlighting the value that Geospatial Technology can have beyond the study of geography itself.

So far we have only considered the impact of developments in technology on society. But there is also another side to this coin. The ways in which scientists, professionals and students apply the Geo-ICT systems also has a profound and sometimes unexpected impact on their further development. This interaction between technology and society has been the object of study by scholars of technology innovation. One area of research that is particularly relevant to our investigation is the interaction between science and technology development. We consider what lessons can be drawn from recent developments in this field in the next section.

## 1.2 Science-Technology Innovation

Norman Bradburn, Assistant Director for Social, Behavioral and Economic Sciences at the US National Science Foundation (NSF) has claimed that "at last, long-held but unverified hypotheses about the importance of locational and spatial variables can be tested. We are at the dawn of a revolution in a spatially oriented social science" (Bradburn 2004, v). This bold claim is largely based on the tremendous advancement that has taken place over the last few decades in ICT in general and in GIS in particular. Today's systems offer scientists unprecedented opportunities to collect, store, analyse and visualise georeferenced data. As the exemplary contributions to Goodchild and Janelle (2004) show, Bradburn's optimism is not strictly hypothetical: scholars from a variety of social science disciplines have indeed taken up these opportunities to carry out spatially-oriented case studies at a range of geographical scales. Nor should it be seen as mere rhetoric. The collection is one of the early fruits of the Center for Spatially Integrated Social Sciences (CSISS), founded in 1999 at the University of California (Santa Barbara, USA) with a multimillion dollar grant from the NSF "to develop unrestricted access to tools and perspectives that will advance the spatial analytic capabilities of researchers throughout the social sciences" (Goodchild and Janelle 2004, 14).

The CSISS does not stand alone in its mission. Besides special issues of journals and conferences and workshops for spatially-oriented scholars from particular disciplines, interdisciplinary initiatives similar to CSISS can also be found elsewhere, for example the Qua Si Project run by Bicocca University in Milan, Italy, and the Spatial Information Laboratory (SPINlab) at VU University, Amsterdam, the Netherlands. On the one hand, initiatives such as these show that leading scholars and funding bodies have great confidence in the added value of spatial methods and tools. On the other hand, they suggest that their widespread dissemination will not occur spontaneously. As Goodchild and Janelle state in their preface: "Though capable of adding substantive analytical power and theoretical insight to most areas of social science research, the notion of 'spatial social science' is in its formative stages" (Goodchild and Janelle 2004, vii).

How successful are these schemes in bringing about the desired change? Are we really on the brink of a spatial turning point in the social sciences? What about the natural sciences? Are advancements in Geospatial Technology indeed the driving force behind a growing appreciation of spatial methods? And, placed in the context of long-term scientific evolution, how legitimate is it to refer to these developments as 'revolutionary'? These and similar questions will be our central focus in this book. In the next section we explore some of the lessons that can be drawn from recent studies on the history and philosophy of science and technology.

## 1.3 Explaining Shifts in Scientific Practice

Before the Second World War, scholars of the history and philosophy of science generally showed little interest in the dynamics behind scientific change. There were, of course, some notable exceptions. People like Pierre Duhem (1861–1916), Hélène Metzger (1889–1944) and Alexander Koyré (1892–1964) in France and George Sarton (1884–1956), the Belgian-American historian of science, *did* take a critical interest in the historical evolution of scientific knowledge and practices before 1945. Apart from this, there was the odd publication by philosophers of science on how science should be practised, but this did not stimulate any serious engagement with the historical development of scientific investigation. Academic as well as popular thinking was dominated by the idea that a 'scientific revolution' had occurred in the West between the late sixteenth and early eighteenth centuries. Through close examination of their surroundings with new instruments and methods, scientists had mastered the workings of nature, guiding them away from medieval prejudice towards modern enlightenment. Subsequent generations of scientists were believed to have built on the findings of their early modern predecessors, gradually extending knowledge and bringing humanity closer to the truth (Bird 2008).

Following the military destruction caused by the First World War, the rise of dictatorships and economic crises during the interwar period and the humanitarian disasters of the Second World War, such a positive assessment of modernity as an age of continuous improvement, with science as its driving force, could no longer be upheld. Particularly influential in breaking away from this linear perspective was the American philosopher of science, Thomas Kuhn. In *The Structure of Scientific Revolutions* (1962), Kuhn argued that scientific disciplines experience alternate periods of 'normal science' and 'crisis', separated by scientific revolutions. During periods of normal science, scientific development is driven by a so-called 'paradigm', a particular set of academic practices that scholars within the discipline universally adhere to. The focus is on answering questions raised by the paradigm, using generally accepted theories and tools. Problems that cannot be solved through the methods in use will either be ignored or downplayed. Yet, once these problems (or 'anomalies') start piling up, scientists may lose faith in their paradigm and a 'crisis' will occur. This will be followed by a 'revolution' during which the old practices are revised and a new paradigm formulated. Another period of 'normal science' will set in, with its own questions, tools and methods.

Although Kuhn's concepts of 'normal science', 'paradigm', 'crisis' and 'revolution' are no longer being refined as tools of analysis, his thesis is still an important point of reference for historians, philosophers and scientists alike. Its impact on the study of the history and philosophy of science can still be seen today. First, by arguing that scientific change does not merely consist of refining existing knowledge based on existing theories, but also of raising new issues and approaching these in novel ways, Kuhn stimulated a profound interest in historical development. Second, by claiming that science is fundamentally about solving the puzzles raised by a particular paradigm rather than reaching absolute truth – an ideal that could only be aimed for by 'hard', natural scientists – Kuhn enabled his followers, including Paul Forman, another historian of science and a curator of the Division of Medicine and Science at the National Museum of American History, to widen the concept of 'science' to include 'soft', social disciplines. Third, by arguing that scientific questions, methods and tools are not determined by scientific progress but by the outcome of negotiations between scientists, Kuhn drew attention to the social and cultural factors that led them to reach a particular consensus.

This last contribution has been an important stimulus for the emergence of the social history of science. Stephen Shapin and Simon Schaffer, winners of the 2005 Erasmus Prize for their groundbreaking work on the historical interaction between science and society, were pioneers in this field. Focusing on the debates between

Robert Boyle ('the experimentalist') and Thomas Hobbes ('the theorist') about the principles of natural science, their *Leviathan and the Air Pump* (Shapin and Shaffer 1985) was a first attempt to assess the importance of social factors in settling scientific disagreement. They found that Boyle's experimental approach prevailed not because his experiments were always successful or his conclusions always correct, but because his methods were socially more attractive. In the aftermath of the English Civil War (1642–1651) avoiding dispute was the main priority. In those circumstances a scientific method that produced provisional findings based on experiments that could be repeated was preferred to an approach whose absolute claims were likely to cause irresolvable friction (see interview with Simon Schaffer by Peter Giesen: 'Weten is vertrouwen geven', *de Volkskrant*, 12 February 2005). In this way, science and society impact on each other; not only do social conditions stimulate science to develop in a specific direction, but science itself is used to create a particular political reality.

Along similar lines, but more radical in its conclusions, is work by the French philosopher Bruno Latour. Like Shapin and Schaffer, Latour considers social trust to be the key to establishing methods as 'valid' and findings as 'facts'. Unlike Shapin and Schaffer, Latour does not believe in the mutual interaction between science and society, but sees the two as inseparable. His actor-network theory, vividly presented in *Science in Action* (Latour 1987, see Shapin 1988 for critical response) and more recently in *Reassembling the Social* (Latour 2005), portrays scientific development as a constant process of adoption and translation between networks of scientists and their allies. These allies are not restricted to human actors but include all resources that make one's alliance stronger (data, theories, instruments, publications, funding, etc.). Ultimately, the network with the best resources will prevail, its findings will become facts and its methods the norm. Crucially, by integrating instruments and theories into his framework, and by referring to 'technoscience' instead of science and technology, Latour broke away from the traditional dichotomy between the two.

But Latour was not the first to do this. As early as 1982, Barry Barnes signalled the growing appreciation of technology and presented a first interactive model. This no longer depicted technology as a mere tool that served the needs of science, but as a creative force that acted on an equal footing towards scientific advancement (Barnes 1982). This preliminary model, with much inspiration from the social approaches to science outlined above, has been further developed by Wiebe Bijker, Thomas Hughes and Trevor Pinch into the Social Construction Of Technology or SCOT model (Bijker et al. 1987, Bijker 1995). In line with Shapin and Schaffer's ideas on science, the SCOT model emphasises the social dynamics of technology development: the success of a technology is not a reflection of its intrinsic qualities but of its social attractiveness. Scholars should therefore focus on examining how specific interest groups (different groups of potential users, investors, manufacturers, etc.) come to see particular designs as more or less attractive. Crucially, the SCOT model does not restrict itself to the initial process of selection, but also considers how a technology is subsequently used and developed.

In other respects the SCOT model is less comprehensive. For example, in assessing the process of selection it looks exclusively at the arguments presented in human–human interaction. Latour's actor-network theory takes it one step further by also considering the use of material resources and symbols (including visual representations) to demonstrate the desirability of a particular technology (Mackenzie and Wajcman 1999). This addition is crucial when considering the qualities of the technology under investigation, since one of the distinct qualities of Geo-ICT is its ability to generate visual representations (such as maps or 3D simulations). This brings us to the lessons that can be drawn from the above discussion for the purposes of this study.

The conclusions of this overview are threefold. First, scientists do not inhabit an ivory tower, but are part of society. Their theories and methods are therefore not natural laws but the product of construction. Second, once a scientific practice (or paradigm) has been established, the focus will be on preserving it by addressing questions which it is best equipped to answer. Its fundamental rules will only be revised if alternative methods and instruments generate superior social appeal. Third, technology often plays a key role in bringing about such change. Rather than being an external tool, it is an integral part of the world of science, which means the introduction of a technology affects scientific practice as much as the particular use made of it by scientists affects its own development.

What implications can be derived from these findings? First, because the use of methods and technology is a social process, studying the acceptance of spatial thinking and Geo-ICT requires us to look beyond their 'objective qualities'. Instead, we need to explore why particular qualities appeal more or less to particular groups of scientists. Second, because scientists tend to stick to generally accepted practices we need to assess how spatial methods and Geospatial Technology fit into current methods and what potential they offer to raise the social appeal of science. And third, because the application of new methods and tools tends to have profound effects on scientific practice as well as the methods and tools themselves, we cannot restrict ourselves to the issue of acceptance. Instead, we need to explore the levels of dissemination of spatial thinking and Geo-ICT and examine the ways in which their application affects scientists and vice versa.

## 1.4 Book Content and Key Questions

To deal constructively with the issues identified in the previous section, we have divided up the book into five parts.

The first part consists of three interdisciplinary contributions, each focusing on one key aspect of our study: spatial thinking, spatial data collection and analysis, and visualisation. In Chapter 2, taking the programmes run by CSISS as a case study, Donald Janelle and Michael Goodchild evaluate the dissemination of spatial thinking in recent decades. In Chapter 3, Euro Beinat and John Steenbruggen sketch four scenarios for the integration of Geo-ICT in science over the decades to come. And in Chapter 4, Chunglin Kwa, Mieke van Hemert and Lieuwe van der Weij explore the ways in which three generations of visualisation technology have affected scientists' engagement with the natural landscape: landscape painting, aerial photography and remote sensing.

Part 2 consists of five chapters exploring the historical development, current use and future place of spatial thinking and Geo-ICT in social science disciplines. In Chapter 5 Alfred Wagtendonk, Philip Verhagen, Steven Soetens, Karen Jeneson and Maurice de Kleijn describe the role of Geo-ICT in archaeology. In Chapter 6 Onno Boonstra demonstrates the great potential but limited adoption of Geo-ICT within history. Chapter 7 is a detailed overview by John Stillwell of the history of Geo-ICT in demography. In Chapter 8 Jasper Dekkers and Piet Rietveld describe the adoption of Geo-ICT in economics. And Arjan de Wit, Adri van den Brink, Arnold Bregt and Rob van de Velde explain in Chapter 9 how spatial planners invented Geo-ICT, but are still learning how to master it.

Part 3 consists of two chapters related to the natural sciences. In Chapter 10 Joseph Strobl describes how physical geography benefits from some early adopters in Geo-ICT, but that established paradigms are slow to change. Mark Cresswell, in Chapter 11, seeks to examine the specific roles of location and time in the epidemiology of tropical diseases.

Part 4 draws attention to developments in three emerging disciplines. In Chapter 12 Johan van Schaaik and Jasper van der Kemp explore the role of spatial analysis and Geo-ICT in the scientific study of crime. Sisi Zlatanova and Andrea Fabbri discuss the value of spatial tools for risk and disaster management in Chapter 13. And in Chapter 14, Maria Teresa Borzacchiello, Irene Casas, Biagio Ciuffo and Peter Nijkamp describe the enthusiastic adoption and profound impact of Geo-ICT in transportation science.

Part 5 is intended to provide more general reflections. In Chapter 15 Joop van der Schee and Henk Scholten examine to what extent recent initiatives for the introduction of Geo-ICT and spatial thinking skills in secondary education can serve as a template for similar programmes in higher education. The book concludes in Chapter 16 with a synthesis of the main findings from the constituent chapters.

To ensure consistency in the structure of the disciplinary chapters, we asked all authors to respond to the following key issues in their own discipline:

1. The growing significance of location-based approaches;
2. The dissemination of Geo-ICT in research and teaching;
3. Effective ways of applying Geo-ICT in location-based research;
4. Technical and methodological obstacles preventing an optimum use of Geo-ICT;
5. Ways in which scientists and others (can) contribute to overcoming these obstacles.

A series of guidelines was provided for each issue, as outlined below.

1. *The growing significance of location-based approaches*
   Three key questions are associated with this issue.

   - To what extent is this discipline spatially explicit (e.g. geography) or spatially implicit (e.g. history)?

- Which spatial relations are scholars in your discipline particularly interested in? In other words, what is distinct about the way in which scholars in your field approach space and location (whether quantitatively and/or qualitatively)?
- To what extent have scholars in your field been increasingly aware of the significance of location? And how does this awareness manifest itself: in the birth of spatial subdisciplines, in the collection of georeferenced data, in the development of spatial frameworks, etc?

2. *The dissemination of Geo-ICT in research and teaching*
   The focus of this issue is the way in which knowledge and awareness of Geo-ICT is disseminated in the research community. We asked all authors to reflect critically on the 'Geo-ICT diffusion model', a descriptive model outlining seven levels or phases of integration, put together by the editors based on interviews with leading scientific Geo-ICT users. The stages of the model on which authors were asked to comment are:

   - *Stage 1 Champions*: A small group of eager scholars explore the possibilities of Geo-ICT and publish their findings.
   - *Stage 2 Guest speakers*: Given their publications, these 'champions' are invited to appear as guest speakers in other universities.
   - *Stage 3 Conferences*: The guest appearances result in invitations to conferences, where initially they will be the only scholars presenting research based on Geo-ICT. After a while full conferences, or at least large parts of them, are actually dedicated to Geo-ICT.
   - *Stage 4 Staff training*: These conferences stimulate the demand among colleagues for training in the use of Geo-ICT.
   - *Stage 5 Optional modules:* The same scientists start offering courses in Geo-ICT (or courses that require the use of Geo-ICT) in their own universities, initially as an optional part of a degree.
   - *Stage 6 Large-scale databases*: The effective use of Geo-ICT for research purposes requires the construction of large-scale databases (the collection and storage of a large body of *georeferenced* data).
   - *Stage 7 Full integration*: The availability of such data collections will no doubt further stimulate the demand for training in their use, particularly if the first examples of their successful application are being published. This can eventually result in the full integration of Geo-ICT in research and teaching. As we understand it this is a situation in which a substantial proportion of academics use Geo-ICT structurally for their research and Geo-ICT-training has become a compulsory part of both undergraduate and postgraduate programmes.

   So, the questions asked of contributors were as follows:

   - To what extent does the Geo-ICT integration or diffusion model resemble the process of integration in your discipline?
   - If there are recognisable stages, what stage of integration is your field currently going through?

  - If the suggested stages are not evident, could you suggest a sequence or model that better resembles the evolution of the use of Geo-ICT in your discipline?

3. *The discovery of effective ways of applying Geo-ICT in location-based research*
   We suggested three dominant approaches or frameworks in which Geo-ICT can be applied in research practice:

   - *Geodatabase* approach, in which data and its organisation are critical and location is a specific component in the database (e.g. Oracle Spatial);
   - *Geomapping* approach, in which visualisation and map-making is the main focus;
   - *Geomodelling* approach, in which analysis is of paramount importance and location is a key variable in explanatory models.

   The questions posed to the disciplinary authors were as follows:

   - Which of the three Geo-ICT frameworks (geodatabase, geomapping, geomodelling) is most commonly used by scholars in your discipline?
   - Why do you think this framework is currently most popular?
   - Which of the three Geo-ICT approaches or frameworks could be applied most effectively in the future? In other words, which of the frameworks is potentially most fruitful to researchers in your field?
   - To what extent is your discipline ‘knowledge-driven’ (e.g. geography) or ‘engineered’ (e.g. disaster management)?
   - How does this affect the feasibility of each of the three frameworks?

4. *The technical and methodological obstacles preventing the optimum use of Geo-ICT*
   All innovative technologies encounter resistance. The point of this section was to allow the authors to reflect on what particular obstacles were associated with Geo-ICT adoption and use in their discipline. The questions for authors in this context were as follows:

   - Which technical obstacles (limitations posed by software and hardware on your ability to collect, integrate, visualise, analyse and communicate spatial data) have offered the most serious hindrance to optimum use of Geo-ICT in your field?
   - Which methodological obstacles (conflicting methods and approaches, lack of adequate training, etc.) have offered the most serious hindrance to optimum use of Geo-ICT in your field?

Besides limitations in technical and methodological disputes, we suggested two other factors that may affect the acceptance and level of dissemination of Geo-ICT: the ‘perceived usefulness’ of the system and its ‘perceived ease of use’. These are key concepts of the Technology Acceptance Model (Davis 1989, Davis et al. 1989) and have been tested and confirmed repeatedly as a model for successful (or unsuccessful) introduction of technologies in business. The extended model, referred to as TAM2 (Venkatesh and Davis 2000) was tested using longitudinal data

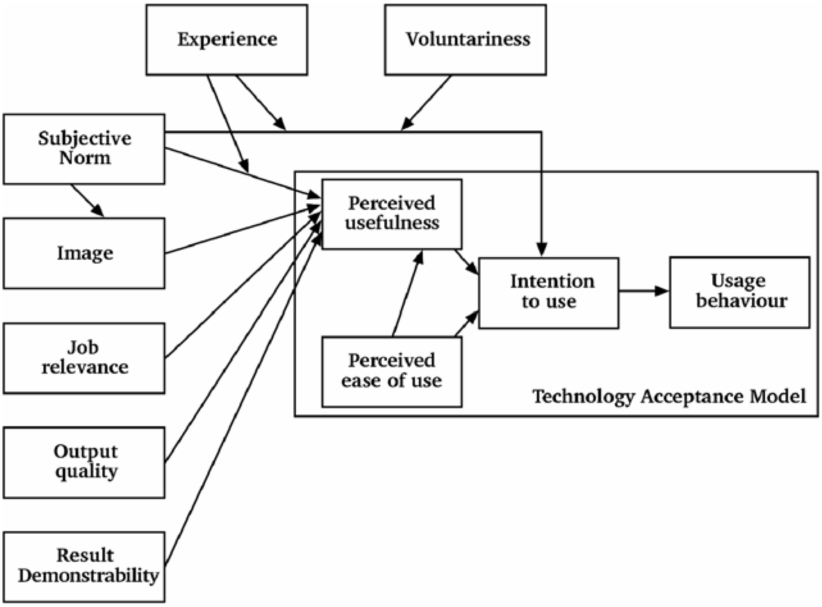

**Fig. 1.1** TAM2, extension of the Technology Acceptance Model (Venkatesh and Davis, 2000)

collected from four organisations. The outcome indicated that both social influence processes (subjective norm, voluntariness and image) and cognitive instrumental processes (job relevance, output quality, result demonstrability and perceived ease of use) all significantly affected user acceptance. Here we propose it as a useful tool to help explain growth, stagnancy and decline in the use of Geo-ICT in science, without testing its legitimacy fully. We asked the authors to reflect upon it and judge its usefulness for explaining Geo-ICT user behaviour in their own discipline (Fig. 1.1).

5. *Ways in which scientists can contribute towards overcoming these obstacles*
   The contributing authors were asked to respond to the following questions:
   - To what extent and by what means have scholars in your field contributed to overcoming ‘technical’ and ‘methodological’ obstacles that prevent optimum Geo-ICT use?
   - How could scholars in your field best contribute to overcoming the current obstacles?
   - Which other factors, outside the direct sphere of academia, have made a positive contribution to overcoming past and current obstacles?

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# Chapter 2
# Location across Disciplines: Reflections on the CSISS Experience

**Donald G. Janelle and Michael F. Goodchild**

## 2.1 Introduction

The importance of geographical location as a mediator of societal and environmental processes has been acknowledged for several centuries. Nonetheless, it is only recently that scholars have had access to powerful computational and modelling tools to account for the role of location in explaining processes and patterns of change. Related to this new reality, this chapter has two objectives. First, it seeks to document the expansion of locational perspectives across disciplines based, in part, on programmes of the Center for Spatially Integrated Social Science (CSISS)[1] in the United States. The second objective draws on the experiences of CSISS programmes for nurturing an understanding of core spatial concepts in conjunction with the exposure of students to spatial analytic tools. The chapter identifies fundamental spatial concepts and their value to scientific reasoning and to the development of sound policy applications in business and civic life.

## 2.2 Extending Locational Perspectives across Disciplines – The Experience of CSISS

CSISS was founded in 1999 to develop research infrastructure in the social and behavioural sciences (Goodchild, et al., 2000). Since then, CSISS has facilitated the sharing of ideas and methods among researchers in the social and behavioural sciences, promoting the national dissemination of spatial analytic tools, including

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[1] CSISS was funded by the National Science Foundation (NSF BCS 9978058), hosted by the University of California Santa Barbara and directed by Michael Goodchild (see www.csiss.org). Its week-long workshops were offered through UCSB (2000–2004) and Ohio State University (2001–2003), the University of California Los Angeles (2000), the University of Washington (2000) and Pennsylvania State University (2003).

H.J. Scholten et al. (eds.), *Geospatial Technology and the Role of Location in Science*,
GeoJournal Library 96, DOI 10.1007/978-90-481-2620-0_2,

cartographic visualisation, geographic information systems (GIS), pattern recognition, spatially sensitive statistical analysis and place-based search methodologies. Through workshops, web technologies and publication programmes, CSISS enhanced accessibility to these tools and ways of thinking and fostered opportunities for scholars to master spatial methodologies.

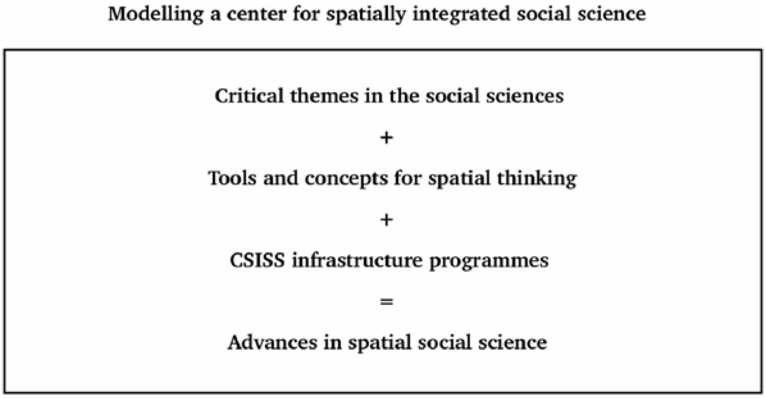
The establishment of CSISS coincided with a period in the history of the social sciences when scholars from a wide range of disciplines were beginning to acknowledge the importance of space and time for providing context to observations. Space is increasingly seen as a means for organising knowledge, a basis for addressing and modelling fundamental social concepts (such as interaction, separation and connectivity) and as an element in evolving theory. Although objective measurement of underlying trends in scholarship is difficult, CSISS has collected statistics on the prevalence of spatial thinking in the literature, interest in its training workshops and activity on its website. All of these support the assertion that interest in space has grown and that funding initiatives from governments and foundations have had a significant impact on the ability of social scientists to make use of spatial thinking, tools and data (Goodchild 2004).

### *2.2.1 Modelling a Programme for National Dissemination*

Although the move to incorporate spatial methodologies had already begun prior to the founding of CSISS, advocates for spatial thinking in most social sciences were small in number. There was little evidence of spatially informed instruction at undergraduate levels and, with the exception of a few disciplines (e.g. archaeology, geography and planning), graduate programmes had not integrated spatial analysis into their training. Faced with the question of how best to present the case for spatial analysis in the social sciences, CSISS developed an operational strategy to advance spatial methods to a more central position across various social science communities. Figure 2.1 represents the programmatic model that guided CSISS deliberations and initiatives.

This model recognises the key role that space plays in human society and in the structuring of social processes. The CSISS strategy acknowledged that nearly every domain of the social and behavioural sciences could benefit from concepts of spatial thinking and from tools of spatial analysis. Hence, beginning with core themes in the literature of the social sciences and with evidence of applications in meeting societal needs, CSISS designed programmes to provide infrastructure to help scholars to add spatial context to the prevailing practices, applications and theories of their disciplines.

Table 2.1 and the paragraphs that follow outline this formulation, with examples of themes identified in the work of social scientists. They include an itemisation of spatial perspectives and tools of potential value in addressing research about these themes, list programmes organised to help promote the development of tools and expertise appropriate for the social sciences, and suggest anticipated outcomes for judging the success of CSISS programmes.



**Modelling a center for spatially integrated social science**

**Critical themes in the social sciences**

**+**

**Tools and concepts for spatial thinking**

**+**

**CSISS infrastructure programmes**

**=**

**Advances in spatial social science**

**Fig. 2.1** Modelling CSISS

#### 2.2.1.1 Themes

The thematic interests and theories intrinsic to the social sciences were the catalyst for establishing the kinds of spatial tools, concepts and programmes that would be of greatest service to researchers, instructors and practitioners. These themes span scales from the local (e.g. sense of place) to the global. They reflect needs that range from good description to prediction for promoting understanding and explanation of patterns of change and societal processes. They also touch upon all of the fundamentals for defining social wellbeing, including health, economy and political process. In addition, they reflect needs for methodological developments (e.g. risk assessment, flow data analysis and small-area analysis).

#### 2.2.1.2 Spatial Tools and Concepts

The primary tools featured in CSISS programmes and publications were geographical information systems and data visualisation technologies. Spatial statistics were treated in association with spatial econometrics and exploratory spatial data analysis and made use of such software packages as GeoDa (Rey and Anselin 2006) and Geographically Weighted Regression (Fotheringham, et al., 2002). Tools and concepts related to traditional spatial analytic concerns, such as optimisation methodologies and analyses of interaction matrices, were supplemented with social science applications of agent-based spatial models, Bayesian spatial analysis and remote sensing.

#### 2.2.1.3 CSISS Programmes

The key themes of social science research and the tools and concepts of spatial thinking were drawn together though a set of interrelated programmes of best-practice examples, web-accessible resources, training opportunities and expert meetings to push the development of applications and of new methodological tools.

**Table 2.1** Infrastructure programmes to promote spatial methods and thinking in the social sciences

Integrating social science themes and spatial tools through CSISS programmes to achieve desired outcomes

| Themes | + Spatial Concepts and Tools | + CSISS Programs | = Outcomes |
|---|---|---|---|
| Human–environment interactions | | | |
| International conflict | | | |
| Equity | Agent-based spatial modelling | Specialist meetings | New applications |
| Health and disease | Analytical cartography | | |
| Small-area analysis | Bayesian analysis | Workshops | Diffusion of spatial analysis |
| Cultural analysis | Dynamic visualisation | | New journals |
| Globalisation | | Tools development | |
| Risk assessment | Exploratory spatial data analysis | | New social science resources |
| Demographic processes | Flow data analysis | Best-practice publications | International conferences |
| Space-time accessibility | Geographical information systems | | |
| Governance | | Learning resources | Advances in theory |
| Community organisation | Location-allocation modelling | | |
| Externality effects | Point pattern analysis | Place-based search | New collaborations |
| Electoral processes | Remote sensing | | |
| Crime and law enforcement | Spatial econometrics | Internet portal (www.csiss.org) | New programmes for funding research and training |
| Sense of place | Spatial interaction modelling | | |
| Etc | Etc | | |

For example, CSISS-sponsored research-oriented specialist meetings drew participation from leading scholars in several fields to reflect on core issues in the social sciences. Eight separate meetings held in the period 2000–2005 engaged more than 220 leading scholars to explore gaps in knowledge and new potentials for spatial perspectives in science and planning.[2] They addressed traditional domains of social science inquiry (e.g. equity, risk analysis and health, spatial externalities in economics and globalisation) as well as new areas of investigation where spatial thinking and

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[2] See http://www.csiss.org/events/meetings/specialist.htm for information on CSISS specialist meetings.

technologies might add value (e.g. location-based services that exploit GPS and wireless technologies, and the application of time-geography concepts in transportation planning). They identified scientific agendas and workshop needs for young scholars, proposed learning resources essential to the diffusion of tools and concepts, initiated the creation of new spatial research tools and explored dissemination practices to reach potential users of spatial methods. Meeting participants also fostered collaborative networks and helped in the development of best-practice publications of exemplary social science applications (Anselin, et al., 2004; Goodchild and Janelle 2004a). All of these programmes are described in detail at www.csiss.org, but two programmes – the workshops and tools development – deserve special attention.

### Workshops

CSISS sponsored or cosponsored more than thirty intensive week-long or two-week-long residential workshops to introduce the latest and most authoritative approaches to the methods and tools of spatially integrated social science. Workshops help to advance cross-disciplinary collaborative networks among participants by stressing the commonality of the spatial perspective to problem identification and research approaches. The workshops were based on three distinctive but complementary strategies for national dissemination. The first was an integrative research strategy for workshops held in the years 2000–2004, which were devoted to meeting the immediate research needs of PhD candidates, postdoctoral students and untenured professors.[3] The second was a focused research strategy, exemplified by the 2005–2006 GIS and Population Science training programme (GISPopSci),[4] which targeted a large proportion of PhD students in a small discipline (demography). A third strategy was designed to address undergraduate instruction, as reflected in the 2004–2007 SPACE (Spatial Perspectives on Analysis for Curriculum Enhancement)[5] workshop programme. SPACE participants included undergraduate instructors from many disciplines who were committed to including spatial methods in their undergraduate teaching. All three strategies envisioned broad national dissemination through follow-up initiatives by participants (e.g. presentations to colleagues, research proposals, new courses and publications), all of whom were

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[3] See http://www.csiss.org/events/workshops for information on CSISS workshops.

[4] The GIS Training Program for Population Scientists, was directed by Stephen Matthews and funded through Pennsylvania State University's Population Research Institute by an award from the National Institute of Child Health and Human Development (NICHD, R25 HD047744-01). In cooperation with CSISS, this programme offered two-week long workshops at UC Santa Barbara and at Pennsylvania State University. See www.csiss.org/GISPopSci.

[5] SPACE (Spatial Perspectives for Analysis for Curriculum Enhancement; http://www.csiss.org/SPACE) was funded by NSF through the Curriculum, Course, and Laboratory Improvement – National Dissemination programme of the Division of Undergraduate Education (NSF DUE 0231263). It was hosted at the University of California, Santa Barbara and directed by Donald Janelle. Workshops were held at UCSB, Ohio State University, San Diego State University, San Francisco State University and the University of Oklahoma.

**Table 2.2** Workshops in GIS and Spatial Analysis by CSISS (2000–2007)

| Number of | Participants | Applicants |
|---|---|---|
| Anthropology/Archaeology | 59 | 123 |
| Criminology | 21 | 45 |
| Demography, Population and Health | 98 | 227 |
| Economics | 63 | 192 |
| Environmental Studies | 18 | 33 |
| Epidemiology | 11 | 27 |
| GIS | 30 | 75 |
| History | 7 | 10 |
| Human Geography | 123 | 422 |
| Political Science | 55 | 95 |
| Public Policy | 17 | 80 |
| Regional Science | 5 | 6 |
| Sociology | 115 | 200 |
| Statistics | 9 | 22 |
| Urban Studies/Planning | 44 | 133 |
| Other | 31 | 99 |
| Totals | 706 | 1789 |

selected on the basis of evidence of their success and potential as active researchers and dedicated teachers.

A total of 384 scholars participated in CSISS-sponsored workshops, another 324 benefited from workshops sponsored by CSISS through SPACE and GISPopSci, and several hundred more took part in CSISS-sponsored events at annual meetings of learned societies. These included special sessions and short workshops in association with many academic communities, including the Society for American Archaeology, the American Anthropological Association, the American Political Science Association, the Population Association of America, the American Society of Criminology, the Association of Social and Behavioural Scientists, the Association of Collegiate Schools of Planning, the Regional Science Association, the American Sociological Association, the Rural Sociology Society, the American Agricultural Economics Association, the Southern Demography Association, the Association of American Geographers, the Social Science History Association and the University Consortium for Geographic Information Science.

The disciplinary breadth of CSISS programmes is revealed by the diversity of associations mentioned in the previous paragraph. However, participation in residential workshops provides evidence of a significant commitment of academic energy by several hundred scholars from across the full range of social science disciplines and subfields (Table 2.2).

### Spatial Tools

From its inception, CSISS was committed to the development of spatial analytic tools to serve the needs of social scientists. Under the direction of Luc Anselin and his team of software developers at the University of Illinois, Urbana-Champaign

(UIUC), this effort resulted in the creation of *GeoDa*$^{\text{TM}}$, released in 2003 as a freely available and easy-to-use software package to analyse spatial data and to account for such geographical effects as spatial autocorrelation and spatial heterogeneity. Rey and Anselin (2006) review the development and utility of *GeoDa*. Complementing *GeoDa*, Anselin's team established a web-based clearinghouse on tools for spatial data analysis and established a website for accessing tutorials and sample datasets (Anselin 2005).[6] They also contributed to spatial analysis components for the open-source R statistical software package.

*GeoDa* offers an interactive environment of dynamically linked windows for displaying spatial data with maps, statistical and exploratory data graphics, and tables. Its value for the social science community resides in its convenient interface and use of standard ESRI shapefiles, its capabilities to combine multiple simultaneous visualisations (e.g. maps, 3D representations, cartograms and parallel-coordinate plots), and its facility for assessing spatial effects and for implementing spatial regression analyses. The drawing of scientific inference from form (e.g. locational patterns) to process (e.g. space-time patterns) is an ambition that social scientists have long pursued. Although not seamless in its execution, *GeoDa* facilitates this valuable reasoning process. Workshop programmes through CSISS, the UIUC Spatial Analysis Lab, the Arizona State University GeoDa Centre and the Inter-university Consortium for Political and Social Research (based at the University of Michigan) have featured *GeoD*a for spatial analysis in the social sciences. Through such programmes and through direct downloads of the software (more than 40,000 by mid 2009), the *GeoDa* user base has expanded beyond initial expectations across dozens of disciplines and several dozen countries. It is now widely used for research and teaching.

#### 2.2.1.4 Outcomes

Assessing the outcomes of CSISS programmes is complicated by the interactive and multiple efforts of many organisations (e.g. academic societies, businesses, foundations and government agencies), academic institutions and individuals, all of whom have shared in the task of disseminating new technologies and perspectives for scientific research and problem solving. Although important, CSISS is just one of many contributors to the development of tools and training programmes that have helped scholars with disciplinary theory and new applications. The efforts of several programmes (local, national and international in scope) have collectively built momentum for increased spatial awareness in science and society (Goodchild 2004).

Leading scholars from a range of disciplines have noted the heightened importance of spatial reasoning in transforming the fundamental understandings of the social sciences (see, for example, Knowles 2000; Lobao 2003; Colwell 2004; Butz and Torrey 2006; Voss, et al., 2006). In the United States, funding agencies, such as the National Science Foundation and the National Institutes of Health, have estab-

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[6] Resources on general spatial analysis tools are available at http://www.csiss.org/clearinghouse/; the specific resources in support of *GeoDa* are at http://geodacenter.asu.edu.

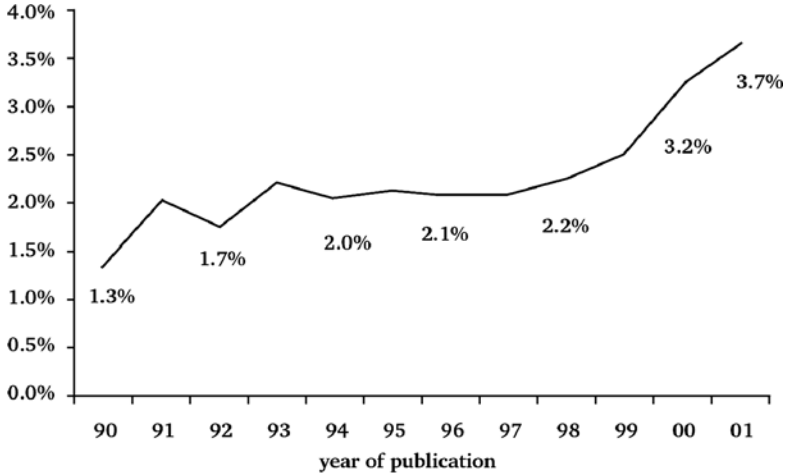

**Fig. 2.2** Percentage of social science articles with spatial analytic themes 1990–2001 (source: CSISS–see details at http://www.csiss.org/resources/litsearch.html)

lished priorities to promote uses of spatial analytic tools across a wide range of research themes. For example, the Human Spatial Dynamics funding programme of the National Science Foundation issued a call for proposals relating specifically to spatial social science.

A CSISS literature analysis revealed a sharp increase in the proportion of all social science journal articles using spatial methods dating from around 1998 (see Fig. 2.2). Nonetheless, the percentage of such articles remained small relative to the potential and it was not clear in 2001 that the ‘spatial turn’ in the social sciences had reached a point of self-sustained growth. Importantly, Wilson’s (2007) tally shows a continuation of the upward trend through 2005 in the use of spatial terminology in the titles and keywords of articles for social science journals.

Recent publications suggest that there is a growing momentum toward spatial social science. Journals in several disciplines have dedicated individual issues to exploring applications of GIS and spatial statistics, often arising from conferences attended by scholars form diverse disciplines and nationalities. Examples include *Social Science History* 24(3) (2000), *Agricultural Economics* 27(3) (2002), *Political Analysis* 10(3) (2002), *Political Geography* 21(2) (2002), *Proceedings of the National Academy of Sciences* 102(43) (2005) and the *American Journal of Preventive Medicine* 30(2) (2006). The 2008 launch of *Letters in Spatial and Resource Sciences* highlights the transdisciplinary and transnational nature of this transition and the need for an authoritative forum that can offer more rapid dissemination of research findings than traditional journals.

### 2.2.2 Documenting a ‘Spatial Turn’ in the Social Sciences

Special issues of journals, broad interdisciplinary participation in training programmes, new tools and easy access to spatial data all point to the momentum for a ‘spatial turn’ in the social sciences during the past decade. The establishment of the new Research Network in Spatially Integrated Social Science, funded by the Australian Research Council, and the new SPLINT (Spatial Literacy in Teaching) programme in the United Kingdom, are evidence of strong nodes of dissemination elsewhere in the world.[7] Of special importance are new programmes set up at individual universities to nurture awareness and integration of spatial perspectives in research. Examples in the United States include Harvard University’s Center for Geographic Analysis, Brown University’s initiative on Spatial Structures in the Social Sciences and the recent establishment of spatial@ucsb – a spatial studies centre dedicated to promoting spatial thinking in all branches of knowledge – at the University of California, Santa Barbara. Another example is the University of Redlands, a small liberal arts institution with strong ties to the Environmental Systems Research Institute (ESRI). It seeks to place spatial tools, such as GIS, into the curriculum for access by all students. In Europe the SPIN (spatial information) Laboratory, serving both the Faculty of Economics and the Faculty of Earth and Life Sciences at the Vrije Universiteit Amsterdam, stands out with its multidisciplinary orientation and the integration of research programmes with regional, national and continental planning issues.

The growing popularisation of spatial tools also feeds the growing interest in spatial methods and in skills for informed spatial reasoning. The use of maps in print and visual media, the spread of geographical positioning systems (GPS) and vehicle navigation systems, the easy access to map and satellite imagery via geobrowsers (e.g. Google Earth™ and Virtual Earth™) and web-based mapping tools all point to a growing need for spatial perspective and for broad concern for education in basic spatial literacy. The increasingly widespread adoption of Web 2.0 practices (e.g. geotagging of information in WikiMapia®, voluntary citizen input of photographs to Yahoo’s Flickr™, and other resources) reinforce these concerns. Against this background, a brief reflection on the CSISS programmes and strategies suggests lessons to consider in developing programmes to maintain the current momentum in the social sciences. Applications of these lessons may also encourage general spatial literacy for informed use of spatial tools embedded in the popular media.

## 2.3 Building Foundations for Spatial Thinking across Knowledge Domains – Lessons Learned

Although the roots of CSISS lie primarily within the discipline of geography and its links with the National Center for Geographic Information and Analysis (NCGIA), experiences since 2000 have exposed a much broader interdisciplinary interest in spatial methods. Out of this has come recognition of how the theoretical and thematic perspectives of diverse knowledge domains can contribute to and benefit from

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[7] Information on Australia’s Research Network in Spatially Integrated Social Science is provided at www.siss.edu.au; the SPLINT programme in the United Kingdom is described at http://www.le.ac.uk/cetl/splint.html and at http://www.casa.ucl.ac.uk/projects/projectDetail.asp?ID=66.

a more explicit focus on spatial thinking (Goodchild and Janelle 2004b). The lessons learned from the CSISS programme focus on the importance of diversity, leadership, action at local levels and the inclusion of fundamental spatial concepts in education.

### *2.3.1 Lesson One: Diversity as Strength*

The diversity of interest from across disciplines adds to the value of spatial thinking for formulating theories and solving problems. Strength through diversity is achievable when scientists and communities of all kinds have access to the latest tools to find, analyse and evaluate information. An array of tools and a breadth of data sources, accessible to both professionals and lay populations, are especially important in the realm of geographical information. Location (including concepts such as place, space and time-space) may be seen as the natural context for the integration of information across knowledge domains to solve problems. The importance of location as a framework for organising, searching and retrieving information on any topic is demonstrated by the remarkable growth in use of geobrowser technologies and by the functionality of geodigital libraries (e.g. the Alexandria Digital Library).[8] The dissemination of spatial analysis beyond its core disciplinary origins requires multiple strategies for diversifying the user base and expanding the range of training programmes to serve students, professionals and populations of varying skill sets and educational needs. For CSISS, these multiple strategies included workshops for both researchers and teachers, meetings between experts to explore new research directions, web access to resources, publications and the development of new analytic tools.

### *2.3.2 Lesson Two: Leadership*

Leadership in spatial thinking has its origins in different fields. Because of the importance of disciplinary structures in the administration of knowledge (and of academia), significant progress can be achieved if influential scholars within a field adopt leadership roles in the dissemination of spatial thinking and in the application of spatial tools. Using this leadership to form support networks that bring learners into contact with mentors can have a strong impact. In the dissemination efforts by CSISS, applications of spatial analysis by prominent representatives of specific disciplines were, in general, most persuasive in building support for spatial methodologies in specific research and teaching communities. Co-opting participants in training workshops and specialist research meetings as agents of dissemination is a very useful approach, providing it serves the participants and is valued by peers in their own disciplines.

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[8] See http://alexandria.ucsb.edu/.

### *2.3.3 Lesson Three: Embedding Spatial Thinking in General Education*

The experiences of working with several hundred participants in CSISS programmes and the findings of the National Research Council's report Learning to Think Spatially (NRC 2006) suggest a general need to address the absence of an explicit focus on skills in spatial reasoning in education at all levels. It is important to make the concepts of spatial thinking explicit and to provide illustrations of their applications. Examples should show how use of spatial thinking advances scientific understanding, facilitates problem solving in everyday life and fosters a deeper appreciation of the locational context of policy debates and conflicts at local, regional, national and international scales. CSISS programmes, especially its SPACE programme's focus on undergraduate instruction, viewed spatial thinking as a foundation for informed citizenship and for information analysis and assessment. A principal argument in support of such an initiative is that spatial perspectives offer a means of integrating theory within and across disciplines, and for matching theory with evidence. Spatial analysis can therefore provide a foundation for interdisciplinary cooperation, for example in seeking to understand the coupling of environmental and social processes in the study of planning problems at local and regional scales.

### *2.3.4 Lesson Four: Acting Locally*

Putting spatial thinking to use is achieved most easily and cogently by acting at the local level. Local context provides opportunities in teaching for students to explore problems of tangible interest in their daily lives, to build expertise in the uses of data and tools to answer questions of importance to the community, and to gain appreciation for the relevance of spatially informed decision making. It is also important to position the study of localised problems and phenomena within the context of broader regional and global issues, a process easily accommodated through the application of spatial concepts such as location, scale, neighbourhood and spatial dependence.

## 2.4 Foundation Concepts for Spatial Thinking – A Geospatial Perspective

The list that follows represents a consolidation of more than two dozen distinct spatial ideas discussed by de Smith, et al., (2006) into a constellation of eight primary concepts. An objective is to position concepts and their importance to scientific reasoning as the driving force for the selection and use of spatial tools. In arriving at this listing, the focus is on ideas that are demonstrable at all levels of space and time (from subatomic to galactic, from the past to the future and from microseconds to ions). In general, the concepts should be understandable to young children in the form of simple illustrations, but sufficiently engaging at the most advanced levels for thinking about scientific and social problems. Each should be expandable from a five-minute explanation to a lifetime career of research and application.

- *Location* – Understanding formal and informal methods of specifying ‘where’
- *Distance* – The ability to reason from knowledge of relative position
- *Network* – Understanding the importance of connections
- *Neighbourhood and Region* – Drawing inferences from spatial context
- *Scale* – Understanding spatial scale and its significance
- *Spatial Heterogeneity* – The implications of spatial variability
- *Spatial Dependence* – Understanding relationships across space
- *Objects and Fields* – Viewing phenomena as continuous in space-time or as discrete

Concepts such as those listed above have been a foundation for researchers for centuries, enhanced in recent decades through the use of computational and visualisation tools and vast and easily accessible information resources.[9] Such concepts and tools need to be as central to general education as reading, writing and arithmetic. In conjunction with the appropriate spatial tools, they provide a basic scaffold for designing research, solving problems and structuring education programmes. This is the intent behind a recent initiative at the University of California, Santa Barbara.

## 2.5 Transitioning to Spatial Thinking through spatial@ucsb

Drawing from its experience as the primary host for the National Center for Geographic Information and Analysis (NCGIA) and its core curriculum project in GIS, from the lessons learned in the CSISS programme and from inspiration provided in the National Research Council’s report Learning to Think Spatially (NRC 2006), the University of California, Santa Barbara launched spatial@ucsb in 2007. The mission of spatial@ucsb, a centre for spatial studies under the direction of Michael Goodchild, is to (1) facilitate the integration of spatial thinking into processes for learning and discovery in the natural, social and behavioural sciences, (2) promote excellence in engineering and applied sciences, and (3) enhance creativity in the arts and humanities. It goes beyond the focus on geospatial interests to integrate spatial thinking into the corpus of reasoning across all the domains of knowledge for research and teaching.

The centre is leading a campus-wide effort to frame curricula to equip UCSB graduates with concepts, methods and applications of spatial thinking appropriate to interdisciplinary and transdisciplinary communication, research collaboration and community need. This curriculum embrace the geospatial concepts listed above, but it also explores concepts (and tools) for spatial thinking in design fields and in

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[9] See http://teachspatial.org.

the humanities and arts. Examples include the link between form and function in architecture, the search for pattern in speech and text, the use of spatial notation in music, the use of spatial metaphor in the sciences and humanities, the importance of place in cultural and social studies, and the spatial elements of aesthetics in the visual arts.

The centre provides a web portal to curriculum and learning resources and a web forum for the exchange of ideas and training opportunities for researchers and students.[10] Like its predecessor organisations (NCGIA and CSISS), spatial@ucsb promotes research on new tools and applications of spatial thinking. It sponsors advanced research seminars, specialist meetings and workshops to serve UCSB academic needs and to help stimulate research based on national and international collaboration.

## 2.6 Conclusions

Appreciation of the relevance of spatial perspective in science is augmented by a growing level of expertise in spatial methodologies on university campuses and in business, public-sector agencies and community organisations. The extent of this shift and the breadth of its influence on different areas of knowledge create conditions suited to the kinds of curriculum changes envisioned in this chapter. This is especially the case in the emergence of academic leaders as potential allies who see the need to imbue science education with the powerful insights of the spatial perspective and to position spatial thinking as important (if not essential) to scientific understanding and to sound public policies. There is, however, a need to document these transitions more fully than is possible in this chapter. There is need for a systematic and more complete monitoring of trends in the literature, of software adoption and of general scientific interest in the importance of locational factors in understanding processes.

The application of geographical technologies and its effective integration with information and communication technologies has made significant inroads into most of the social sciences and into the medical sciences. Interest in the role of location and space as fundamental frameworks for accessing, analysing and processing information has intensified through the rapid dissemination of web-based technologies and through innovations for visualising intensities, associations and connections across information sets. New tools, such as GeoDa and Geographically Weighted Regression, have helped move analysis to a new plane of discovery, but, nonetheless, technical and methodological obstacles still impede optimum use of geographical technologies. For instance, van der Wel et al. (2007) note that traditional geoscience tools (such as GIS) are data driven and based on static and discrete layers of information. As such, they are not easily adapted to meet the needs of some knowledge domains that lie outside the geospatial sciences.

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[10] See www.spatial.ucsb.edu.

Technological enhancements for the integration of space-time data resources and for the analysis and display of longitudinal information are required to capture processes of scientific interest. As an ideal, one might envision capabilities for data analysis that match the current capabilities of agent-based spatial modelling and microsimulation to display space-time processes (Janelle 2005). Another possibility, following van der Wel et al. (2007), is to adopt aspects of meteorological modelling and visualisation for process-driven space-time displays.

In addition to the spatial concepts featured in Section 2.3, there is a need to accommodate other notions of spatial thinking – for instance, concepts of spatial cognition related to relative position, shape, size and orientation (Newcombe 2006). Moreover, if significant improvements in education are desired, support resources will need to be assembled, organised and made easily accessible, including exemplary course units, exercises and instruments for learning assessment. The value of achieving general spatial literacy is a goal worthy of such effort.

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# Chapter 3
# Location Awareness 2020: Addressing Auto-identification and Location in the 2020s

**Euro Beinat and John Steenbruggen**

## 3.1 Introduction

The rapid evolution of location technologies, wireless communication and sensors make it increasingly feasible to identify and locate any valuable resource or individual, wherever they may be, in real time. This capability underlines a fundamental development: we are becoming increasingly used to knowing the 'where' of people or things in a way that is similar to our general ability to know precise time. This has a vast potential for altering and improving business processes, such as logistics or the global supply chain, as well as public services, such as health care and transportation. At the same time, it provides a considerable opportunity for consumers and citizens in areas such as personal and family security, gaming and entertainment. The broad and deep variety of applications, combined with the intrinsic relationship to personal information, also raises critical issues, such as the impact on privacy.

Organisations that adopt these technologies are faced with some fundamental questions, which are in part typical of early-stage technologies, but which are magnified by the deep and pervasive implications of location and identification technologies and the 'internet of things'. How will organisations operate in a hyper-connected world? What will be the boundary between the inside and outside of an organisation change? How can the benefits and risks be assessed while there are large uncertainties about the technology and its acceptance? What does privacy mean when all information can be interrelated without individuals being aware of it?

This paper presents a scenario analysis that tries to address these issues. The work was originally carried out for the Dutch Directorate-General for Public Works and Water Management (Rijkwaterstaat in Dutch, or RWS). The mandate of RWS is to ensure the mobility of goods and people, accessibility to transport infrastructures

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and safety of transportation. RWS has found that location services can add value to its processes and make them faster and/or more efficient (Wagtendonk et al. 2005). The advances in travel management, vehicle and transportation technology mean that the core activities of RWS need to anticipate and adapt to technological innovations that shape the transport industry and information provision to travellers. Sensor-based environments, such as radio frequency identification (RFID), provide means to link the physical word (e.g. cars) and the virtual world (e.g. the IT infrastructure). They make it possible to manage, monitor and serve transportation in a much more sophisticated way. The speed of development of these technologies and services, and their disruptive nature, underlines a range of opportunities, but also highlights the need to map these developments over the long term, manage the change process and address fundamental challenges, including privacy and information control.

How should the organisation look at these developments and take the intrinsic long-term uncertainty into account when making investment decisions? How do these developments affect the organisation mandate and its scope of activities? Should the organisation simply adapt to market developments, or should it proactively influence how it evolves? Questions like these are at the core of any organisation that depends for its core activities on location and the identification of people or goods or things.

The study ‘Location Awareness 2020’ (Beinat et al. 2006) looks at the evolution of location aware technologies and services, and of their adoption, in year 2020. It provides a framework for addressing the uncertainty of long-term developments and an opportunity to strategically discuss the relationship between strategies and their future viability.

## 3.2 Location Awareness

Location-based services are context aware services, where the role of location is of primary importance for defining the context of the user and thus of the information services that can be provided to the user. Location awareness can be defined as the ability of individuals or machines to make decisions based on the awareness of present (past and possibly future) location of themselves and/or of the objects that have a bearing on the decision.

Location awareness may affect planning decisions, travel choices, allocation of mobile resources, inventory of firms, etc. The information systems that support location awareness are called ‘location aware systems’ and the information services that they provide are called ‘location-based services’.

In the recent past location awareness was limited by technology constraints. The only truly widespread and standardised location technology was satellite location, which is widely available but has a range of limitations, the most important being the failure of GPS location in indoor or covered environments. The emergence of sensor-based networks and commercial RFID solutions make it possible to address the ‘where’ in general terms, independently of the surrounding environment. It is now possible to locate a car with GPS, a person with a mobile phone, a parcel with an RFID tag and so on. In other words, technology is reaching the level of maturity that makes location and identification determination feasible – economically and technologically – in every environment and situation where it is useful for personal information management and business process support. Table 3.1 gives an overview of the areas of application and research for location awareness.

## 3.3 A Long-Term View on Location Awareness: Drivers and Trends for 2020

Location aware services clearly have a potential for improving business processes and public services. Even a superficial analysis of these services, however, makes it clear that their evolution cannot be addressed in technology terms alone. The ability to identify and locate essentially any asset, vehicle or even person has far-reaching implications for how we structure businesses, implement personal or homeland security, manage mobility or healthcare. The range of applications, combined with the concerns related to privacy management and dataveillance (Beinat et al. 2006) imply that the adoption, or otherwise, of automatic location and identification depends on business, social and lifestyle choices, as well as technology capabilities.

At the same time, the complexity of technology and social and economic developments, and the impact of these developments on the evolution of location awareness, makes it impossible to look at the future of location and sensor environments in terms of forecasts. The number of variables involved is prohibitively large and several trends are interrelated in ways that are only partly understood. It is important, therefore, to identify drivers (technology evolutions, societal changes, work conditions, etc.) and trends that shape the possible evolution of location awareness and cluster them into plausible ways to create multiple scenarios.

Scenarios are narratives of alternative environments in which today’s decisions may be played out. They are not predictions, nor are they strategies. They are hypotheses of different futures specifically designed to highlight the risks and opportunities involved in specific strategic issues (Ogilvy and Schwartz 2004). Scenarios are based on drivers: those underlying factors that set the pattern of events and determine outcomes in the environment and timescale being considered (to 2020). These are the elements that “move the plot of a scenario, that determine the story’s outcome” (Schwartz 1991). Drivers are identified from studies, reports, statistics and the input of key experts involved in research or business activities that shape the future of location awareness. Workshops, interviews, informal conversations, and also any other source of hints on the future, are used to identify the set of drivers that define the scenario workspace.

Table 3.2 illustrates the drivers detected in the LA2020 study (see Beinat et al. 2006 for a full description of these drivers). As an example, consider the driver ‘Attention for food quality’. The increased availability of information regarding

**Table 3.1** Location aware services and areas of application and research (adapted from Williams 2006)

| Area | Driver of the demand for Location Awareness | Application areas | Location technologies used | Issues |
|---|---|---|---|---|
| Business | Growth in mobile work<br>Need for constant communication and information<br>Demand for efficiency and lower operations costs<br>Demand for flexibility | Workforce management<br>Asset and resource tracking<br>Manufacturing management<br>Warehouse management<br>Transportation<br>Distribution chain<br>Healthcare | Satellite location<br>Network (telecom) based location<br>Wi-Fi and RFID | Uncertainty on ROI<br>Unclear adoption from market<br>Implementation costs<br>Maturity of technologies |
| Public sector | Public order and safety needs<br>Terrorism<br>Public health<br>Emergency services and disaster management | Emergency management<br>Staff coordination<br>Healthcare equipment, patient and staff location | Satellite location<br>Network (telecom) based location<br>Wi-Fi<br>RFID | Interoperability<br>Reliability<br>Quality of services<br>Maturity of technology<br>Uncertainty on ROI |
| Consumer | Personal safety and security concerns<br>Personalised services<br>Penetration of mobile handsets | Personal and family tracking<br>Personal safety<br>Healthcare<br>Navigation<br>Community and social networks | Satellite<br>Network (telecom) based location<br>Wi-Fi | Privacy<br>Fragmentation of technology offering<br>Interoperability<br>Quality of services and usability |
| Science, R&D and innovation studies | Increased use of sensor and sensor data<br>Development of sensor enabled infrastructures<br>Demand for new concepts for the internet of things<br>Attention to social dimensions of location awareness | Internet of things<br>Contextual awareness<br>Human-computer interaction studies<br>Logistics, transportation, healthcare, safety<br>Ethics, privacy | All standard technologies available | Debate on technology society is in its infancy<br>Lack of paradigms for issues such as privacy |

**Table 3.2** Drivers for the LA2020 study (see Beinat et al. 2006 for full details). The red drivers slow down adoption; green drivers facilitate adoption; blue drivers can work either way

| Technology drivers | Society drivers | Business drivers | Policy and regulation |
|---|---|---|---|
| True (data) mobility | Attention for food quality | Visibility in the global supply chain | Standardization of sensors, identification and location technologies |
| Availability of location as a standard feature of communications | Environment and global change, energy efficiency and energy sources | Data synchronization services | Emergency location mandate for telecom operators and VoIP |
| Electronics is embedded in clothes | Counter movements to the market economy | Mobile payments | Road and congestion charging |
| Electronics is embedded in cars and transportation infrastructures | Bottom-up information services, peer-to-peer and networked societies | Resource allocation and efficiency | Terrorism and global crime |
| Electronics is embedded in homes and appliances | Post-modern nomadism, individualism | Asset protection | eCall platform in Europe |
| Micro sensors collect essential field information | Privacy intrusion | ICT adoption by health care | Risk of epidemicson a global scale |
| Multiple overlapping location and identification systems are available | | Neo-productivity services such as presence, location, authentication, payment | Privacy laws and RFID regulation |
| The semantic web | Content availability and bottom-up services | | |
| | Mistrust for traditional institutions and organizations | | |

healthcare and the cause-effect links between diet, food, lifestyle and health has raised the awareness of citizens and has also triggered a demand for increased visibility and information regarding the quality of food and its source. Consumers increasingly require full and detailed information on the source, treatment and processing of food and its components, which requires the availability of food tracking throughout the global supply chain. Food and animal tagging is one of the areas where diffusion of end-to-end visibility is virtually complete in the next 10 to 15 years. This will be a driver for the development of inexpensive, reliable and pervasive ways of tagging animals and food products and track food from its source to the consumer.

Each driver points towards a specific direction of development as far as location and sensor services are concerned. It may facilitate or hamper the development, diffusion and adoption of these technologies. Trends are the result of sets of drivers that appear to identify a broad direction of development. A trend is a cluster of drivers which point towards a structural change that is important in defining a scenario.

Establishing a systematic understanding of the driving forces through clustering enables the exploration of interdependence and relations of causality among the drivers. The aim is to produce a set of clusters that will be internally coherent and separate from each other, although some driving forces may occur in more than one cluster (Van der Heijden 2002). The interdependence between drivers and trends is not necessarily linear, nor is there always a direct cause-effect relationship between a driver and a trend. The clustering is a logical exercise which aggregates drivers that together seem to pinpoint a certain evolution.

As an example, the *availability of intelligent infrastructures for public services, business and personal use* is a clear trend. Intelligent infrastructures, or smart spaces, are the result of the increasing ubiquity of computing and of the more widespread adoption of contextual services in business and personal life. Efficiency, security and safety are among the key drivers for the increasingly common availability of intelligent infrastructures. Typical areas where this is developed include:

- Transportation network, roads, railways, waterways for services like navigation, tracking, or road charging;
- Warehouses, for services like vehicle location and identification, automatic inventory management;
- Yards and hubs for distribution, for services like location of goods and wares, inventory management, supply management;
- Office spaces, for services like space utilisation, emergency management, people and resource location and presence;
- Museums, entertainment locations, for theft prevention, asset security, flow management, access control, people safety.

Other trends detected are:

- *Availability of personalised and auto-adaptive services*. Location and sensor services will enable the creation of systems that are more intelligent, personalised and user cantered.

- *Lifecycle visibility for goods and people are common*. The need to streamline the global supply chain, to facilitate global transactions and coordination, partnership, subcontracting and outsourcing are the reasons to implement lifecycle visibility (cradle-to-grave) for goods.
- *Public and business services require location and identification*. Essential services that require location and identification will probably include 112 emergency calls for all mobile and fixed calls, and the eCall mandate for vehicles and cars.
- *Virtual digital communities form important social structures*. The current trend towards the creation of communities linked by interest rather than geography will continue to the point that these communities become common social structures which to a certain extent define societies.
- *Governments regulate location and sensor services*. The intimate relation between location, identification and privacy raises concerns for the possible misuses of this information for surveillance, improper marketing and police activities. Governments will take action to protect citizens and introduce rules for preventing privacy intrusion.
- *Privacy-enhancing technologies and privacy services are available*. Privacy-enhancing technologies (PETs) provide solutions to some of the issues that may arise in the realm of privacy.
- *Dataveillance is a social concern*. In location and sensor services there is a visible concern about privacy protection and dataveillance. This concern may explode and impact the business, suppliers and users of RFID if major privacy incidents occur. It may also remain latent, balancing awareness of the pervasive nature of location and sensor systems with the good information available about them and the privacy protections in place.
- *IT, communication and sensors increasingly interoperate*. The deployment of location and sensor services will follow an arc similar to that of the internet. We should expect a proliferation of local systems (for example in hospitals, highways, stadiums, single industries, etc.) that support primary applications in areas where the added value of location and RFID is immediately visible and independent of the widespread standard-based adoption in other interrelated sectors.
- *Business and community values compete for development guidance*. Countries that want to grow and thrive in the 21st century are likely to look for ways of closing the income gap with the United States. A legitimate alternative view – a minority one, but one which is becoming increasingly vocal – is that of sociopolitical movements and NGOs that underscore the failure of market economy and global trade and stress environmental concerns, global change, unfair labour practices and social equity.

## 3.4 Scenarios for Location Awareness in Year 2020

Constructing scenarios from trends is the exercise of coherently combining trend outcomes into plausible sets which correspond to scenarios. Technically speaking, any combination of trend outcomes is a scenario, but most of these combinations

**Table 3.3** Scenario matrix and scenario names

| | Closed systems | Open Systems |
|---|---|---|
| Business drives | BIG BOYS<br>Closed systems: multiple competing standards, non-interoperable technologies, few large players<br>Business leads, individual values, economic and political liberalism, growth, materialism | FREE PLAY<br>Open systems: standardisation, ubiquity, interoperable systems, many players of all size<br>Business leads, individual values, economic and political liberalism, growth, materialism |
| Community drives | STEP ASIDE<br>Closed systems: multiple competing standards, non-interoperable technologies, few large players<br>Community leads, community ethics, social networks and responsibilities, cohesion, sustainability | SOCIAL TECH<br>Open tech: standardisation, ubiquity, interoperable systems, many players of all sizes<br>Community leads, community ethics, social networks and responsibilities, cohesion, sustainability |

are either very similar or logically inconsistent. Experience with scenario planning suggests limiting the number of scenarios to a handful of very different ones, which are able to shed light on plausible yet very different futures. It is common to base this exercise on the identification of the pair of trends that are believed to have the greatest effect in defining a scenario and the highest level of uncertainty regarding the potential outcome. The scenario matrix (Table 3.3) defines the four scenarios as combinations of the possible states of these two key trends –open vs. closed systems and "business drives" vs. "community drives". The extremes proposed capture the essence of a world in which each trend has progressed to its extreme, with all the other trends and drivers discounted. These other trends and drivers are then added to produce the general characteristics of each of the four possible scenarios as plausible and internally coherent stories (Van der Heijden 2002).

### 3.4.1 The Free Play Scenario

This scenario is dominated by a business culture and by the availability of sophisticated open technologies that support location and sensor services (and other IT). Location and sensor services are pervasive. They create opportunities for growth and the delivery of essential and sophisticated services, and form the basis for efficient global supply chains, as well as public order and safety organisations. There is a generally positive attitude towards innovation and smart technologies; the fear of their misuse has been dispelled by several years of growing adoption, open communication, lack of incidents and measurable benefits.

Citizens and business will find it difficult to access services or operate without adopting, actively or passively, sensor and location technologies. Passports and personal IDs will be tagged. Food, medicines and most goods come with auto-ID and location capabilities. Their use is safe under the widespread availability of privacy technologies, which ensure a high and reliable level of protection and especially a high level of control from the end user. Privacy management is a flourishing industry that is able to channel the latent concern about dataveillance into a business opportunity that satisfies the concerns of citizens.

Governments are important adopters of the technology for public order and safety, healthcare and homeland security. Governments do not interfere with business dynamics, and besides enforcing rules for fair play they leave the adoption of location and sensor services to the market. Worker rights with respect to location and sensor services are kept to the minimum to prevent clear abuse, but the task of finding an acceptable compromise is left to market players.

This scenario is compatible with high economic growth, globalisation and fierce competition. It is also compatible with a business-oriented attention to non-business themes, such as global change or equity, which are addressed by business instruments like trading or removal of labour barriers.

#### 3.4.1.1 Snapshots

- Speed limits on roads are dynamically adjusted to traffic and environmental conditions. Road charging is dynamic (price depends on the context of the transportation network). Advanced technologies permit charging for the use of the infrastructure, receiving compensation for not using the infrastructure and trading the right of using the infrastructure between users.
- Electronic patient dossiers and personal IDs are linked, thanks to wearable or implanted medical IDs.
- All cars are equipped with satellite navigation, RFID, a biometric key and electronic plate. Parking is paid automatically based on occupation of a parking space.
- Personal identification devices (integrated into mobile phones or worn in clothes) are common for business and family purposes, to be always contactable and to achieve a sense of security and connectedness with a community of choice.
- SGoogle (Semantic Google) is able to compile the biography of a person, a specific car, building, sports club, etc. just by entering the name.
- Privacy banks serve consumers who wish to coordinate and track their privacy transactions and maintain a full overview of their privacy account.
- Consumers can verify the history of a food item by typing in the electronic product code (EPC) of the item on the shop’s website.
- Major funds are released by the EC to universities and laboratories working on the concept of ‘One-ID’, a unique and universal code for all living and material ‘items’.

## *3.4.2 The Step Aside Scenario*

This scenario is characterised by a diffuse perception that social concerns should prevail over plain business needs, and by the realisation that this is not taking place effectively. Free market forces have taken advantage of the ambiguous position taken by governments on trade, competition and liberalisation to create strong positions in various economic sectors, such as retail, healthcare, automotive and infrastructure. In this scenario social priorities are out of step with the economic sector.

The public sector takes a hands-on approach to privacy protection and enforces measures that slow down or prevent some applications and services. Nonetheless, governments are unable to fully represent and interpret the mood of society, and unable to counterbalance the dynamics of major players. This leaves space for a strong following for NGOs, which replaces political representation to some extent and counterbalances the strength of economic players.

The conditions are created for the adoption of location and sensor services only in selected environments and for specific services, such as services of clear public interest (emergencies, road charging, pollution control). At the same time, players that lead in some business areas adopt these technologies to foster their bottom line, but create islands of adoption, possibly using proprietary implementations that optimise results without the overhead of open standards.

The level of adoption of location and sensor services is high but fragmented. This is similar in other IT domains and the development of digital communities is somewhat hampered by technology walls, although widespread as a community glue.

Dataveillance is not a major concern. Technology limitations make it difficult to profile individuals efficiently. Combined with the strong government hand in regulating the handling of personal information, this reduces the chance and the incentive of privacy intrusion.

This scenario is compatible with medium/high, but unbalanced, economic growth, with globalisation in some sectors and regionalisation in others. It is compatible with a strong attention to themes such as global change and equity, although these are poorly reflected in the structure of the business economy. This creates a situation of unrest and tension which does not favour innovation.

### 3.4.2.1 Snapshots

- Telecom operators have acquired the right to provide advanced commercial Galileo services (level 3) on an exclusive basis.
- Profiling of consumer habits is prohibited by law.
- China adopts its own universal EPC system, to which western countries need to adhere to do business with the Far East.
- Congestion/road charging is adopted in major cities and on motorways; the rest of the network is not covered.

- NGOs have successfully launched ‘tag-free’ shopping centres, becoming a retail power for the opt-out community.
- Legislation imposes the ‘kill’ feature in RFID tags, to deactivate them after purchase.
- A consortium of European universities has established the ‘Zero Tagging Initiative’ to spread and stimulate the science of untagged economies and the benefits of alternative tools.

### *3.4.3 The Social Tech Scenario*

This scenario describes a society with attention to community topics, such as social inclusion and sustainability, in a high-tech world where IT plays a major role in economic development and service provision.

Location and sensor services, as well as other IT devices, are highly standardised and interoperable. The IT industry is dynamic, innovative and accommodates large players and a wide spectrum of small enterprises that rapidly gain visibility for providing innovative services.

In this context, both industry and government play an important role and business factors in the need to account for non-trade issues, such as sustainability, social inclusion and protection of the individual. Innovative location and sensor services are widely adopted and used, but their introduction and evolution is strongly supervised, and sometimes limited, by the public sector for ethical or precautionary reasons. This impacts the diffusion of location and sensor services adopted by industries and the public sector in areas where the balance between benefits and business/social costs are clearly favourable.

The space for a market for privacy services is limited because of the heavy intervention of the public sector in this area, supported by strong NGOs and public opinion. Dataveillance is nonetheless a hot topic because public opinion recognises the availability of sophisticated interoperable technology which is kept at bay by regulation. This cap is by definition unstable and the possibilities of technology are such that it is virtually impossible to completely avoid free riders and unwanted exploitations.

At the same time, communities and services based on the ability to mesh a variety of content sources create entertainment, cultural and social digital communities, becoming a fundamental source of socialisation and also education and service provision. The availability of open source RFID marks a departure from industry supported standards and allows even very small players to adopt very sophisticated technologies.

This scenario is compatible with medium/high economic growth, with an emphasis on innovation rather than globalisation, reduced dependence on fossil fuels and environmental sustainability. It is compatible with strong attention to themes such as global change and equity, which are addressed with a positive attitude towards the possibilities of technology and the solutions that it may offer. This creates a positive, but selective, perspective on innovation, and in particular those innovations that foster community and social values.

#### 3.4.3.1 Snapshots

- Human auto-ID and chip implantation is prohibited by law.
- Open source RFID is available: ‘Open EPC Global’ is available free of cost, based on peer-to-peer designs and managed by the Open EPC Global Foundation.
- Venture capital investment in location and identification technologies exceeds that of biotechnologies.
- The London School of Economics launches the faculty of ‘Sociology for the Internet of Things’, the first global research and education centre for addressing the social dimension of seamless visibility for people and things.
- Lyon adopts the first city-wide ID and emergency chip service. A small, standardised card extension to mobile phones that provides authenticated access to all public spaces, most entertainment venues and all public transport, including payment.
- Wall Mart has institutionalised the position of a consumer representative, co-selected together with consumer organisations, in the executive board of directors.
- National Authorities supervise the use and collection of location and RFID data: they audit operations and may stop businesses on the grounds of threats of privacy violation.
- Cars are equipped with ‘envirometers’ that measure environmental impact in addition to consumption and speed, based on location and external information provided by the network.
- Road use is charged per kilometre travelled with rates changing during the day, depending on traffic conditions.
- Dataveillance stories are common on the evening news, together with environmental issues and cooperation with developing countries.
- Digital ‘communes’ share information and whereabouts between members to create global digital cohabitation experiences.

### *3.4.4 The Big Boys Scenario*

This is a scenario in which the economy is dominated by large multinational players which have a strong degree of control over several sectors of the economy. The attitude towards these players is not negative and a general business attitude permeates society. Business needs are the main drivers for adopting location and sensor technologies.

Governments take a largely hands-off approach to the constraints on or incentives to innovation, without the ability or mandate to compensate for the strong role of business players. Privacy regulations are limited to basic prescriptions.

This unbalanced division of power results in many ‘walled-garden’ service offerings and many diverse devices serving different needs and managed by different players in a maze of subscriptions and commercial offers.

Governments, on the other hand, are heavy users of location and identification technologies for security and emergency services. Governments have a strong position in these areas, partly to ensure that business and economic activities can flourish even under the permanent threat of terrorism or criminality. Security needs have pushed governments towards measures that limit personal freedom and allow the collection of large amounts of personal information on the grounds of safety needs. Although privacy concerns are widespread, there is also a common understanding that these measures are necessary and thus acceptable.

Public services are regularly outsourced to commercial players, from transportation to healthcare or justice on grounds of better efficiency. This has created powerful business conglomerates that heavily influence the speed and type of innovation. Small companies thrive in the business culture, but face difficulties as soon as they start competing with the dominant players, making it difficult for small players to emerge.

Dataveillance is a major concern. The realisation that few players have a large degree of influence over the handling of personal information, and that governments exploit identification and location technologies for prevention purposes, is a source of concern for citizens, who regularly use privacy enhancing technologies to counterbalance the threat.

This scenario is compatible with medium/high economic growth, with an emphasis on corporate business. Large social inequalities are normal in this context, and plain business practices are regarded as an appropriate social glue. This scenario is also compatible with a strong attention to growth, liberalisation and thin government, without much attention to issues such as social inclusion or environmental aspects. This creates a positive attitude towards innovation and technology in general, but mainly as a means to serve the interests of big players or security.

#### 3.4.4.1 Snapshots

- Berlin and Copenhagen have decided to adopt road charging based on the Road+ system. Five major competing systems are currently available and adopted in cities across Europe.
- The RPI Show (Real Privacy Intrusion Show) on EuropeTV, also known as the ‘Orwell show’, is a major success. Movies, clips, tracks and stories of privacy intrusion provided by people are collated together into ‘horror’ stories.
- All transit passengers at Amsterdam airport must carry an electronic ID that contains full biometrics. Each passenger is allocated a risk score computed from a synthesis of information from thousands of public and private sources worldwide. Passengers with a score lower than 54 are not allowed on board.
- The VU University Amsterdam has patented its full portfolio of RFID and location awareness studies and licenses them to governments and corporations in exchange for funding research on RFID and location awareness.

## 3.5 The Implications for Science and Research

There are several implications for science emerging from this scenario analysis. At the most direct level, scenarios can address the direction of scientific research, leading it into areas that appear to be particularly fertile for conceptualisations and/or further development. Scenarios are used to stimulate ‘strategic conversation’, but also to assess the robustness of strategic choices. A robust strategy is one that delivers its goals within more than one scenario, and as such is less sensitive to a scenario assumption or setup. The same can be applied to research: scenarios can indicate those areas where research will necessarily accompany the development of a certain scenario. Some research areas do appear to have a more fundamental impact on all scenarios and are therefore ‘robust’ and will be essential in any of the scenarios.

The adoption of location and identification is based on factors that are only in part influenced by single industries or applications. For this reason it is essential to understand the key drivers and trends, and their interplay, if we are to understanding the directions of development without forcing unreliable predictions. This is not a one-off exercise. It should be a continuous effort to map the un-mapped, understanding the signals that may direct the future in one way or another. The science of scenario building is well developed, but there is vast amount of research that could improve the foundation, theoretical basis and applicability of methods. Improving these methods would be a necessary step to facilitate their general use and to facilitate the institutionalisation of future-testing public and private strategies.

Technology for location and identification will simply become available. The phenomenon appears to be driven by a ‘gravitation force’, something that can be resisted or deflected, but not stopped. The usefulness of the internet-of-things infrastructures will grow with the ubiquity of subinfrastructures, while their marginal adoption costs will decrease correspondingly. As an example, the London congestion charging system is an island of adoption which, in spite of its positive results, is very expensive to maintain and is suboptimal in terms of IT because of its isolation. If the same system were to be adopted by other cities or for other purposes, then the overall exploitation costs would rapidly decrease and the overhead on single users or city administrations would be very low. This suggests the need for strong coordination at the early adoption stages between multiple cities or road infrastructure managers. Research into standardisation can play a major role in this respect.

The ubiquity of the location and identification infrastructures raises the spectrum of information control and dataveillance. The amount and detail of information available will be a formidable incentive for business and governments to exploit it for purposes different from the original one. The scenarios above indicate that this may unfold in terms of a managed concern or a full blown opposition, but also that addressing the dataveillance concern cannot follow a ‘retrofitting’ approach, but must be considered as a design aspect of the new internet-of-things infrastructure. Failure to do so may raise privacy and information control objections so strong as to put off or stall deployment, even in areas where their usefulness and necessity is unquestioned. The scenario study clearly addressed a major lack of understanding of the full spectrum of the privacy aspects linked to identification and location.

While there is a vast amount of pseudoscientific literature, there is nothing close to a coherent framework to address the concerns, risks and threats of privacy linked to the hyperconnectivity implicit in the internet of things. Research in these areas need to address the foundations of privacy, the philosophical issues of real-time visibility, the balance between benefits and threats, and the legal and organisations dimensions of privacy.

The scenarios have implicitly raised the necessity of addressing the medium- and long-term future of location awareness technologies and applications in education. While there is a wealth of courses dedicated to RFID, radio engineering, location-based services, IT standardisation and the like, there is a major educational gap in addressing the overall impact of ubiquitous and silent computing in business and society. For this multidisciplinary approach it is essential that the science of the internet of things evolves into a discipline where technology, economics, innovation and philosophy meet. There is a clear difficulty implicit in the extremely broad range of disciplines involved. Nonetheless, it is a matter of fact that location awareness is not just a technology domain. It is a domain that affects all aspects of business and personal life, and as such a range of areas need to be simultaneously considered in education as well. This can also offer universities and schools a spectrum of options for differentiating and offering very relevant studies, which will certainly appeal to many students fascinated, and at the same time frightened, by the growing digitalisation of societies. Themes like this one will probably rank high in education popularity, perhaps in the same range as climate change, renewable energy or the economics of globalisation.

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# Chapter 4
# Visualising Landscapes: Do Pictures Represent Theory or Data?

Chunglin Kwa, Mieke van Hemert and Lieuwe van der Weij

## 4.1 Introduction

Scientists have ambivalent feelings about pictures of landscapes. Take for example a picture of an estuary, obtained by remote sensing, that depicts in various shades of blue and black the mixture of warm and cold water, or water with different degrees of salinity. Geographers would be ready to point out that such a picture is 'merely a pretty picture', effective in communicating research to lay or policy audiences, but not much else. Numbers and equations are the real thing, and they hide behind the pixels which make up the picture. What is really interesting is what cannot readily be seen in the picture: quantitative relationships between variables attached to the pixels. Geographers and ecologists are aware of the fact that pictures obtained by remote sensing are not straightforward renderings of the landscape like ordinary photographic pictures. Remote sensing pictures, despite their mimetic and aesthetic appearance, should be seen as measurements processed by various modelling procedures. The models are more interesting than the pictures, scientists would argue.

In this chapter, we argue that the aesthetic features of landscape pictures play a role in many stages of research in geography and landscape ecology. They have served (and continue to serve) to define the object of investigation. In this sense, pictures contain 'theory' as much as they represent data. The same is true for ordinary black and white photographs. During an important stage in the development of landscape ecology, aerial photographs were 'data', too, similar in some degree to the way electron microscope pictures served cell biology. And yet, interpretation is never far away when viewing photographs; one has to know what to look for in order to see patterns. We will argue in this paper that the ability to discern patterns is dependent on the availability of two historically formed Gestalts: the holistic and the fragmented landscape.

In a second stage of the argument, we will argue that Gestalts offer scientists two subsequent options. The first, which is always taken, is that Gestalts are at the

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beginning of a road towards increasing mathematisation. In many cases, a first step on this road is diagrammatic reduction. In philosophical language, derived from the work of Edmund Husserl, eidetic images are formed. The Greek word *eidos* means form, shape or pattern, with more than a hint of essence to it. According to Husserl, a Gestalt is an important sense already mathematised because of its links with (geometric) space, time and causality (Husserl 1953). The object is approached from the angle which gives maximum possibilities to use already available geometric features. In the process of transforming a photographic picture into a diagram, unnecessary details are discarded; background is filtered away. When eidetic images appear on paper they usually feature clear line drawing. Such a drawing may be developed into a 'model', a drawing which is yet further generalised (Lynch 1990), and geometrisation is a further step on this road. To Husserl, to grasp an *eidos* is to grasp the essential mathematical nature of the object under investigation.

A second option, however, is kept open when not only images-as-data but also their subsequent mathematical treatment is sufficiently rich to produce images (usually through model simulations) which allow for a 'reality check'. By themselves, visualisations of model results are highly eidetic: they are representations of hydrological and ecological theory as much as they are representations of empirical data. But researchers visualise simulation results in order to test a mathematical model for realistic behaviour. Apparently, images enable a qualitative understanding of a system which mere mathematics does not. The qualities of these images do not revolve around geometric abstraction, but rather, in an opposite way, show the unforeseen. Inspecting images for unexpected outcomes can be seen as a form of 'de-mathematisation', in other words, following Husserl's route in the reverse direction.

Art historian Barbara Maria Stafford compares medical illustrations made at the end of the 18th century favourably with the neo-classicist style prevalent at that time and exemplified in the silhouettes drawn by Johann Caspar Lavater. She says that these silhouettes gave a "reductive image of the body … imprisoned in a geometrical grid" and that neoclassicism did not promote thick description, but codification (Stafford 1991, 103). Neoclassicism was a style in art with neo-Platonist leanings, going for essence rather than appearance and depth rather than surface. In contrast, anatomical drawings had something baroque to them. An appreciation of the many details of the body guided the tactile sensuousness of the hand holding the scalpel.

Stafford subsequently extended her argument to visual information in general. There are two sorts of information, one lending itself to integrative abstraction, the other to establishing linkages. The first merges or collapses individual characteristics and processes. The second connects separate entities into inventive arrangements and allows us to discover meaningful relationships between incongruous objects (Stafford 1996, 73–4).

Likewise, there are two forms of 'reality check'. One is to check the behaviour of a simulated parameter, an 'essential parameter', against reality by taking a measurement. It is quite a different form of reality check to discover in the visual display of a simulated model run that something strange is happening, that some parameters behave in a strange and 'unrealistic' way. To use constructed pictures in this way is a form of demathematisation.

This article, then, takes issue with Husserl's understanding of a Gestalt as an already mathematised notion. While it is certainly possible to treat a Gestalt in this manner, and accordingly to reduce 'fullness' (Husserl's *Füllen*, the *sinnliche Qualitäten*) to the presupposed essence of a Gestalt, it also appears to be possible to have oneself redirected to richer forms of reality.

## 4.2 Landscape

The concept of landscape, as used by ecologists and geographers, differs in an important way from the lay concept of the natural landscape. The latter retains many visual connotations and very often it is loosely understood as a natural landscape as it can be apprehended by a viewer. The scientific landscape is dominated by systematic connotations. One of the very earliest scientific definitions of landscape was given in 1850 by the German geographer K. Rosenkranz: "Landscapes are relative wholes, stepwise integrated local systems of factors comprising all realms of nature" (Schmithüsen 1973, 169). However, the difference between the scientific and the lay concept should not be overestimated. They are like two sides of a coin, finding their common origin in Alexander von Humboldt's development of the concept of the natural landscape from the painterly landscape. Before Humboldt (i.e. prior to 1800), the word 'landscape' referred to a specific genre of paintings and was only occasionally used metaphorically to designate a piece of land which had the looks of 'a landscape' (Kwa 2005). Humboldt argued against the biogeographers of his day that similarities in terms of the ratio between plant genuses, for instance in characterising the grasslands of Europe and America, were more important than the differences in terms of species present. To drive his point home, Humboldt invited his readers to look at the paintings by Jacob Ruisdael and other, mostly Dutch, painters of the 17th century. He drew attention to how Ruisdael made the foliage of different trees blend together. The skilful rendering of some details while omitting others suggested a whole with distinct 'elements of mass and magnitude' (Humboldt 1807). Humboldt convinced his readers that the composition of a landscape brought forward the individuality of a certain plant district. 'Landscape', when understood as a natural landscape, is in fact a metaphor.

The obvious question is whether Ruisdael, Frans Post, Nicolas Poussin and others had depicted real existing landscapes. The answer is no. Landscapes were composed in the studio, usually by bringing together in one composition four to six landscape elements. For some of the elements, studies had been made in the form of drawings, other elements were copied from other painters. Topographical accuracy was not aimed at, but painters and viewers did appreciate 'naturalness'. It is impossible to look into the minds of 17th century painters, but we may reasonably surmise that a mental concept of 'landscape' as something out there in nature did not exist. Humboldt's discovery of the natural landscape would not have been possible without the Romantic movement of which he was part. Humboldt and his contemporaries saw unities, 'systems' in today's parlance, where previously there were none. The existence of wholes was not a gratuitous assumption by Humboldt. He saw them produced by the social relationships between species of very different kinds, forming associations. Associations as such were not visualised by Humboldt; they were of a more abstract nature.

Humboldt did not formalise the typical painterly view of landscapes into Gestalt-like diagrams, and neither were diagrammatic representations developed by Humboldt's students. Ecologists did not produce formal analyses of visual material. The schematic representation of a transect or a forest profile comes closest to the landscape-as-painting, but they have not been subjected to further formalisation either.

Only in a very loose sense may we call a Gestalt the depiction of a landscape as seen by a viewer who is standing erect on the ground. It was popular among tourists in the 19th century to hold up a frame with delicately coloured glass and thus produce a ready-made 'landscape'. We believe that the lay mental image of 'landscape' is different from 'panorama', which, according to dictionary definitions, is either more wide-angled than a 'landscape' or has a higher vantage point, producing a typically oblique view of the land.

The conceptual significance of the lay image of landscape for science is very weak, if it exists at all. Geographers and ecologists can do without it. Theirs is a systems conception of landscape, the idea of which was developed especially in the period from the 1930s to the 1970s, from Arthur Tansley to Eugene Odum. The familiar systems diagrams depict functional relationships between compartments, for example between producers and consumers, identified on the basis of their function with regard to energy flow within the system. The systems ecological models of the 1960s and early 1970s achieved a dramatic reduction of complexity by attempting to show that ecosystems with up to 120 state variables and more than 1,000 parameters could function in a predictable homeostatic manner, on the basis of an analogy with cybernetic systems.

After the termination of the International Biological Programme (IBP) in 1976, during which several very big systems ecological models had been developed, several modellers previously active in the IBP raised various objections to the models. Compartmental models were seen as unable to account for critical differences between species within a compartment. Moreover, the models treated ecosystems as homogeneous areas without spatial differentiation, and they had no concept of temporal discontinuities within the ecosystem either. The systems ecological models were criticised for being 'point models', as if functional relationships in one 'point' of a biome or landscape could explain the functioning of the system as a whole (Kwa 1993). In essence, the systems ecological models had successfully mathematised an abstract notion of what is a 'system'. They were abandoned, not because they could not stand up to empirical verification, but because they were being compared to a richer notion of what an ecosystem or a landscape was.

## 4.3 Ecotope

The ecotope (in Anglo-Saxon literature often called ‘landscape element’ or, alternatively, patches and corridors) was a chance discovery made in the 1920s (the word ‘ecotope’ was coined in the 1930s). Ecotopes were found to be present on photographs taken from the air, a practice which itself derived from reconnaissance activities during World War One. A fairly small group of workers, comprised of geographers and ecologists then started to use aerial photography as regular data-input in their work.

Within ecology, and perhaps to a lesser extent within geography too, this was fairly unique. One would expect that the advent of photography would have given ecology an important means of investigation. Frederic Clements (1905) had instructed ecologists in the use of photography, but even he fell short of applying what he taught. In practice, photographic pictures were used only to illustrate what had been ascertained by sampling and counting. No ecologist used photographic pictures as data. A case in point are the associations of the French-Swiss school. They are supposed to be identified on the basis of the written field notes or the relevé of a certain number of plots or quadrats, even though the latter may be selected by visual inspection for their homogeneity. When photographs occur in publications, they may show a certain association named in its caption, but the association is never identified from a photographic picture.

In sharp contrast, the ecotope did not exist before aerial photography. The unit was discovered independently by several researchers in the 1920s, and accordingly received a host of different names: sites, landscape cells, unit areas and tiles (German: *Fliesse*). Carl Troll (1939), a German geographer, argued that all these names referred to a single entity, the “smallest unit of landscape”, and in 1950 he renamed it ‘ecotope’. Although this term is still in use, more recently other terms have been proposed as well, such as land unit (Zonneveld 1989) and patches and corridors (Forman 1982). The physical basis for identifying these units is that they can be readily found on pictures on scales between 1:10,000 and 1:25,000.

Stereoscope viewing of two pictures taken consecutively from an airplane during its flight above the landscape made it easier to distinguish between different ecotopes. As Zonneveld (1989, 76) points out, drainage patterns and relief can be observed only on stereo images. The ability to distinguish between ecotopes was taught at institutions such as the International Institute for Aerial Survey and Earth Sciences (ITC) in Enschede, the Netherlands, and geography departments around the world. Interestingly, black-and-white photography remained standard long after the development of colour photography (Fig. 4.1).

The typical mosaic landscape consisting of ecotopes may well be called a Gestalt. Produced by the aerial photograph, it was backed up by the older panoramic view of the landscape as it can be obtained from bell towers and mountains, from which anthropogenic landscapes can be seen. Indeed, part of the attractiveness of the concept of ecotope is that it apparently corresponds with land units known since the Middle Ages, such as cultivated fields with hedgerows and pastures with wooded banks.

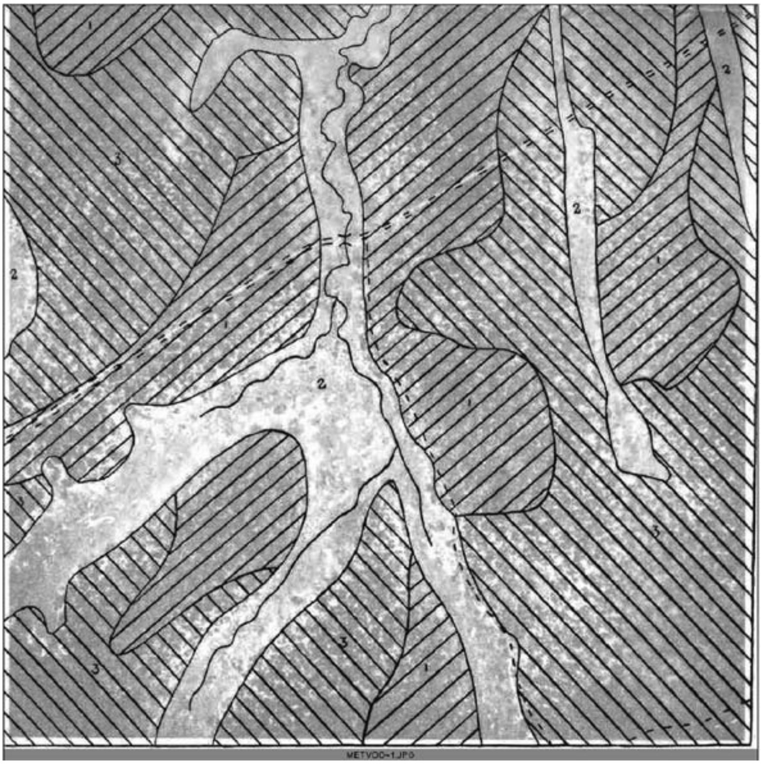

**Fig. 4.1** An aerial picture made by R. Bourne in Rhodesia, diagrammatised by Carl Troll (Troll, 1966, Tafel IX/Bild 11)

The ecotope was shown to exist in natural landscapes as well, and have roughly the same size as in anthropogenic landscapes. Troll advanced the hypothesis that this was no coincidence: old anthropogenic landscapes followed the ecotope pattern of the natural landscape. Ecotopes acquired further practical significance when they were identified with, for instance, functional habitat types. In general, the concept of ecotope proved to be useful in several disciplines, enabling interdisciplinary cooperation.

The ecotope Gestalt differs markedly from the Humboldtian landscape Gestalt: the latter is a unified landscape, the former is fragmented. The systems ecological perspectives on natural ecosystems followed the Humboldtian logic, emphasising functional relationships within an ecosystem, including ecosystems of roughly the size of landscapes. Systems ecological models treated the landscape as one integrated whole, usually at the price of ignoring spatial heterogeneity within the landscape.

Landscape ecologists who were committed to both the ecotope and the systems view of the landscape have tried to identify the functional relationships of systems ecology with chorological relationships, or the ‘horizontal’ relationships between different ecotopes, such as the transportation of mineral-rich water from one landscape unit to another (Zonneveld 1989, 72). While Zonneveld made no claim that these chorological relationships could carry the full burden of systems ecological theory, such a claim is implicitly present in the landscape ecology of Richard Forman and Michel Godron (1986, 454). They present another example in which the basic system ecological questioning, the search for mechanisms leading to 'stability' of ecological systems, was recast in the language and the pictorial conventions of spatially heterogeneous landscapes.

In principle, spatially identifiable landscape cells, patches or ecotopes, may take over the role of the more abstractly conceived 'compartments' of the older systems ecology. In this context, we might notice that already the ecotope of aerial photography allowed for diagrammatic reduction. Troll drew lines around individual ecotopes, separating not only savannah from forest but also distinguishing between different types of forest.

Nevertheless, landscape ecology has tackled a richer set of questions than the ones centred on stability. From the 1980s on, the landscape-as-mosaic received further backing from ecologists combining systems ecological and populational perspectives. Daniel Botkin (1993) and Herman H. (Hank) Shugart (1998) developed 'gap models' of forests starting out from the observation that when a large tree falls down, creating a 'gap' in a forest, it is not usually replaced by a tree from the same species. The gaps, being of the size of a large tree crown, are noticeably smaller that ecotopes. But generalising on gaps, Shugart made the observation that "when viewed at an altitude of one or a few kilometres, most terrestrial ecosystems are noticeably patchy" (Shugart 1998, 178).

Neither Shugart nor Botkin came from a tradition that had used visual material as an input to research, but from 1986 on they used visual material obtained from remote sensing as data to feed into their landscape models. Through their work, and the work of many others, the ecotope and related concepts has received a far wider application than they had ever had during the decades of black-and-white photography. But the ecotope would change in an important sense.

## 4.4 The Digital Ecotope

Ecotopes cannot be derived as naturally from remote sensing data (whether from satellites or airborne) as they once did from aerial photographs. Imaging techniques such as multispectral scanning use electronic means for recording data (on heat emission by the earth's surface). The data, presented as pixels on a two-dimensional surface, are not ready for visual interpretation in their recorded state. In common parlance, they need to be 'digitally enhanced'.

A variety of techniques to pre-process the images are available, such as software programs for pattern recognition like Imagine or eCognition, commercial products which are also used for the processing of MRI brain scans. To monitor floodplain vegetation, river researchers at the Analytical Chemistry department (University of Nijmegen) and Geography department (University of Utrecht) in the Netherlands, use multispectral images to distinguish between forested areas, grasslands, shrubs, bare soil and water. These areas have different ‘spectral signatures’ and are recognised as different ‘objects’ through segmentation by eCognition, but come out clearly only after some tinkering.

Apart from using available programs, such as those mentioned above, the Nijmegen researchers are involved in developing new density-based clustering methods to classify (pixel) datasets, and through this and other mathematical techniques to improve upon the production of maps of riverine areas which are used by Rijkswaterstaat (the Dutch government Directorate for Public Works and Water Management) to manage both natural reserves and control changing land use.

According to the researchers involved, remote sensing data are reliable and cheap, but ‘teaching the computer how to see’ is the most difficult and time-consuming step in the process. Automatisation of ecotope recognition is the ultimate aim, but in discussing the pros and cons of different approaches Rijkswaterstaat notes that “automated procedures have in common that it is problematic to meet the level of quality attained by visual interpretation” (Brügelmann 2004). The computer has to be instructed to discard too finely grained differences between pixels and cluster the data into homogeneous and well separated groups so that a forest appears as one forest area or, when the need arises, to divide up that same forest area into areas with similar values for ‘texture’ and/or ‘contrast’. Automated segmentation is an intermediate product (Figure 4.2a), the end product being a classification of land units (Figure 4.2b) produced by visually interpreting the segmentation. Only a few of the myriad of segments produced by eCognition appear as meaningful, as revealed by a comparison between the two stages. Presuming the existence of ecotopes is a starting point in distinguishing meaningful lines from irrelevant detail and artefact.

Pattern recognition is, then, ecotope recognition. Ecotopes are as much found in the data as they are imposed on the data. The visual appearance of the landscape (in the form of ecotopes, such as a forest) has been the starting point in the process of mathematising the landscape. The ecotope has become part of a thoroughly mathematised theoretical structure, but at the same time the original, visually perceptible ecotope continues to serve as a benchmark against which the process of mathematisation is checked. In the maps themselves, the clustering achieved by mathematical means is further enhanced by assigning different colours to different areas, bringing out more clearly qualitative differences between ecotopes or patches within ecotopes. As the philosopher Françoise Bastide (1990) points out, visualisations such as maps serve to make arguments by supporting an interpretation, in this case about the spatial structure of the riverine area.

Maps are not just the visual end products of scientific investigation, though. In the river research case, maps are combined with other types of information about the land, such as inundation patterns. We may see this as a feedback into the ‘demathematised’ outcome of research, highlighting the importance of visualisation. Maps are therefore more than ‘pretty pictures’ to impress patrons, they are a means of communication between scientists, users and patrons.

Another group which we studied, at WL|Delft Hydraulics, develops modelling software for hydro-ecological simulations of rivers, estuaries and coastal regions.

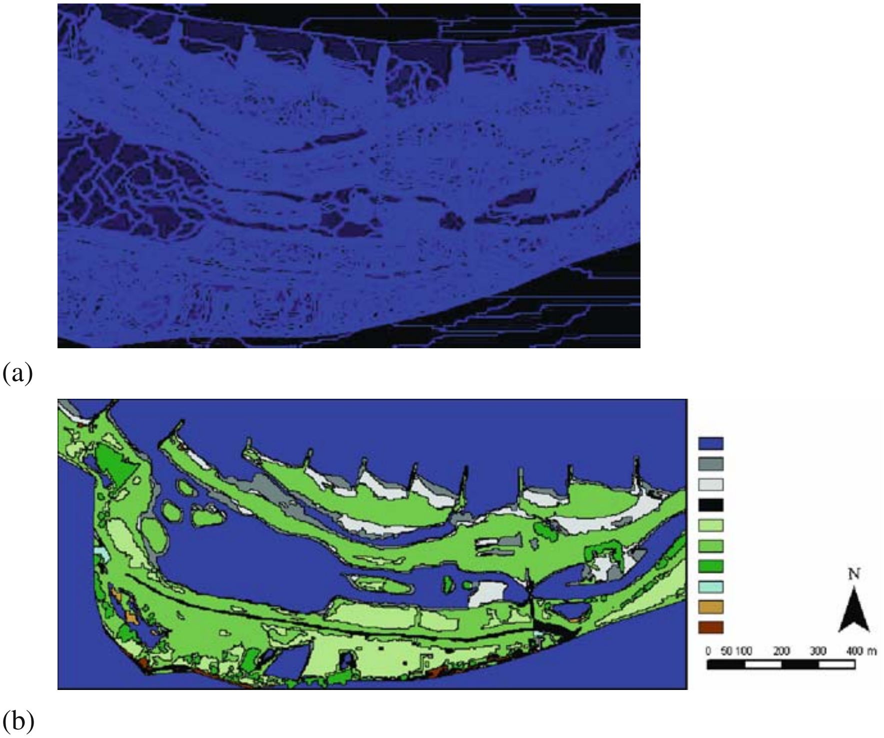

**Fig. 4.2** Modeling of data showing segmentation (a) and land cover classification of flood plain vegetation (b) (Menno Straatsma, 'Floodplain Roughness mapping synergy: lidar and spectral remote sensing', Source: http://www.ncr-web.org/downloads/Straatsma.pdf)

The area of, for example, the southern North Sea is divided into a grid of cells, each of which is described by a number of physical attributes, such as depth. One model simulates water quality and algal growth, another eelgrass recovery.

What role does the visual play in a context that is so highly mathematised? It is precisely because these models are mathematical representations of the area under investigation that the Gestalt is important in evaluating the model. Researchers have to 'play' or 'tinker' with a model in order to get the model parameters right for making sufficiently accurate predictions. Doing this on the level of pure mathematics can be troublesome, whereas images are more easily interpreted. For example, when locating errors in the model it is possible that a certain cell in the grid has not been programmed correctly, causing it to behave out of sync with neighbouring cells. This may go unnoticed when displaying results in their quantitative complexity. When viewing results of, for example, algae concentrations as a map, this error will stand out. A more interesting scenario is when unexpected concentrations of algae appear in a certain area. In this case it has to be determined whether it is a model artefact or whether it is due to natural causes. An often used method to find this out is to display model results in the form of an animation. Seeing changing

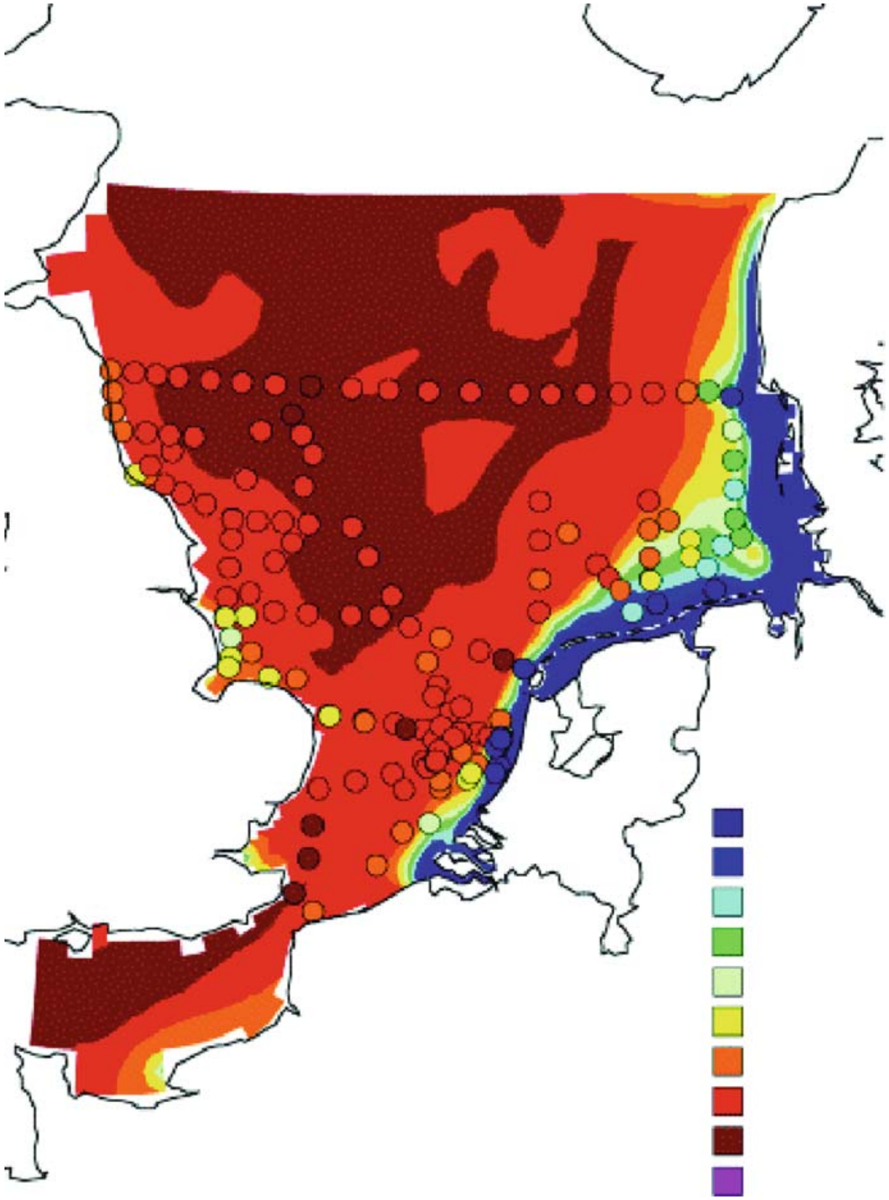

**Fig. 4.3** Map showing a comparison between a model calculation for surface layer salinity (coloured pattern) and measurements made at sea (circles). Original caption: Validation result for 3D hydrodynamic calculation (salinity) for the surface layer for March 1989. Coloured patterns are the model results, filled circles are measurements from the NERC cruise (NERC 1992) (source: Los et al. 2008)

patterns of algae concentrations allows the researcher to determine the cause of a certain anomaly and decide whether it is a ‘real’ event or an artefact.

In Figure 4.3, we see a comparison between in situ measurements of North Sea salinity at several locations and model results. In the article in which this figure was used, more quantitatively precise comparisons between measurements and model results, in the form of graphs, were given as well. However, this figure was included even though the use of colour categories for the salinity of the water makes it less exact. What this figure conveys is a comparison between patterns, rather than numbers or precise dimensions.

Although constructing a computer model for the ecology of a particular body of water is an inherently mathematical job, it is interesting to see how much of the work of fine-tuning a model and making it adequate is done by means of visual representation. Building the spatially explicit hydro-ecological models that are used and developed at WL|Delft Hydraulics is in part dependent on the demathematised Gestalt of the aquatic ecological ‘landscape’. Through visualisations such as these, the integrative abstraction that mathematical modelling allows is partly discarded in favour of an image that gives researchers a qualitative feel for their research object.

## 4.5 Conclusion

Without pattern recognition, landscapes in the era of remote sensing would have a purely atomic structure. They would be ruled by the size of the individual pixels. Patterns are not an objective structure of the landscape and while pattern recognition as such may be the innate capability of the scientist-as-human, discerning specific patterns is not: patterns are recognised thanks to the availability of Gestalts of the landscape. We should understand this as a cultural availability, since Gestalts are not timeless entities. Before 1800, landscapes did not exist outside of canvas or paper. After 1800, the Humboldtian holistic or systemic landscape first came into existence, followed more than a century later by the fragmented landscape of ecotopes and patches.

Gestalts may have something about them that allows for a reductive operation toward the Husserlian *eidos*. Visualisations of whole systems have always focused on the unseen: food webs cannot be readily seen in nature, and the compartments lumping species with similar functions in the ecosystem are theoretical constructs. In contrast, the landscape of ecotopes has retained a link with visible nature. In the process of mathematising ecotopes, that link may be severed. We have tried to show that very often this is not the case, that visualisations, being products of mathematisation, are brought back into the realm of the visible.

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# Chapter 5
# Past in Place: The Role of Geo-ICT in Present-day Archaeology

**Alfred J. Wagtendonk, Philip Verhagen, Steven Soetens, Karen Jeneson and Maurice de Kleijn**

## 5.1 Introduction

The popular view of archaeologists digging with pickaxe and trowel is far removed from present-day archaeology, in which Geo-ICT is increasingly used to support archaeological research. The relatively rapid uptake of Geo-ICT, especially geographical information systems (GIS), by archaeologists in the 1980s and early 1990s[1] (see e.g. Kvamme 1995 for an extensive overview) can be explained by the inherent spatiotemporal nature of the archaeological record and the traditional importance of mapping in archaeology at different scales, from intra-site to regional level. Equally important is the development of archaeology from a cultural-historical, monodisciplinary science into a multidisciplinary, partly geo-based discipline. As a result of this development, environment and topography have acquired more prominent roles. Also important was the introduction of archaeological surveying, or walking the field. Currently available surveying techniques generate large amounts of spatial data, and consequently a need for spatial analysis.

However, the advance of Geo-ICT in archaeology is not as obvious and common as might be expected. For many years the appropriate use of Geo-ICT in archaeology has been – and still is – a fierce subject of debate, especially in the academic community, which has led to a rather patchy application of Geo-ICT throughout the discipline. To understand this variation we will take a closer look at the history and cultural aspects of archaeology itself, its characteristics in terms of location and space, its practitioners and stakeholders.

We first define archaeology as a scientific discipline by describing its development and culture and the variation in research fields and methods with respect to time and location. This is followed by a discussion of the strengths and shortcomings of the Geo-ICT applications. Finally, we review the opportunities for and main

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[1] The term GIS was first used in an archaeological context by Hasenstab (1983).

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obstacles to the effective use of Geo-ICT in archaeology and the potential for further development.

## 5.2 Archaeology Defined

We can broadly define archaeology as the systematic study of the history and nature of past human cultures through the recovery and analysis of physical remains or traces and environmental data. The study of material objects and traces in the soil is the means by which humans in ancient times are studied in the context of their natural, social and cultural environment (KNAW 2007). Archaeology has been strongly influenced by other social sciences, like anthropology, philosophy and human geography. At the same time, archaeology is also highly dependent on data, methods and theories from the natural sciences. This has led to the development of various 'naturalist' subdisciplines like geoarchaeology, archaeobotany, bioarchaeology and archaeometry.

When looking at current archaeological practice, different subdivisions are possible. For example, archaeology can be subdivided into the collection, storage, conceptualisation, analysis and representation of archaeological data. However, it is more interesting from a Geo-ICT point of view to distinguish between the following three fields of activity:

- field archaeology
- archaeological heritage management (AHM)
- academic research.

Field archaeology entails different types of fieldwork, ranging from survey to excavation. Data generated by field archaeology is used both by AHM practitioners and academic researchers. While academic research focuses on the analysis and interpretation of archaeological spatiotemporal patterns and processes, AHM deals with the question of how to protect the archaeological record, as part of the cultural heritage, within the framework of national and international legislation.

Roughly speaking an archaeological 'workflow' consists of three stages:

1. Prediction: Where can we expect to find the remains of human activity in the current landscape? These predictions are based on spatial analysis of known archaeological patterns in relation to the environment and on theoretical assumptions about human behaviour.
2. Search: On the basis of the prediction, archaeological remains are traced and discovered features are identified.
3. Interpretation: What do the collected archaeological data tell us about human behaviour in the past? A number of theoretical frameworks may be employed for this.

These three stages form a cyclical process: the results of searching for and interpreting the archaeological data will obviously have an impact on future predictions.

## 5.3 The Perception of Space and Time in Archaeology

Even though the role of space and location in archaeology might seem indisputable, there is a tendency among archaeologists to regard time rather than location as central to archaeology (e.g. Shanks and Tilley 1992, 7). Renfrew (1983, 316) states that "the prime concern of geography is with man in space, that of archaeology with man through time". In his view, location-based methods like survey and excavation are merely the tools needed to identify and order the traces of the past.

Location is of primary importance to archaeology, since site and object location is a deliberate human choice, at least in part defined by characteristics of the location and its surroundings. The spatial dimension is therefore one of the fundamental attributes of archaeological data. Nevertheless, it should be recognised that neither temporal nor spatial aspects can be neglected in archaeology; they cannot be treated separately. It should also be stressed that at this point there are no standard satisfactory ways of analysing or representing spatiotemporal data.

Before the 1960s, the treatment of space in human studies was limited to a descriptive synthesis of what happens where (Conolly and Lake 2006). Nowadays it is acknowledged that the exact spatial location (in x, y and z) of each object or phenomenon in relation to the natural environment and other objects provides vital clues about the object itself (dating, find configuration) and of the archaeological context in which it was found. Unfortunately, many assumptions about past economies and societies are still made in an insufficiently documented and only two-dimensional physical landscape, which is often far removed from what these data could reveal in a dynamic and three-dimensional landscape and the human interaction with that landscape. For example, certain pieces of pottery found in a pit can give an approximate chronology to that pit. This allows a site consisting of various house remains, ditches and pits to be disentangled to reveal its development over time. The sequencing of archaeological phenomena on the basis of their geographical location, vertical positioning and mutual spatial relations is therefore the core business of archaeologists, whether the object of study is a feature (such as a well), a site (such as a village) or an entire region.

The introduction of GIS and digital georeferenced data provided new possibilities for investigating these complex spatiotemporal find assemblages and in turn prompted new research questions (Neustupný 1995). Although the interpretation of archaeological data itself improved tremendously, a strong but unjustified argument against the use of GIS was that it is too environmentally deterministic (Gaffney and van Leusen 1995). This argument was based mainly on the fact that the models used were borrowed from geographers and, indeed, environmental studies. Both Gaffney and van Leusen (1995) and Llobera (1996) argued that because archaeologists used specific geographical models, GIS was obviously more geographically focused, and that this could be avoided by the implementation of archaeological/cognitive models. As such, viewshed and cost distance analysis and the study of the evolution of site distribution in a dynamic landscape is much more telling for the understanding of human activity in the landscape.

It is too easy to use Thiessen polygons to define territories without considering the relief of the landscape. An even more striking example is the use of a blank map with only coastline and dots for archaeological sites to explain the distribution of sites. Clearly, this approach largely ignores human perception of the landscape. Nowadays, adapted cost distance and viewshed analysis can be used to model a humanised landscape in an objective, measurable manner, in which territories (and their economic potential), lost road networks (and trade routes), lost sites and defensive mechanisms can be hypothesised and predicted (see e.g. Soetens 2006).

## 5.4 Factors Influencing the Role of Geo-ICT and Location in Archaeology

Apart from the role of education and the approach to technology and information science that archaeologists have adopted in general, three more specific factors influence the use of Geo-ICT in archaeology:

- the archaeological field of activity,
- the nature of the archaeological record,
- the theoretical perspective.

### *5.4.1 The Field of Activity*

*Field archaeologists* mostly employ Geo-ICT for fast and efficient recording of the location of archaeological findings. In today's field archaeology this is essential as the opportunity to record these locations is usually very limited (see Section 5.5 for more details).

National and local government agencies responsible for *archaeological heritage management* (AHM) need reliable information in order to uphold the law. They need to know the location, expectation and quality of archaeological remains. Geo-ICT can be a powerful tool for supporting decisions on what to protect or excavate, and it is used as such by almost all institutes involved in AHM (see Section 5.6 for more details). National legislation and planning regulations also influence the use of Geo-ICT in archaeological heritage management. In this respect the Netherlands is unique in Europe for having adopted predictive site modelling as a prominent tool for AHM (Verhagen et al. 2006).

*Academic archaeologists* mainly use Geo-ICT for integrating, accessing and analysing large quantities of multidisciplinary spatial data, allowing for more accurate and more reliable data entry. Because the data is collected digitally and stored in digital systems, the accuracy and reliability can be checked right away in automated procedures, as opposed to conventional data collection with a fieldbook in which handwritten data needs to be introduced manually in a database. Relevant research themes in this respect include the reconstruction of prehistoric land use, the analysis of site visibility and the modelling of mobility in the landscape. The IT facilities and level of education available at universities largely determine the use that individual archaeologists can make of Geo-ICT. At the VU University Amsterdam, for example, the creation of an independent centre for spatial analysis (SPINlab) in 2001 has facilitated and stimulated the use of spatial technology in various disciplines, including archaeology. In the USA the CSISS (Center for Spatially Integrated Social Science) at the University of California (UCLA) plays a comparable role.

### *5.4.2 The Archaeological Record*

The archaeological period, soil conditions and geographical aspects determine to a large extent how archaeologists deal with location and to a lesser extent with Geo-ICT. No deciphered written sources are available for pre- and protohistory, so all knowledge about human behaviour in these periods is inferred from the location, distribution, interpretation and dating of objects and man-made structures in relation to the ancient environment. It can be roughly stated that the more traces and objects from the past that are buried in the soil, identified over larger areas, the more geospatial technology will be used.

A major difference exists between the treatment of archaeological features buried in the soil and remains that can be found at the surface. Local and regional history of erosion and sedimentation, combined with the effects of agricultural practices (ploughing) determine to a large extent the concentration, condition and visibility of artefacts at the surface. Geo-ICT is frequently used for data collection during field survey (see Section 5.5), data storage, analysis (e.g. to make distribution maps and predictive models) and spatial data presentation. However, the study of subsoil archaeological features also involves stratigraphy, sedimentology, pedology and C14 dating. Geo-ICT is then useful for making interpolation maps of soil samples, or for 3D representation and analysis of the subsoil. Furthermore, Geo-ICT based methods like remote sensing and geophysical prospection are applied successfully to detect buried archaeological remains. The use of Geo-ICT at site excavations, however, is less common.

Regional differences in archaeological resources translate into different Geo-ICT approaches. Lock and Stančič (1995) compare in this respect the relatively simple, two-dimensional archaeology of the greater part of North America with the European archaeological record of the last six millennia, “a dense and complex three-dimensional palimpsest”. Regional landscape analysis in Europe is therefore more concerned “with relationships between sites in terms of territories or spatial units representing social, political, and economic interactions” and to a lesser extent “with human perception of landscape, especially the symbolic and ritual” (Lock and Stančič 1995, xiii).

Apart from these field methods, other data may be used as well, for example from the study of material objects like pottery from museum collections, or art-historical archive studies, iconological and epigraphic research and the study of built monuments. Local and/or regional field survey data from various sources may also be compared to better understand regional variability.

### *5.4.3 Archaeological Theory*

A major factor influencing the use of location and Geo-ICT methods concerns the theoretical research schools developed within archaeology over the last 30 to 40 years. The Anglo-Saxon world has produced two important paradigms: New or processual archaeology (1970s) and post-processual archaeology (1980s and 1990s). Spatial information was central to processual archaeology and the identification and analysis of spatial patterns and relationships became one of the major aims of archaeological study. In the post-processual approach, the focus shifted to the reconstruction of 'social space'. This entails a completely different view of space and spatial relationships, but even for the reconstruction of 'social space' (for example a 'religious landscape'), geographical location of the initial archaeological object remains the starting point. To what extent Geo-ICT methods actually give shape to such social spaces is a different issue and is still debated today (Llobera 1996).

Major differences in theoretical approach are also found between nations and between continents. In most European universities, archaeology is incorporated into the arts faculties. In central and southern Europe we mainly find cultural-historical approaches with a strong empirical basis. From a Geo-ICT perspective, this mainly includes the construction of databases, indexes and distribution maps (KNAW 2007). The Anglo-Saxon countries, particularly the USA, are more oriented towards anthropology. In the Netherlands and the Scandinavian countries, empirical and theoretical approaches are combined. In general, the approaches with the strongest spatial focus are found in subdisciplines such as landscape archaeology and geoarchaeology. These approaches have a longer research history in the UK, the Netherlands, the USA and Canada, but strong interest in spatial archaeology is growing worldwide.

## 5.5 Geo-ICT and Archaeological Data Acquisition in Field Archaeology

Academic researchers and archaeological heritage managers have one thing in common: they are dependent on the results of fieldwork. In most countries the bulk of archaeological fieldwork is carried out in AHM, often by commercial companies (e.g. in the USA, UK and the Netherlands), and in other countries almost exclusively by public services (Belgium, the Mediterranean countries). This is why the AHM community is more influential than universities in establishing generally accepted practices as well as the implementation or rejection of innovations in field archaeology, Geo-ICT included. In field archaeology, Geo-ICT is mainly used as a tool to improve the efficiency and quality of data gathering. Field methods largely determine what type of Geo-ICT application is used: mobile mapping, for example, may be very useful for a field survey, but presently it does not provide much added value for an excavation.

Field archaeologists use three methods to gather data:

- desktop study
- prospection
- excavation.

### 5.5.1 Desktop Study

Present-day archaeology starts at the desk. Desktop study methods are especially important for the prediction stage of the archaeological workflow, which determines where the archaeologist is going to search. The areas where archaeological remains are most likely to be found may be delimited by studying literature and the results of previous archaeological research and by analysing existing maps. Nowadays a broad range of digital geodata sources is available for desktop study, including regional archaeological databases, digital maps of geology and soil type, digital elevation models,[2] georeferenced historical maps, aerial photography and high-resolution satellite imagery.[3] Geo-ICT is a convenient tool to bring these data sources together, produce maps and enable the archaeologist to make informed decisions. In most cases, Geo-ICT is used in a rather limited explorative way: the available spatial data sources are visually checked for interesting information (for example, the location of a suspicious-looking mound) and this is then printed out to help plan the fieldwork. More advanced analyses, like predictive modelling, the extraction of information from digital elevation models and the automated classification of satellite imagery, is not often performed. In fact, these more advanced options are mainly used when there is no intention (or possibility) to go into the field on short notice. An impressive example of this is the North Sea Palaeolandscapes Project,[4] which used 3D seismic data to map the drowned landscapes from the Palaeolithic and Mesolithic in the British part of the North Sea. This is a desktop study on an enormous scale, in an area where there will not be much opportunity to do fieldwork before the next Ice Age.

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[2] Based on either stereoscopic satellite imagery, such as, SPOT, CORONA or LIDAR.

[3] IKONOS, Quickbird.

[4] Coordinated by the University of Birmingham; see www.arch-ant.bham.ac.uk/research/fieldwork_research_themes/projects/North_Sea_Palaeolandscapes/index.htm

## *5.5.2 Prospection*

Archaeological prospection aims at tracing archaeological remains by making observations at preselected sample locations. The choice for a particular prospection strategy depends on the characteristics of the archaeology involved and the type of landscape. Four major categories of field methods can be used to tackle the problem of successfully detecting archaeological remains:

- field survey
- core sampling
- trial trenching
- remote sensing and geophysical prospection.

### 5.5.2.1 Field Survey

A cost-effective method of archaeological prospection is field survey or reconnaissance survey. Site locations are detected by walking across parcels of cultivated land and recording the archaeological materials. The potential of field walking for discovering archaeological sites is limited: it will only reveal information on archaeological remains that are within a depth of approximately 50 cm (the plough zone). In areas without cultivated land (grassland, forests, urban) the chance of detecting sites is much lower or zero. For this reason it is used more extensively in regions like the Mediterranean, the Near East and the south-west of the USA than in Britain or Scandinavia.

Field survey is an ideal prospection method for the use of mobile GIS mapping. Determining your exact location in a field is essential to field survey, but it is one of the more difficult tasks. The accuracy of standard GPS measurements is now within 1 to 3 metres, which is good enough for most types of survey. The introduction of mobile mapping in field survey also improves the quality of data entry. The use of automated lists and routines ensures more standardised data entry and increases the speed and effectiveness of data control, especially since post-processing of analogue to digital data is no longer needed. The use of mobile GIS also brings other advantages, such as the possibility of directly compiling find density maps on the basis of the recorded visibility characteristics. However, essential requirements for successful transition from conventional analogue recording to mobile mapping are careful planning, custom application development and training in the use of the methodology (Wagtendonk and de Jeu 2007).

### 5.5.2.2 Core Sampling

Core sampling is primarily used in areas where buried archaeological remains can be expected. It is a relatively cheap way to penetrate the soil: depths of up to 7 metres may be reached with simple manual coring equipment. While it is principally a geological survey method, it has also become a standard method for field archaeology in the Netherlands. However, it is not well suited for finding archaeological sites with a low density of artefacts because the diameter of the cores is often too small to guarantee detection in these cases.

GIS based mobile mapping is useful for core sampling survey as well. It can be combined with digital lists for the description of the cores. However, standard GPS does not provide accurate readings for elevation. As the z values are essential for interpreting stratigraphy, a separate measurement of elevations using digital levelling instruments is often performed. Increasingly, LIDAR-based elevation models (with a vertical accuracy of ± 10 cm) are also used to derive the z values after returning to the office.

Core sampling data is three dimensional, and is often presented in the form of profiles (for a single core) and transects (connecting several cores in a row). The interpolation of relevant stratigraphical levels to elevation surfaces is also routinely performed.

#### 5.5.2.3 Trial Trenching

When the archaeology is buried, but not too deeply, trial trenching is certainly the best field method. Trenches are dug at regular intervals up to depths of 1.5 metres and the archaeological features and finds encountered are recorded. This method is not different from full excavation in its execution, but it only samples a portion of the terrain studied. The use of Geo-ICT in trial trenching is therefore the same as in excavation (see Section 5.5.3).

#### 5.5.2.4 Remote Sensing and Geophysical Prospection

Some buried archaeological remains can be detected and interpreted without excavation by techniques that are more commonly used in other disciplines, like geology and agricultural engineering. A distinction can be made between techniques that take images from the air and a number of ground-based geophysical prospecting techniques (including electrical resistivity measurements, magnetometry and ground-penetrating radar). The ‘air-based’ images are primarily used in desktop study and are cost-effective because they will cover large areas at relatively low costs. However, in most cases they will not unequivocally reveal the extent and nature of archaeological remains, so just as in other disciplines, the use of remote sensing in archaeology requires ground truthing.[5]

Geophysical techniques require the archaeologist to take measurements in the field. The aim is to detect (archaeological) anomalies from the background of ‘natural’ soil. Whether the use of these methods is cost effective depends mainly on the speed of measurement. Low-resolution measurements (like the newly developed

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[5] Strictly speaking, remote sensing refers to any technique whereby no physical contact is made between detecting device and the object of study. In this sense, geophysical prospection is also remote sensing, but the term is commonly used for prospection from the air or from space only.

systems GTFrontline[6] or the DualEM)[7] can cover 4 to 5 hectares in a day by quad-bike. Electrical resistivity and magnetometry (which are more often used in archaeology) usually cover only a tenth of that extent. Geophysical prospection does not perform miracles either: it cannot interpret the measurements in archaeological terms or define the chronology of traced anomalies. When the features are very characteristic in shape, they can be related to functional attributes or even to period specific built structures.

Three-dimensional geophysical measurements, such as pseudosection and ground-penetrating radar (GPR), are most valuable to archaeology, as they not only provide information in depth and 3D visualisation of the identified anomalies, but they may also distinguish superimposed structures – stratigraphical layers, which are essential to the chronological phasing of archaeological sites. Unfortunately, they are also the most time-consuming, both in the field and in the post-processing phase. New and faster 3D subsurface prospection techniques are currently being developed, but their application in archaeological survey is not yet widespread. Post-processing geophysical data is usually done by specific software applications, such as Surfer, Geoplot and Archeosurveyor, which do not allow for an easy integration of geophysical data into standard Geo-ICT software.

### *5.5.3 Excavation*

From the early days, the potential of GIS to store database and geo-information in one environment was seen as a major advantage for the management of excavations. The separate registration and storage of paper lists of finds, features and drawings inevitably led to a low level of quality control and a long trajectory of data analysis and documentation after excavation. The development of database systems for excavation management has therefore been a major topic of interest for field archaeology, and the first attempts to develop these systems can already be found in the 1980s (Kamermans and Voorrips 1986).

Digital data entry in the field during excavation is possible nowadays, but it is not always done, or only partly. Various practical problems can make it impossible or undesirable to perform such data collection in the field. The data registered during excavation is twofold. First, there are lists of things encountered (features and finds) and of actions performed (like taking a photograph or soil sample). Most archaeologists still use pen and paper for recording these field data. Direct digital data entry is not difficult; it only needs a hand-held computer and a well-designed interface. However, when multiple teams are working in an excavation, they will all need access to such a computer and the database will have to be synchronised. Pieces of paper are then a lot cheaper and easier to handle – but of course the digital data entry problem is then transferred to the post-excavation phase. Second, positioning

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[6] http://www.gtfrontline.com

[7] http://www.dualem.com

all the data requires an accuracy better than 5 cm, which rules out standard GPS equipment for taking measurements. Rather, the drawing is made in a local coordinate system, either using total station measurements, or with a pencil on waterproof millimetre paper. After the fieldwork these drawings are digitised in a GIS. Georeferencing is executed by measuring in a limited number of reference points with geodetic equipment.

Some of the data on the drawing are points (individual finds, sample locations), some are lines (locations of vertical profiles), but mostly we are dealing with polygons representing archaeological features. Constructing digital drawings from total station measurements for all these data categories is not all that easy. Most total stations do not offer a decent graphical output that allow the user to see at a glance whether any mistakes in measurements or coding were made. Furthermore, the measured data has to be connected to the digital lists in order to perform data control. In practice, this means that the total station measurements have to be converted to a GIS editable format that will then be used to construct a map of the drawing and connected to the database. This is hardly an effective way of data management, but for larger excavations it may be preferable to spending many days on digitising paper drawings after fieldwork. What is needed for effective digital data entry during excavation is a system that takes total station measurements in real time, converts and displays them directly as a drawing in a GIS environment and allows for easy correction. As far as we can tell, these systems do not exist at the moment.

There are also a number of integrated systems for post-processing of excavation data. There is not a single archaeological company or institute in the world that will not use a database to store excavation information and perform queries on it. However, fully integrated geodatabase management systems are few. The most successful one seems to be the Swedish IntraSis.[8] It is an object-oriented database system equipped with a basic graphical interface which can display the results of common queries in cartographic form. It is unfortunately not yet fully integrated in GIS; major GIS operations can only be performed by exporting the data to ArcGIS, for example. The system also requires some training and needs to be prepared for different excavation strategies.

## 5.6 Geo-ICT and Data Management in Archaeological Heritage Management

As stated before, archaeology also has an important function in society. Archaeological remains are part of the cultural heritage and are therefore protected by a number of international and national treaties and laws. In Europe, the best known of these is the Valletta or Malta Convention, signed in 1992 by the member states of the Council of Europe.[9] This convention commits governments to institute a legal

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[8] www.intrasis.com; other commercially available packages include ArcTron and AdLib.

[9] http://conventions.coe.int/Treaty/en/Treaties/Html/143.htm

system to protect their archaeological heritage, which explains why the largest market for Geo-ICT in archaeology is found in cultural heritage management. In most European countries, a national geographical database of archaeological finds has been developed by government agencies; in the USA, similar databases exist at the state level.

The Dutch national archaeological database, Archis, has always been at the forefront of Geo-ICT developments and is a good example of a well-established nationwide database. Originally, Archis was conceived as a tool for both scientific research and heritage management. The database therefore contains information on the state of the archaeological monuments (the level of protection and preservation) as well as quite detailed information on the archaeological content of protected and non-protected sites (such as typology, dating and literature references). It is predominantly seen as a convenient digital archive to be consulted for desktop study. Its use for academic purposes is increasing, but is nowhere near its potential. This is partly because the information stored in Archis is far from complete. In the current Archis interface, users can combine the archaeological site and research information with different types of background layers, such as the Indicative Map of Archaeological Values, topographical maps and soil maps. There are also links to digital documents stored in the documentation system maintained by the RACM.[10] The Archis system is user-restricted to registered archaeologists only. However, some of the information is presented to the general public on the internet.[11]

Regional and local authorities usually have their own Geo-ICT systems. The level at which these are developed and used varies. Most Dutch provinces have good Geo-ICT departments and archaeological information is managed within a larger Geo-ICT framework. Some of them even present their archaeological information in a web GIS, like the province of Zuid-Holland.[12] Municipalities, however, tend not to have such excellent facilities. Archaeology has only recently become a major concern of municipal authorities and many still have to find their way through the subject matter. Municipalities that already have an archaeological department have mostly developed local archaeological information systems tailored to the very specific needs of individual archaeologists. However, there is growing awareness of the need to integrate archaeological data with other municipal data sources like cadastral information and permit registration systems. Furthermore, over the next few years municipalities will start to publish much of their archaeological data on the internet, not only because of the new archaeological legislation, but also because of the demands of legislation on the accessibility of public data.

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[10] Rijksdienst voor Archeologie, Cultuurlandschap en Monumentenzorg, the national service for archaeology and monuments.

[11] www.kich.nl

[12] chs.zuid-holland.nl

## 5.7 The Geomodelling Framework Applied to Archaeological Research

It is important to realise that for the average archaeologist the distinction between different geomodelling frameworks is irrelevant, although geodatabases and geomaps are an essential component of most archaeological work. Modelling is less prominent, in that it is not a recording device and archaeologists only recently have come to realise the potential of geomodels.

### *5.7.1 Geodatabase Framework*

Databasing in archaeology is essential, because it allows adding information to spatial (archaeological) entities, such as period, site type, material and location of material, thus linking locations (per period, through trade or other type of contact, site to topography and environment).

Archaeological sites can also be managed in databases on site conditions, preservation history, restoration, assessments of sites, visitor numbers and even accountancy (ticket revenues). It is worth noting that what is considered a spatial database in Geo-ICT might look quite different in archaeological reality. The 'spatial database' in many cases consists of a normal database with a location field referring to map units drawn on a paper or a CAD-based map. Database training is not a component of the archaeological education programme and recording accurate 3D information remains a specialist's domain.

### *5.7.2 Geomap Framework*

Time-frozen maps, or maps of different periods, are probably the most used application of GIS in archaeology because they represent the most obvious use of Geo-ICT for most archaeologists. Finding the archaeological site on Google Earth to add a ready-made top view of the site for funding applications is an equally common practice and requires hardly any Geo-ICT experience. Even 2.5D relief models with site dots are a good way to visualise the relation between land and site distribution. For example, in certain periods nearness to the sea was preferred, while in more dangerous periods higher elevations were preferred since they offered a better defence. On highland plateaus, sites are often located on the very edge of the plateau because they would not take up valuable fertile areas. The use of multidimensional models varies through time and region, for a number of reasons, some but not all of which are related to location. Antiquity, sanctity and longevity of a site may often prove more relevant for its continued survival than the quality of its location.

One of the most important tools for spatial analysis in archaeological research is the distribution map (see example in Fig. 5.2). Since the early days, researchers produced these maps for almost every category of archaeological material, pottery being the most prolific. In the cultural-historic approach, archaeologists used the distribution of a certain type of pottery to come to conclusions concerning the spread of ‘cultures’. On these maps natural elements such as soils, rivers, mountains and vegetation often served to ‘set the stage’ on which human activities, translated into different types of archaeological material, took place. It is unfortunate that today’s archaeologists too often still rely on 2D imagery to conceptualise the physical landscape, which deprives them of an accurate spatial concept of the region being studied.

### *5.7.3 Geomodel Framework*

Archaeologists are only just now discovering the possibilities offered by spatial analysis and modelling in modern-day Geo-ICT programs. In studies that try to analyse the economic dimension of a society in the past, spatial analysis tools are now being applied to calculate agrarian potential, cost-distance relations and erosion. It is only in the last ten years or so that explanatory models have been being applied in archaeological science, and certainly not always or everywhere. Nevertheless, distance, cost distance and viewsheds together with pinpointing site locations to their land use, geology and topography are among the most powerful tools, both for shaping theories and for predicting the location of unknown sites.

Many archaeologists, however, feel that the results of such studies are too unreliable because they depend on too many assumptions. Archaeologists interested in

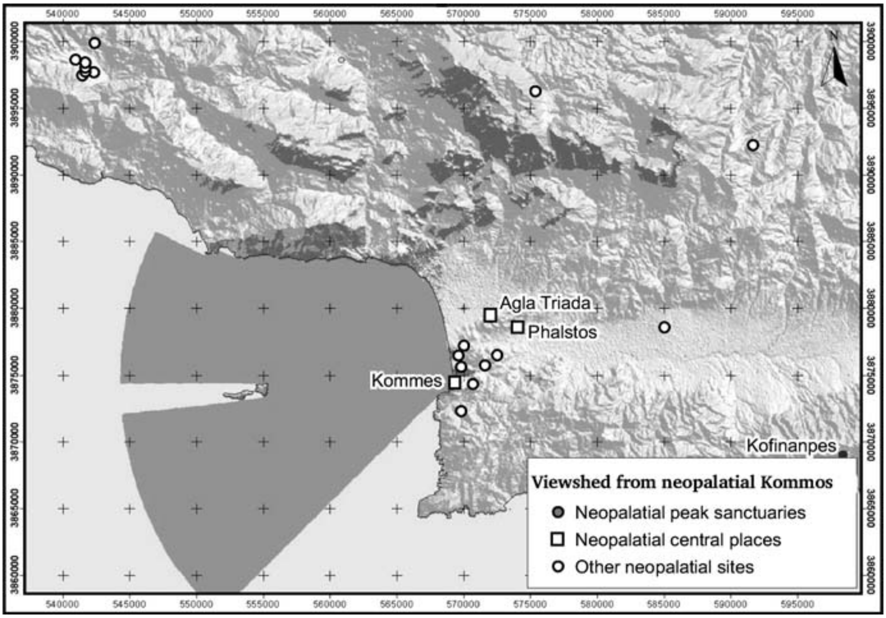

**Fig. 5.1**

the ‘social space’ of past cultures in particular claim that a GIS is too deterministic. Also, the GIS programs themselves are partly to blame by not providing standard tools and possibilities for visualising associated error and uncertainty in map results. However, these objections also underline the fact that the most relevant data is not recorded or used and that data input should include error and uncertainty. A growing number of researchers are looking for ways to reconstruct these social landscapes, viewshed analysis being one of the most frequently used instruments (see Fig. 5.1). In this approach the reconstruction of ‘what could be seen’ from a particular point in a (tangible) landscape can enable the reconstruction of an image that is thought to be indicative of past meanings (Llobera 1996; Soetens et al. 2003).

Apart from specific GIS procedures, geomodels can also be set up to compare different possible scenarios of a past landscape, evaluate the probability, data uncertainty and/or completeness of each scenario. A model can provide explanation for the emergence of certain patterns.

It is the combination of all three frameworks that provides added value, but in terms of archaeological research, geomodelling is certainly the most promising for explanation theory or for management.

## 5.8 Case Study: Examples of Geo-ICT in Archaeology

### *5.8.1 The Murge Project*

Since 1980, the Mediterranean section of the ACVU (Archaeology Institute of the VU University Amsterdam) has been conducting archaeological research in the Salento Isthmus region in Southern Italy. The subject of this project is to understand how local communities both shaped and interacted with the landscape during the first millennia before Christ and how they responded to and interacted with Greek and Roman colonialism. The first aim of the survey was to define the extent of the site of the Archaic settlement L’Amastuola. The second aim was to study settlement patterns in different landscape types from the Ionic to the Adriatic Sea. The landscape was divided into different plateaus and a sample area from every plateau surveyed (Burgers and Crielaard 2007).

From 2004 a newly developed application was used, as described in Wagtendonk and de Jeu (2007), with a combination of GPS and mobile GIS to define and map unit borders and digitally record unit characteristics. Mapped units were spatially linked to digital forms in which specific unit characteristics were recorded. Discovered material was recorded in an associated sample database of the mobile GIS application. After analysis of the collected artefacts the resulting database was linked to the spatial referenced units in the GIS. Having collected data in a GIS, it was then easy to query the data in any desired way. To locate archaeological find spots density maps of different types of pottery were produced, in which calculated densities depend on the survey coverage and recorded visibility characteristics. The distribution of absolute numbers of impasto sherds is shown in Fig. 5.2. By linking

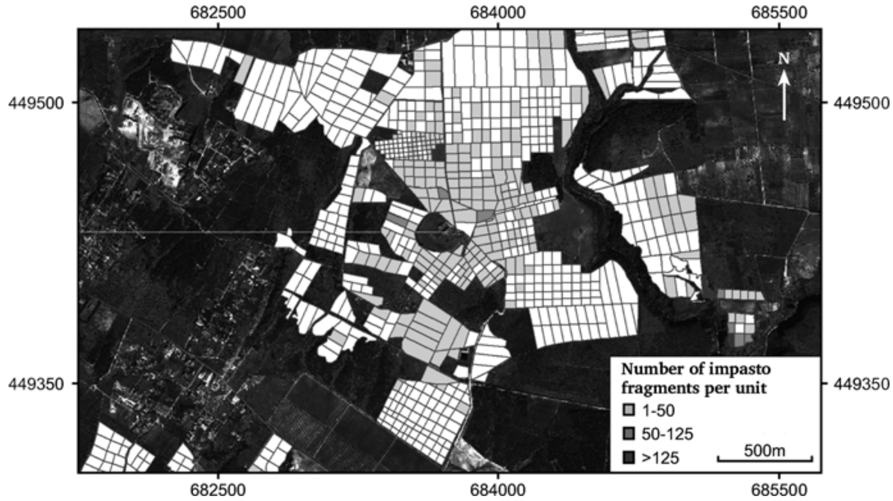

Fig. 5.2

density maps to geomorphology, archaeological land evaluations, distance to water or elevation models, conclusions can be drawn about human behaviour in this region for different periods, together with a potential for predictive models.

From a Geo-ICT point of view, the most innovative aspects are the extensive use of mobile Geo-ICT tools and the development of an archaeological mobile GIS application for efficient, verifiable and more uniform data entry. Further accuracy improvements of the Murge mobile GIS are possible and components of the geomodel need to be integrated into the mobile geomap to make real-time field analysis and interpretation of density patterns possible. It can then be used to adapt and improve fieldwork strategies on the spot. Therefore, mobile GIS should definitely be more firmly introduced in the field for real-time data entry and evaluation. The combination of seeing find densities and satellite imagery simultaneously is a valuable tool for discovering new sites.

### *5.8.2 Almelo Indiëterrein*

The second example concerns the use of GIS in commercial archaeology, a project by BAAC BV.[13] This company was appointed to investigate the area of the Almelo Indiëterrein. The objective of the research was to locate 't Kolthof' or 't oale hoes', a farm from the 15th century for which an approximate location was already known. At locations with significant traces trial trenches were enlarged and/or a second level was excavated (see excavation plan in Fig. 5.3a). Traces from the 15th century were

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[13] Bouwhistorie, Archeologie, Architectuur- en Cultuurhistorie (a Dutch archaeological company).

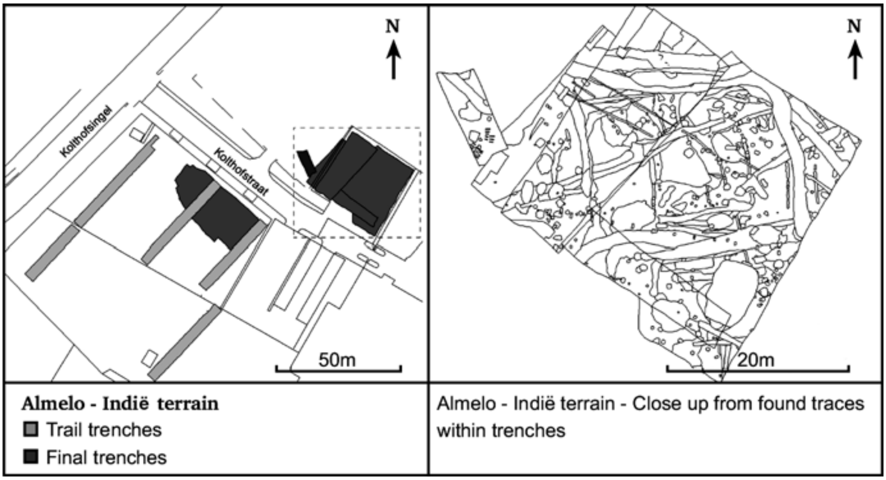

**Fig. 5.3**

found, but also remains from previous periods dating back to the 11th century.[14] The archaeological remains were drawn manually in the field, after which they were scanned and digitised in vector format. For every trace, surface height was measured and when a trace was dug out the depth of the trace was recorded. After the analysis of the artefacts the specific characteristics were recorded in a database, which was later linked to the digitised drawings in a GIS.

Using the project's GIS database, the 600 recorded traces were interpreted by queries and by visualisation of the distribution of those traces and specific pottery types (see Fig. 5.3b). By querying the database on chronology, synchronous traces revealed different structures that belong to the same phase. By ranging pottery amounts per surface unit, higher densities of sherds display the higher possibility for site locations. The biggest advantage of Geo-ICT here is definitely the integrative power of the GIS database, which makes the analysis and interpretation of a very complex dataset possible.

## 5.9 Stage of Geo-ICT According to the 'Geo-ICT Integration or Diffusion Model'

It is rather surprising that Geo-ICT has not found widespread application in archaeology. Integration from post-processual archaeology has played an important role in the negative attitude towards Geo-ICT, so much that at the moment there are few academic institutes or departments teaching or researching spatial analysis and

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[14] R.G. van Mousch (2007): Almelo, Indiëterrein. Archeologisch onderzoek (BAAC-rapport 06.401), 's-Hertogenbosch

Geo-ICT in archaeology. There are no dedicated journals[15] and it is not uncommon to leave instruction in Geo-ICT for archaeologists to geography departments. On the other hand, there are a substantial number of academic archaeologists working with Geo-ICT, and in Europe two annual conferences[16] and two journals on quantitative archaeology[17] provide ample space for presenting and discussing the results of Geo-ICT-based research, often in special issues. Furthermore, several books have been published since the early 1990s that specifically deal with GIS or spatial technology and archaeology (see Allen et al. 1990; Lock and Stančič 1995; Gillings et al. 1999; Lock 2000; Westcott and Brandon 2000; Wheatley and Gillings 2002; Conolly and Lake 2006; Mehrer and Wescott 2006). Other books discuss the use of GIS from the perspective of digital technologies in general (e.g. Evans and Daly 2006) or discuss the use of GIS or spatial thinking and GIS in a wider array of social disciplines, including archaeology (see Aldenderfer and Maschner 1996; Goodchild and Janelle 2004).

To get a better idea of the degree of integration of Geo-ICT into archaeology, the generic model introduced in this book was applied to the VU University Amsterdam, for which a detailed description of the Geo-ICT development in archaeology can be provided. Using the model, two different stages of development are observed:

- The IGBA (Institute for Geo- and Bioarchaeology, Faculty of Earth and Life Sciences) is in stage 5 ('GIS module optional part of degree').
- The ACVU (Archaeological Institute, Faculty of Arts) is in stage 4. Here students get some basic training in GIS, while GIS and other Geo-ICT techniques are used by some researchers in a more advanced way (often facilitated by the research group at the IGBA or the SPINlab). Based on the study programmes (Table 5.1) and our personal knowledge of the situation at other Dutch universities, the scale in Geo-ICT integration varies between stages 3 and 5.

However, if we apply the model to the global academic archaeological community things become more complicated. To present this properly, we would need exact quantitative information on the different components of the model, which we did not consider here.

**Table 5.1** GIS courses in the archaeology curriculum of Dutch universities

| University | compulsory | optional |
|---|---|---|
| Rijksuniversiteit Groningen (RUG) | x | |
| Vrije Universiteit Amsterdam (VU) | | x |
| Universiteit Van Amsterdam (UVA) | | x |
| Universiteit Leiden (UL) | | x |

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[15] Except a single volume of *Journal of GIS in archaeology*:

[16] Computer Applications and Quantitative Methods in Archaeology (CAA) and the International Workshop on Archaeology and Computing in Vienna.

[17] *Internet Archaeology* and *Archaeologia e Calcolatori*.

A number of other initiatives also illustrate the use of Geo-ICT in archaeology. Even if incomplete, the Timemap project of the Archaeological Computing Laboratory (Department of Archaeology, University of Sydney) maps on a worldwide scale the ongoing GIS based archaeological research projects on a website.[18] Another interesting initiative is the online collaborative organisation Archaeoinformatics.org, established to promote cyberinfrastructure initiatives for archaeology, particularly data-sharing initiatives. Their website includes an online survey with 30 questions considering the use of technology in archaeology, and opinions about the use and access to digital data in the profession.

Authors like Sarris and Jones (2000) have reviewed the use of GIS and geophysical techniques for the use of archaeological survey in the Mediterranean, but as far as we know, no recent comprehensive studies in the use of Geo-ICT in archaeology exist. An interesting attempt in quantifying the global use of GIS by academic archaeologists has also been made by Gourad (1999) in an online survey.[19] His survey was conducted between 1998 and 1999 and resulted in 140 useful entries from all over the world, but dominated by USA entries (55%). The survey revealed an academic user group of relatively inexperienced GIS archaeologists. Only a minority of these users (15%) used more than the standard GIS functionality by developing

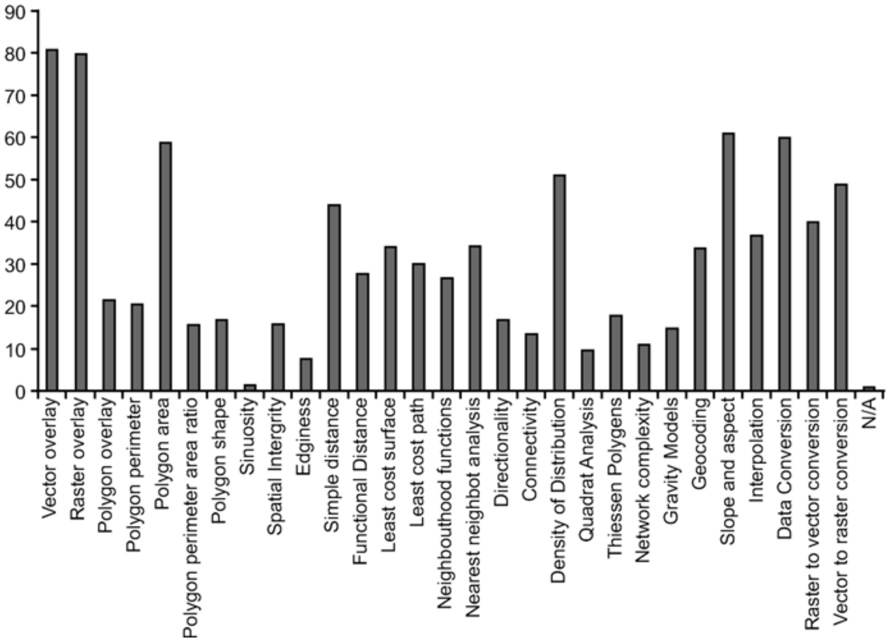

**Fig. 5.4**

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[18] http://www.timemap.net/epublications/2002_archaeology_index/index.htm

[19] http://users.erols.com/gourad and http://www.gisinarchaeology.com

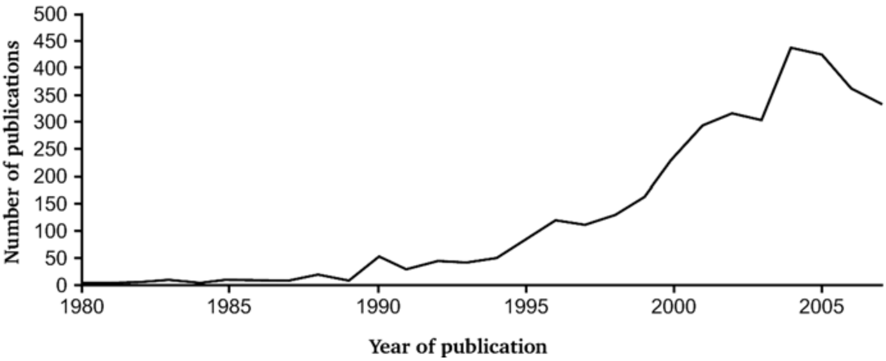

**Fig. 5.5**

their own algorithms. GIS was most used and appreciated for display and visualisation purposes, but also for common applications of GIS in archaeology, such as predictive modelling, intra-site analysis and archaeological heritage management (AHM). Also, the results for the most used analytical functions (Fig. 5.4) are in line with expectations. A worrisome but not unexpected result is the outcome of the knowledge assessment, which reveals a low awareness of the common pitfalls and possible errors in GIS data and GIS analysis. Gourad's results are more or less in line with our own observations stated in this chapter, although these survey results are outdated and the representativeness of the respondents is unknown.

Finally, when Google Scholar was searched for 'archaeology AND GIS' and 'archaeology' by year of publication, the initial enthusiasm around 1990 is clearly visible, as well as a general growing use of GIS in these publications (Figs. 5.5 and 5.6).[20]

## 5.10 Technical and Methodological Obstacles to Optimum Use of Geo-ICT in Archaeology

In the preceding sections we have presented a broad overview of the application of Geo-ICT in archaeology. It is clear that location is very important for the collection, analysis and interpretation of archaeological data. However, the level of application and acceptance of Geo-ICT in archaeology is variable, and in some cases it is even opposed. An effective use of Geo-ICT can only be made if the effort of its use is balanced by the results. This means that, for example in field archaeology, the level at which Geo-ICT is integrated into the work process should depend on the field methods applied, the scale of the project, the financial resources available and external demands on the quality of digital data. It is therefore almost impossible to

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[20] Obviously, this is only an approximation, since GIS is not mentioned in all relevant publication titles (e.g. GIS is SIG in French), Google scholar also lists the citations to the counted papers (hits include articles that do not have 'GIS' and 'Archaeology' in their title but cite articles that do), etc.

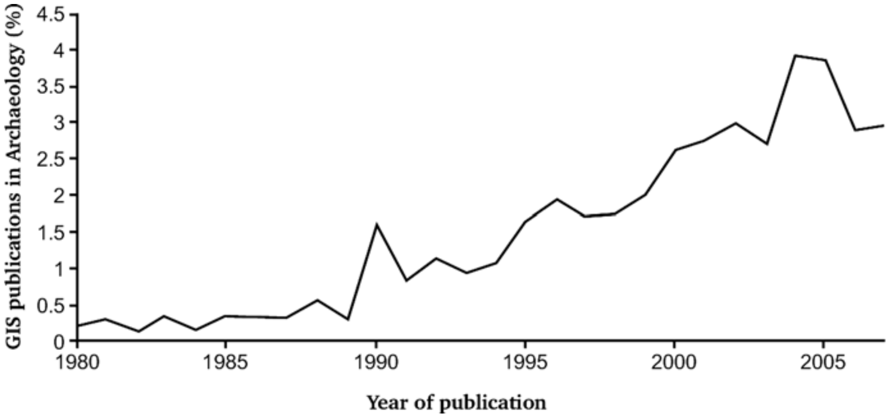

**Fig. 5.6**

identify all the obstacles that prevent the ‘optimum’ use of Geo-ICT. However, a number of factors can be identified.

First of all, we have to acknowledge that Geo-ICT, powerful as it may be, is not the ultimate tool for all forms of spatial analysis. For example, the problem of the quality of the often highly fragmented nature of archaeological remains and their relation to the original state of its source cannot be addressed well by Geo-ICT methods without understanding the processes that have transformed them to the current state encountered by the archaeologist. There are two aspects of archaeological data which Geo-ICT, at the moment, is poorly equipped to deal with: the three-dimensional nature of archaeological data and the temporal aspect.

### *5.10.1 Working with 3D data*

A number of archaeologists will be familiar with the use of wireframe models for the representation in 3D of digital elevation models, with or without an overlay of other geodata. Few, however, are aware of the potential of true 3D (solid) modelling, which can be used, for example, for volumetric calculations, coupling attribute data to 3D objects and from there the reconstruction and exploration of the stratigraphy of complex excavations. Some high-end Geo-ICT tools, like ESRI’s ArcScene, offer powerful tools for working with 3D data, but this does not include solid modelling.[21]

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[21] ArcGIS 3D analyst works only with functional surfaces, but one can calculate volumes above or below certain reference polygons. ArcGIS also handles real solid surfaces through ‘multipatch’ surfaces, but this concerns 3D objects created with specific 3D modeling software. For more information, see e.g. http://www.esri.com/industries/mining/business/subsurface-modeling.pdf

GPR and other geophysical measurements that contain depth values are increasingly making use of software based on the volumetric pixel (or voxel).[22] The use of these tools in archaeology, however, is still very restricted. Apart from the pricing of the software (most of it is quite expensive), the complexity of dealing with 3D data and the necessary training and background form the main obstacles. Most of the work in 3D modelling is in classical and urban archaeology, where it is predominantly used for the modelling and reconstruction of architectural remains. The software used is specific for this job, mostly CAD based, and the data are not always easily converted to a Geo-ICT package.

### 5.10.2 Temporal Aspect

We have not found any standard Geo-ICT tools that can deal with spatiotemporal data in a way that is remotely interesting to archaeologists. However, there is a lively ongoing discussion on temporal GIS. For example, Ott and Swiaczny (2001) published a book on the subject that discusses the limitations of commercial GIS packages and presents practical solutions for developing time-integrative GIS. The TimeMap Project mentioned earlier, is an example of a tool developed by archaeologists and other specialists at the University of Sydney to deal with spatiotemporal data.[23] However, we are not only waiting for the right tools, but also for the right methods. Very little successful research has been going on in archaeology itself that allows us to better understand and deal with spatiotemporal problems. It is a complex issue and requires further research on fundamental issues. The dating of archaeological features and finds is far from an exact science and our reconstructions and understanding of archaeological spatial patterns sometimes depend on very limited evidence.

### 5.10.3 Education

In a postgraduate course in Geo-ICT, held in Tours in June 2007,[24] archaeology students were introduced to programming in Python to allow them to make their own routines in ArcGIS. It turned out that the majority of the students had never done any programming before. This, unfortunately, seems to be typical of the level of ICT education in many archaeology departments. Even if Geo-ICT is recognised as a useful tool for certain research questions, the number of people that actually manage to operate a GIS and come up with some useful results is still very limited.

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[22] uch as Voxler; http://www.goldensoftware.com/products/voxler/voxler.shtml

[23] http://www.timemap.net/index.php?option=com_content&task=view&id=124&Itemid=147; http://ecai.org/index.html

[24] http://isa.univ-tours.fr

Most archaeologists, especially of the older generations, have not grasped the idea of (geo)databases and the possibilities of Geo-ICT. Many of them are trained in the Arts, and lack a background in 'the exact and natural sciences' methodology. Consequently, little is known about statistics, spatial modelling, projections, representativeness of data and other important aspects of GIS science. On the other hand, they are easily swayed by the impressive images that GIS can produce – even if these carry no meaning or give false information. As most archaeologists will sooner or later have to deal with GIS-derived results and/or GIS specialists in their work, it is essential that they are all trained in some basic aspects of GIS science.

Fortunately, most universities now offer courses in GIS, but it will probably take a number of years before the scientific use of Geo-ICT in archaeology will be standard practice. Obviously, Geo-ICT has to compete with other subjects in the curriculum, and it is probably not always thought to be worth the investment. In fact, archaeologists may to some extent be excused for not being impressed by the experiences of thirty years or so of ICT in archaeology. In a rather provocative paper, Jeremy Huggett (2004) identified the existence of a high priesthood of 'invocators' of technology, who are (consciously or not) restricting non-expert access to technology.

### *5.10.4 Data Sustainability*

Digital data needs to be archived and preserved, just like archaeological finds and paper documents. However, data that was prepared only a decade ago cannot be read unless the original software and hardware can be traced – most probably in a computer museum – and then the data have to be converted into a format that we use today. And besides the actual data, we also need the metadata descriptions to understand the tables and codes used.

Initiatives at the international level to deal with data sustainability in history and archaeology were already taken in 1995, resulting in the RecorDIM initiative.[25] Most national initiatives, however, are relatively recent, with the exception of the Archaeology Data Service (ADS) in the UK, which started in 1996. The ADS is a digital repository where digital reports, photographs, databases and drawings are stored in a safe location for a fee. The ADS also ensures that the data can always be converted to current software formats. In the Netherlands, developments in archaeological data preservation and standardisation are now moving relatively fast, partly driven by developments in other fields and outside the Netherlands. One of these is the development of the ISO standard CIDOC-CRM,[26] which is designed to ensure document documentation, and even holds empirical provenance, and a record of process history (for example the manipulation of Geo-ICT data).

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[25] http://extranet.getty.edu/gci/recordim/

[26] The International Committee for Museum Documentation; see also http://cidoc.ics.forth.gr/index.html

Last year, a Dutch national archaeological data archive[27] was launched, similar to the ADS. The establishment of this ‘e-depot’ was accompanied by a formalisation of the rules for digital data entry and storage. Digital deposition is now obligatory and includes the creation of detailed metadata reports. In the near future, standards for data exchange in XML and GML will be developed. However, there is still a backlog of old projects that need to be documented and archived. These efforts are desperately needed, but the knowledge and application of the above-mentioned standards and initiatives is still far from widespread. It is not yet common practice among archaeologists to present or preserve metadata together with their research results.

### *5.10.5 Finance*

An overview of obstacles preventing the use of Geo-ICT in archaeology is not complete without considering the financial aspects. Money is one of the major constraints for introducing new technology in archaeology. Archaeology is a relatively small discipline. It is organised in small groups (companies or institutes with more than 100 employees are very scarce) and only modest profits are made in commercial archaeology. New technology, however, requires investments in purchasing software, employing people with the necessary technical skills and getting everyone familiar with it. Changing an existing work process by introducing new technology inevitably means an initial loss of efficiency before the benefits of the new system accrue. Innovation can only be successfully implemented by taking a gradual approach.

Because of the lack of real money in archaeology, big software developers are not fundamentally interested in it. In practice, this means that we are stuck with tools that do only part of what we want them to do, and are too expensive. Equipping the office of an average archaeological company with ArcGIS licenses for all employees would basically bankrupt it. Standard software also comes with a lot of ballast: the geocoding functions of MapInfo, for example, are essentially useless to archaeologists, but they still have to pay for them. Ideally, the archaeologist should make his own tools. The development of IntraSis, for example, shows that this is possible, but for major software development the backing of the whole archaeological community is needed.

Data can be expensive as well. In the USA, Geo-ICT in archaeology took off in the 1980s at least partly because of the availability of digital government data, like elevation models, that were free of charge. In Europe, most of the available digital data are still quite expensive, although this is slowly changing. And while universities may get discounts, commercial companies have to pay the full sum. Obviously, they may pass this on to the contractors they are working for, but competition in a commercial system also ensures that digital data will only be purchased when it is

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[27] E-depot Nederlanse Archeologie; http://edna.itor.org/nl

considered essential to the work done. In the Netherlands, the availability of LIDAR-based elevation data for the whole country at a 5×5 m resolution has revolutionised the way of conducting desktop research and prospection. Every archaeologist today recognises the potential of this data source for making more accurate maps and obtaining z values without having to spend a day in the field making measurements. However, when it comes to using remote sensing images, this consensus does not exist. As the results of analysing satellite imagery are variable and somewhat unpredictable, remote sensing is hardly used at all in Dutch archaeology.

### *5.10.6 Methodological Objections*

The use of Geo-ICT and related 'spatially deterministic' approaches is still caught in the debate between processual and post-processual archaeology. To non-archaeologists this debate may seem rather trivial. It seems as if archaeologists are trying to make an impossible choice between theory and practice in order to decide whether or not to use Geo-ICT. Other social sciences are also dealing with translating human behaviour to a GIS environment and the associated problems of combining social and biophysical data are widely acknowledged. Goodchild and Janelle (2004), for example, advocate the importance of spatial thinking and a wider application of Geo-ICT in the social sciences. However, the debate here is about how to use Geo-ICT methods relating to the concept of human space handled by archaeologists. For example, the archaeologists that directly read meaning from spatial patterning will have fewer problems with the use of the technology than those that consider that spatial patterning cannot be read directly but must be interpreted. Finally, what should be a point of concern, but which is not often raised as an issue, is acknowledging and representing the uncertainty and subjectivity in map results that are inherent to any archaeological research method.

## 5.11 How Scientists can Contribute to Overcoming 'Technical' and 'Methodological' Obstacles

The effective use of Geo-ICT in archaeology is increasingly growing, and its perceived usefulness and ease of use has increased with it. Concepts such as the Technology Acceptance Model and terms like 'perceived usefulness', 'perceived ease of use' and 'intention to use' seem in themselves not very practical for explaining progress with using Geo-ICT, and archaeological science itself pays little regard to this question either.

The dissatisfaction that many archaeologists feel with Geo-ICT comes from the fact that they are mainly interested in going beyond the description of space in geometrical terms to unearth its actual meaning. Current Geo-ICT tools are mostly shaped in very traditional, mainly two-dimensional, ways of thinking about space. They do not allow space to be explored easily from other perspectives. Obviously, a better integration and adoption to Geo-ICT would bring clear advantages for archaeology, but it should not become a goal in itself. Geo-ICT also comprises some weaknesses and risks that have to be taken into account.

Further specialisation and education in Geo-ICT might well solve the above-mentioned issues, but it is feared that this would be at the cost of the basic archaeological training. Self-study, courses, manuals and specialist consultancy are still necessary. The question that remains is whether this would be sufficient when an appropriate spatial method must be selected that requires a thorough knowledge of the theoretical principles behind the applied GIS tools. That same selection of spatial method also demands technical skills to change or develop alternative spatial modelling strategies that better translate the social aspects of archaeological reality into GIS terms. In the end, spending time developing algorithms is not considered to be archaeology.

The problem of insufficient funds for software and data might be overcome by collective purchase and sharing of GIS licenses, facilities and spatial data by the different scientific disciplines using GIS at universities. This model has been adopted at the VU University Amsterdam with the establishment of the SPINlab. Where such a strategy is not possible, archaeologists could rely more on open source software and online communities for sharing knowledge, software and data.[28]

Considering the methodological objections, we observe that in archaeology, regardless of the theoretical debate, Geo-ICT is increasingly applied in different practical and academic archaeological fields of activity. We therefore advocate a more productive academic debate focusing on how to integrate the theoretical, social aspects of archaeology into spatial research. How to capture model error and uncertainty and communicate this to end users has received plenty of attention in the GIS literature (e.g. Goodchild and Gopal 1989; Heuvelink 1998; João 1998; Longley et al. 2001; Mowrer and Congalton 2000) and has also led to practical guides for archaeologists like the 'GIS Guide to Good Practice' by Gillings and Wise (1999) which is also available in an online version.[29]

## 5.12 Conclusions

Archaeologists were among the first scientists and scholars to use GIS and Geo-ICT. Applications in GIS range from subsurface modelling to distribution maps to predictive modelling. However, the unmistakable increase of Geo-ICT use in archaeology has not yet reached its full potential. Archaeologists have not yet fully embraced the possibilities and potential for new research as in other disciplines, such as geography, and no new subdiscipline has yet emerged. For the majority of archaeologists, GIS is just a tool and they do not consider Geo-ICT to be part of the archaeological endeavour. The debate on whether and how Geo-ICT can be applied in archaeology takes place around the dividing line between processual and post-processual archaeologists, although a new theoretical framework may be more liberating. It is still legitimate, however, to question the use of spatially deterministic

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[28] http://www.openarchaelogy.net

[29] http://ads.ahds.ac.uk/project/goodguides/gis

Geo-ICT methods, which may indeed lead to a biased scientific data-driven representation of reality, opposed to more qualitative representations. The outcome of this discussion might be one of the most important contributions of the archaeological discipline to the GIS community. Indeed, what C14 dating has been for time in archaeology, Geo-ICT surely is for location in archaeology. The main issues, as they always have been, are still the lack of data and data quality, the lack of training, infrastructure and support.[30]

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[30] Aldenfelder in http://www.gisdevelopment.net/application/archaeology/interview/ev028.htm

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# Chapter 6
# No Place in History – Geo-ICT and Historical Science

**Onno W.A. Boonstra**

## 6.1 A Place in History

"L'histoire d'un peuple est inséparable de la contrée qu'il habite." This is the very first sentence from the Preface to Part One of *Histoire de France*, published in 1911 (Lavisse 1911). In contrast to what the title suggests, Part One is not about history; it is about geography. In this volume, the author, Vidal de la Blache, elaborated his idea that when peoples who had been migrating across the continents of the world finally settled in places which offered enough opportunities to make a living, these particular places required people to build specific kinds of settlements, use specific tools and create specific living arrangements to survive. All this would lead to a unique way of life, a *genre de vie*, which was ultimately shaped by the physical environment from which it emerged (Vidal de la Blache 1911; Baker 2003).

De la Blache's *genre de vie,* this symbiotic relationship between man and environment and between history and geography, laid the foundation for many scientific disciplines: sociography, anthropology, folklore studies and, to some extent at least, historical science. This makes good sense, because history is not only unthinkable without time, but also without a spatial dimension. Space gives a structure to human behaviour, and the history of human behavior can be appraised much better when geography is drawn into it. The inclusion of geography into the study of historical developments and processes has been advocated from the very beginning of history as a science. The clearest exponent was Fernand Braudel, one of the founding fathers of modern social, economic and cultural history, and a member of the Annales group of Social and Economic History. According to Braudel, historical developments can better be understood if we recognise three levels of histories that all have a different timespan:

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GeoJournal Library 96, DOI 10.1007/978-90-481-2620-0_6,

- histoires évenementielles: the short timespan, which more or less coincides with the political domain of history;
- histoire conjuncturel: the longer timespan, which coincides with the economic domain;
- longue durée: the very long timespan, which coincides with the geographical domain (Braudel 1958).

It is the *longue durée* which evolves unnoticeably from semi-permanent structures which are there because of differences between spatial units or "locations". What a "location" is, has not been stated more precisely by Braudel. He himself has taken the entire Mediterranean basin as a location for his study *Le Méditerrannée*, which dealt with the history of that area in the 16th century (Braudel 1949). But his successors within or outside the Annales group often chose to study a smaller region: Le Pays d'Oc for example, or, in the Netherlands, the provinces of Overijssel and Friesland and the Noorderkwartier region (Slicher van Bath 1957; Bloch 1929; Faber 1973; Woude 1972).

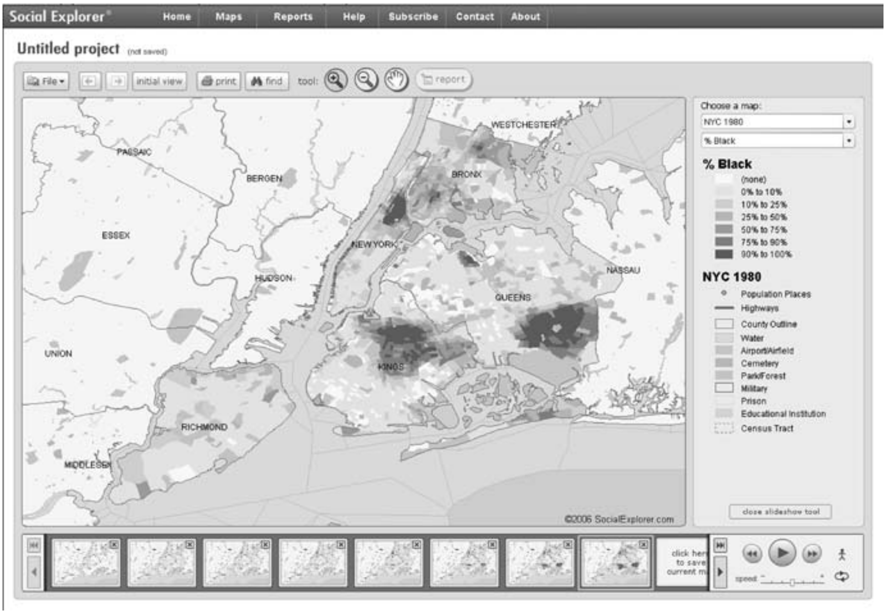
Despite the success of the Annales school and its successors all over the world, mainstream historical science has not embraced geography wholeheartedly. The reason for this is threefold. In the first place, the idea of the *longue durée* – historical processes which pass through specific developments because of a spatial, structural setting – has been popularised to a fixed spatial setting within which only one fixed kind of human behaviour is normative, or even imperative. It is these kinds of *Blut und Boden* theories that have helped to marginalise place in history. Secondly, historians have a tendency to take the nation as a regional focal point. But the nation is a "modern" construct. It cannot yet have permanent structural attributes, and therefore cannot serve as a setting within which long-term historical regional processes should be studied. And thirdly, in recent decades historical science has drifted away from social science, and thus from quantification and statistics. Differences between regions are no longer an input to or purpose of statistical analysis, but a contextual platter of cultural, anthropological and psychological axioms to be used as a setting for describing specific regional features in a literary fashion. One can say that, as a consequence, "space" has gained weight in historical science, whereas geography has not – until recently.

## 6.2 Geo-ICT and the Uses of Geography in Historical Research

Although it is evident that geography has not been given due credit as a foundation for explanatory models in historical science, there are developments within historical science that seem to justify the claim that there is a shift of interest towards geography. Without doubt this has to do with the coming of age of Historical Geographical Information Systems. There is a Historical GIS Research Network (St-Hilaire et al. 2007) and a Historical GIS discussion list (Ell et al. 2006), and in 2007 the History Department at Idaho State University was the first to start a graduate study in geographically-integrated history, which is based on GIS (Marsh 2007). Numerous papers have been presented on historical GIS related subjects at history conferences, notably at large international ones within the domain of economic or social history, such as the American Social Science History Association (SSHA) and European Social Science History (ESSH) conferences, and recently also at large general history conferences (Owens 2006). Not only do these conferences have growing numbers of special sessions on the use of GIS in historical research, but more importantly, a growing number of GIS-based papers are delivered outside these special sessions. Whereas the 2000 SSHA conference had two sessions on historical GIS and no GIS-related presentation outside these sessions, the 2007 SSHA featured seven GIS sessions and three presentations outside of them. Moreover, quite a few historical journals have published special issues on practices within the field of historical GIS: *Social Science History* (2000), *History and Computing* (2001), *Histoire & Mesure* (2004) and *Historical Geography* (2005). Finally, during the last ten years half a dozen books have been published as introductions to the concepts and uses of GIS for historians (Berger et al. 2005; Gregory 2003; Gregory and Ell 2008; Knowles 2002; Knowles and Hillier 2008; Ott and Swiaczny 2001). What these papers, articles and books all show is that within historical science GIS is mainly used as a tool for arranging and visualising historical events and situations. This suggests that only limited use is made of the potential applications of Geo-ICT because there are more ways to use GIS in history. There are six different ways that Geo-ICT applications and related tools can be used in historical science: for presentation, exploration, reconstruction and analysis, as a portal to historical information and to facilitate research.

### *6.2.1 Geo-ICT as a Presentation Tool*

Geo-ICT is used as a presentation tool when the main object is to visualise information, be it location-specific information, regional variation or, more specifically, regional variation through time when other visualisation methods like tables, figures, graphs and text fall short. Of course, “presenting” history with maps has a long tradition. In the nineteenth century historical maps and atlases were designed to display historical events and regional variations, such as Minard’s famous visualisation of Napoleon’s campaign in Russia (Minard 1869). Nowadays, the ease with which maps can be created digitally allows atlases to be published with hundreds of maps showing historical events and regional variation for specific themes, times or regions. A fine example is *England on the Eve of the Black Death*, an atlas based on 15,000 14th century personal wills and thousands of manorial extents and accounts. GIS has been used to create more than 180 maps on manorial structure, land tenure, land use, agriculture, milling resources, markets, fairs, taxable wealth and the tax-paying population to reveal the human geography in England during the fifty years before the Black Death struck the country (Campbell 2006). Other examples include Kennedy et al. (1999), Pitternick (1993) and Spence (2000).



Choose a map: NYC 1980

% Black

**Fig. 6.1** To visualise changes over time, the web-based Social Explorer has a feature to make video presentations from multiple choropleth maps, in this case for racial segregation in New York City, 1910–2000 (New York City 1910 to 2000 race map, 15 Nov. 2007)

A key vehicle for visualising historical events and regional patterns is the internet, not only because the creation and presentation of maps is much cheaper using the internet, but also because web pages are able to represent changes over time much better than printed atlases. A good example of such a web-based atlas is the *Social Explorer*, which has a feature to make a slide show from multiple choropleth maps (Fig. 6.1).

### *6.2.2 Geo-ICT as a Tool for Exploration*

When GIS is used as a tool for exploration instead of presentation, it is not the GIS technique itself which makes it different, but the goal. The purpose is not to visualise patterns that are already known to the researcher, but to discover patterns within regional variations that have not been explored before and try to find explanations inductively. In most cases maps are used for this purpose. Take, for instance, the map by the famous Belgian statistician Alphonse Quetelet, the first choropleth map ever published in the Netherlands (Quetelet 1827). It copies to some extent the map which Charles Dupin drew for France one year earlier (Dupin 1826, published in Dupin 1827). Quetelet's map shows very marked differences in school attendance between the provinces of the Netherlands, which had not been noted before. The regional differences could to some extent be explained by differences in

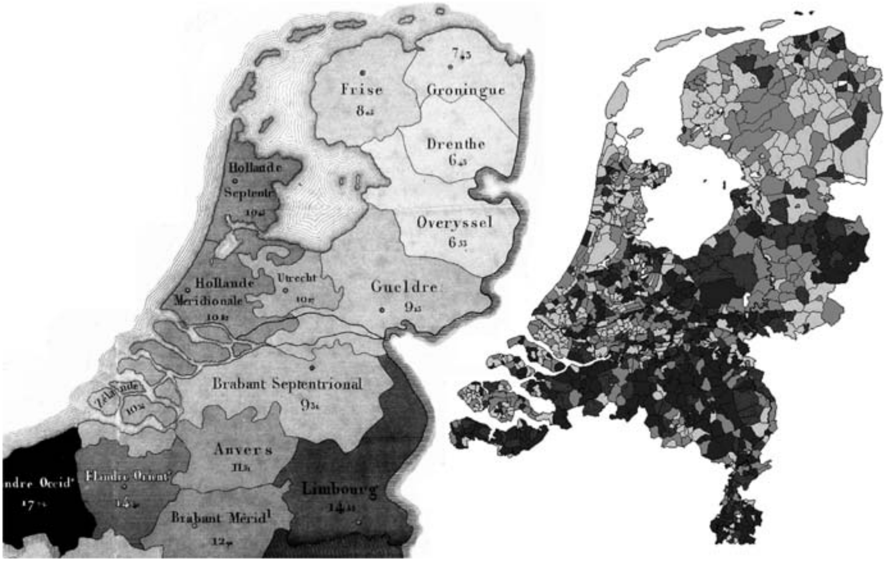


**Fig. 6.2** School attendance and illiteracy in the Netherlands, 1800–1825. *Left*, Quetelet's map of 1829 showing school attendance in 1817, aggregated at the provincial level; *right*, Boonstra's map of illiteracy 1800–1825, aggregated at the municipal level. Traditional explanations of differences, based on provincial data, are no longer adequate

religion, the north being Protestant and the south being Roman Catholic, and also in economic prosperity, pre-industrial Flanders being much worse off economically than elsewhere. Modern visualisations of similar data (municipal rather than provincial) show much more regional variation, which cannot be accounted for by religion and economy alone (see Fig. 6.2). This prompts new discussions and interpretations (Boonstra and Schuurman 2009).

Other examples of the explorative use of historical GIS include Gregory and Ell's new analysis of the Great Famine in Ireland, in which they map parish level demographic data and challenge existing theories of the causes of the famine (Gregory and Ell 2005a), and Andrew A. Beveridge's articles and essays on changing population patterns in New York City using his *Social Explorer* (Beveridge 2002, 2006).

### *6.2.3 Geo-ICT as a Tool to Make Reconstructions*

Reconstruction is also a major feature of GIS for use in historical science. Maps and data can be combined to reconstruct historical and archaeological landscapes and settlements, as well as historical events and historical situations. The process itself can lead to new insights. An example is the reconstruction of the historical map of Aarhus, Denmark, by Garry Keyes and Jens Toftgaard Jensen (Jensen and

Keyes 2003). As no historical land register map of the city from the early nineteenth century exists, use of GIS required the construction of a credible map based on the geographical information and structure inherent in the textual sources. The resulting digital map enables spatial analysis to uncover patterns in urban social and economic structures (Fig. 6.3). The spatial distribution of wealth and occupations, for instance,

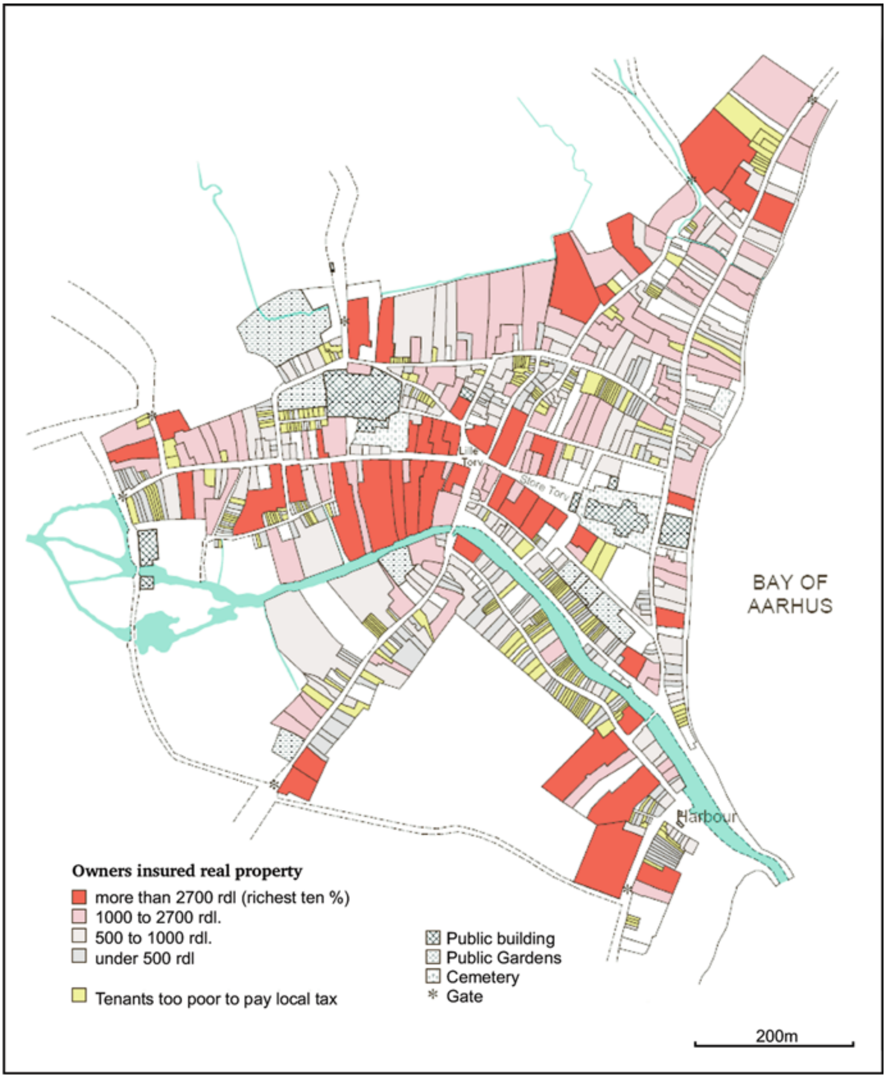


**Fig. 6.3** Jensen and Keyes' reconstruction of the city of Aarhus, Denmark, 1801

give an insight into the structure of the town that was simply impossible to obtain before. It also makes it possible to retrieve information on dwellings or households at an individual level.

There are a few other famous GIS-based reconstructions in the field of historical study. An early example is Schenk's effort to recreate a historical map of land use in southern Germany (Schenk 1993). Nina Piotukh's reconstruction of the Novorgev district in Russia (Piotukh 1996) and Capizzi's reconstruction of land parcels that were split because of the building of fortifications around Paris in 1840–1860 (Capizzi 2004) are particularly imaginative. Other GIS-based reconstructions include Harris (2000), Lilley et al. (2005) and Gauthiez (2004).

### *6.2.4 Geo-ICT as an Analytical Tool*

GIS is used as an analytical tool when special spatial, GIS-related statistical software is used to analyse historical geographical variations or spatial developments over time. The first is called spatial historical analysis, the second spatiotemporal analysis. There are not that many examples of GIS analysis within the field of history. Varet-Vitu and Pirot made a spatial analysis of the locations of administrators of health and public hygiene in the Paris basin around 1850 (Varet-Vitu and Pirot 2004). Another example of spatial historical analysis is the Valley of the Shadows Project, which studied differences in the socioeconomic landscape of southern Augusta County and northern Franklin County before the outbreak of the American Civil War (Sheehan-Dean 2002). Peter Doorn has made a spatiotemporal analysis of the location of settlements in Aetolia, Greece over a very long period of time (Doorn 2006). He found that the location of settlements shifted constantly from prehistory to the present, reflecting changing environmental and social conditions as well as changing preferences. In dangerous times, for example, it would have been sensible to choose a hilltop location and accept the problem of securing a supply of water, whereas in more peaceful times a settlement would flourish better near pasture and arable land. When height, slope, access to water and access to arable land are taken into account, five clusters of landscapes can be discerned. Roman settlements were much more inclined to favour access to arable land, whereas in the Byzantine period settlements were located on the slopes of mountains. Other examples of analytical uses of Geo-ICT are Ashbrook (2006), Chareille et al. (2004), Gregory (2000), Knowles and Healey (2006), Pearson and Collier (1998) and Skinner et al. (2000).

### *6.2.5 Geo-ICT as a Portal to Historical Information*

What Jensen and Keyes have done to retrieve specific individual information from their reconstructed map (see Fig. 6.3) can be done in a more standardised way using Geo-ICT as a tool to access location-specific information. Google Maps and Google

LUCHTFOTO
Waar: Nijmegen
Wanneer: 19-9-1944
Luchtmacht: RAF
Fotonr.: 3036
Vliegrichting: ONO
Instelling: Kadaster

KADASTERKAART (MINUUTPLAN)
Waar: Hatert, Gelderland, sectie A, blad 01.
Wanneer: 1811 - 1832
Instelling: WatWasWaar

LUCHTFOTO

**Fig. 6.4** The Wat was waar website allows the user to select a specific location on a map; all historical information related to that particular location is then shown

Earth are well-known examples of GIS portals to this type of information; Google Earth even supports the visualisation of historical maps on top of today's geographical features.[1] But there are other advanced tools designed specifically to enable public access to historical information. An attractive example from the Netherlands is the Historical Atlas of Nijmegen. Starting from a modern map you can zoom in on a smaller area, after which you can retrieve all kinds of cultural and historical information, from modern day topography to the topography of 1832, historic buildings in the neigbourhood and the archival records of these buildings (Historische @tlas Nijmegen, 15 Nov. 2007). The Electronic Cultural Atlas (ECAI) uses a map to locate archaeological finds and cultural information and (Electronic Cultural Atlas Initiative, 15 Nov. 2007). The *Wat was waar* ("What was where") website goes a step further: by pinpointing a location on a map, and – if desired – by selecting a time period, all archival records related to that particular location within the selected time period are shown (*Wat was waar*, 15 Nov. 2007; see Fig. 6.4).

### *6.2.6 Geo-ICT as a Tool to Facilitate Research*

Acquiring historical data and maps for Geo-ICT purposes is not an easy job. Millions of non-digitised data are scattered throughout the archives, and digitising these handwritten or badly typeset data is no sinecure. Most historical maps are not yet

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[1] In its Featured Contents layer, Google Earth (version 4 and later) has a selection from David Rumsey's collection of digitised historical overlay maps (Rumsey 2006).

available in a digitised format, let alone georeferenced or digitally stretched to match modern coordinate systems, and historians do not have the capacity to do all this work by themselves. It is therefore of great help when organisations make the effort to put their spatial data, their maps and their analytical tools at the disposal of researchers. Users do not then need to create a GIS of their own, or digitise maps and data themselves. Of course, the system must not limit the user too much, because of financial restrictions, for example, or limited ability to acquire the data and maps or to visualise the data. Unfortunately, most interactive historical GIS systems are limited in one way or another. The Portuguese *Atlas Geografica Histórica* can produce maps from a lot of data, but they cannot be downloaded (Atlas Cartografia Histórica, 15 Nov. 2007). The same is true for the Dutch *Bevolkingatlas* (15 Nov. 2007) and the *HGIS Germany* (15 Nov. 2007). The United States *National Historical Geographic Information System* (NHGIS) provides free aggregate census data and GIS-compatible boundary files for the United States from 1790 to 2000, but no interactive online GIS to link these datasets (National Historical Geographic Information System, 15 Nov. 2007). The *Social Explorer* can only map a set of pre-defined census variables (Social Explorer, 15 Nov. 2007).[2] Good examples of really interactive GIS systems are the *Belgian Historical GIS* (15 Nov. 2007) and the *China Historical GIS*, in which a dataset can be downloaded, analysed and uploaded again to create a map (China Historical GIS, 15 Nov. 2007).

## 6.3 Obstacles to Historical GIS

There may be six different ways of using Geo-ICT related tools in historical science, but this does not mean that these tools are used to the full. Even books reviewing the state of the art of historical GIS make two things clear: there is a huge difference between the actual and the potential number of historians using GIS, and when historians do work with GIS, it is outside traditional history departments. Obviously, these are obstacles to historical GIS that prevent its full use.

### *6.3.1 Actual and Potential Use of Historical GIS*

Historical GIS seems to be restricted to a few uses. Table 6.1 shows the potential and actual use of historical GIS formats, subdivided into the three Geo-ICT frameworks as defined in Chapter 1. There is an overwhelming difference between potential and actual use of historical GIS, with the exception of its use as a presentation tool.

Table 6.1 confirms that the potential for the use of Geo-ICT within historical science is not used to the full. For some reason, historians have little intention of using Geo-ICT. The true situation is revealed by considering the stages of Geo-ICT in historical GIS. Table 6.2 shows the actual stages of Geo-ICT integration in historical science.

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[2] Starting in 2008, a subscription to the Social Explorer gives access to more data and maps.

**Table 6.1** Potential and actual use of historical GIS, by historical GIS tool

| | Geo database | | Geo map | | Geo model | |
|---|---|---|---|---|---|---|
| GIS tool | potential use | actual use | potential use | actual use | potential use | actual use |
| 1 presentation | ■ | ■ | ■ | ■ | | |
| 2 exploration | ■ | □ | ■ | □ | | |
| 3 reconstruction | ■ | □ | ■ | □ | | |
| 4 analysis | ■ | □ | ■ | □ | ■ | □ |
| 5 portal | ■ | □ | ■ | □ | | |
| 6 facilitating | ■ | □ | ■ | □ | | |

■ high
□ low

**Table 6.2** Stages of Geo-ICT integration in historical science

| Geo-ICT stage | Geo database | Geo map | Geo model |
|---|---|---|---|
| 1 champions | ■ | ■ | ■ |
| 2 guest speakers | ■ | ■ | ■ |
| 3 conferences | ■ | ■ | □ |
| 4 staff training | □ | □ | – |
| 5 optional modules | □ | □ | – |
| 6 large-scale data | □ | – | – |
| 7 full integration | – | – | – |

■ at a fair number of universities
□ at a very limited number of universities
– nowhere at all

A fair number of universities (but not a majority) have one or two keen champions of historical GIS, and sometimes guest speakers are invited. A fair number of conferences (but not a majority by far) have GIS sessions in their programmes. But the big threshold is at level four, staff training. Staff have been trained to teach and use Geo-ICT in historical science only at a very small number of universities.

### *6.3.2 Historical GIS Outside History Departments*

Another feature which hampers the growth of historical GIS is that historical research with a spatial component is restricted mainly to historical subdisciplines that are not taught within traditional history departments, but outside them, in historical geography, historical economics and historical sociology departments. The technology of Geo-ICT has not been accepted within traditional historical departments, where it is perceived to have little practical application and to be difficult to use. Historians tend to be late when it comes to adopting new technology, even when its ease of use has been established by a large majority of non-historians. But perceived usefulness is a bigger problem. Historians remain sceptical about visualisation. Visualisation has always had limited relevance for historical science, and only as a visual attachment to things that have been stated in words. That visualisation has an added value, that it can serve as a heuristic device, has been recognised by some – mostly specialists in cultural history like Peter Burke and Simon Schama – but not by all. That it can serve as a basis for spatial modelling and spatial analyses of regional variations and developments in the past is way beyond the scope of a traditional historian.

As a consequence, the use of Geo-ICT in historical science is hampered not only by a widespread lack of methodological interest and knowledge among historians, but also by the impossibility to gain such knowledge. Geo-ICT has the privilege of sharing this dubious honour with many other modern methodological tools, and the ignorance of modern methodological tools for historical research in general is alarming. Students now receive little or no training in methodological tools relevant to historical science, whether statistics, palaeography or GIS. Geo-ICT will consequently be used only in a limited way within historical science. Stunning historical examples of Geo-ICT will be presented in other disciplines well before historical science itself, if that happens at all.

### *6.3.3 Time, Data and Historical GIS*

The lack of knowledge and interest in methodological issues is not the only problem. Geo-ICT has a methodological problem of its own, and a major data problem too. The methodological problem of Geo-ICT is that it has not yet been able to resolve a number of spatiotemporal issues. A problem common to historical GIS applications is that boundaries, and as a consequence geographic locations, tend to change over time (Gregory 2002; Gregory and Ell 2005b; Ott and Swiaczny, 2001). Peuquet has stated that a fully temporal GIS must be able to answer three types of queries (Peuquet 1994):

1. Changes to a spatial object over time, such as “Has the object moved in the last two years?”, “Where was the object two years ago?” or “How has the object changed over the past five years?”
2. Changes in the object’s spatial distribution over time, such as “What areas of agricultural land use in 01/01/1980 had changed to urban by 31/12/1989?”, “Did any land use changes occur in this drainage basin between 01/01/1980 and 31/12/1989?”, and “What was the distribution of commercial land use 15 years ago?”
3. Changes in the temporal relationships between multiple geographical phenomena, such as “Which areas experienced a landslide within one week of a major storm event?” or “Which areas lying within half a mile of the new bypass have changed from agricultural land use since the bypass was completed?”

Gregory comes to the conclusion that at the moment there is no GIS system that can cope with these three issues (Gregory 2003).

But even more problematic are the data problems that are inherent to historical science. For instance, the linkage of data to spatial units (as Jensen and Keyes did for the Aarhus reconstruction mentioned above) is a difficult task, not least because of the incomplete and fuzzy character of many historical sources. Although much has been done to visualise the uncertainty of information in maps (Couclelis 2003), the representation of historical data cartographically where both the source map and the data may contain such vaguenesses has not been satisfactorily resolved yet (Unwin 1995). Maps may look more convincing than is justified by the obscurity, ambiguity or incompleteness of the sources. Besides, of the millions of location-specific data in the archives, only a small number have been digitised, and a smaller number still have had location-related metainformation added. It is the sixth use of historical GIS, facilitating, that is the key issue for historical science. GIS will only have a chance of taking off in history when a relevant number of maps have been digitised, vectorised and georeferenced, and the relevant location-stamped data have become available.

## 6.4 Geo-ICT and Its Place in History

In her new book on historical GIS, Kelly Ann Knowles claims that GIS is on the brink of changing historical scholarship: "Quantitative social science historians are embracing GIS already to facilitate the mapping of large datasets, and any other historian with access to the software and the skills to use it can include mapping in research as well" (Knowles and Hillier 2008). According to Knowles, this change is little short of revolutionary, considering how few scholars or students made maps even ten years ago. She continues: "Historical maps are suddenly in great demand as digitally modified, georeferenced images that enable researchers to study GIS as a visual medium of communication and analysis." I am not that optimistic. At the moment, the number of historians who actually use Geo-ICT is very, very low. Jack Owens, who is a prominent GIS-using historian, recently stated that GIS still is largely unknown among the vast majority of professional historians: "a significant percentage of those who believe they know about the technology think it is something they can buy with their next car so that they will not become lost" (Owens 2007). I have to agree with Owens. Fifty years ago, the effort to bring geography into history had limited success; thirty years ago, cliometrics triumphantly entered the domain of historical research, only to wane after a decade. Twenty years ago, it was historical information science that would definitively change historical scholarship, but it did not.

Historical GIS deserves to do better, but I have serious doubts. The problem is that history curricula at universities around the world devote too little attention to teaching research methods and techniques that go beyond the methods of traditional historical science. The heuristic skill of searching, retrieving and evaluating scientific historical literature is practised, but no attention is paid to the methods needed to retrieve historical information from historical data. Academic culture has proven to be a major barrier for statistics and information science in history, and it will be a barrier for Geo-ICT. As a consequence, there is no place in history.

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## Chapter 7

# Geo-ICT in Demography: The Impact of Developments in Geoinformation and Geotechnology on the Discipline of Demography

**John Stillwell**

## 7.1 Introduction

The literal translation of the Greek words for demography is ‘description of the people’. Many scholars have suggested definitions of the subject that vary in terms of the specificity of focus, some being short and very general, such as “Demography is the science of population” (Weeks 2002, p. 4), whilst others are longer and more detailed, for example, “Demography, in the most precise sense of the term, is the quantitative study of human populations and the changes in them that result from births, deaths and migrations” (Ross 1982, p. 147). As with many disciplines, the boundaries that define the content of demography are fuzzy and studies of the population are undertaken by statisticians, economists, geographers and sociologists. Social demography, for example, is a major strand that emphasises the scientific study of population from a sociological perspective. Historians, psychologists and epidemiologists also use demographic concepts since demography is concerned with virtually everything that influences or can be influenced by population size, structure, change or distribution. In fact, the field of demography touches on almost every aspect of human existence.

As Donald Rowland points out in his pedagogic overview *Demographic Methods and Concepts* (Rowland 2003), the origins of demography are to be found in the seventeenth century and John Graunt’s little book *Natural and Political Observations Mentioned in a Following Index and Made upon the Bills of Mortality* (Graunt 1662), which considered many demographic questions, including those relating to causes of death, sex ratios and the components of population change. Moreover, Graunt’s views on the need for social statistics in public administration were visionary, coming over a hundred years before the taking of a regular population census began.

Formal demography is closely associated with the development of theoretical ideas, hugely important among these being theories about the demographic

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transition originating in the work of Thompson (1929), Davis (1945) and Notestein (1945), and hypothesising how countries underwent a transition through a series of stages from a position of having high rates of birth and death to one where both birth and death rates are low. Long before the development of these ideas, in 1798, Thomas Malthus highlighted the relationship between population and resources. He precipitated a debate which has dominated much demographic research activity and political discussion since, and which is likely to continue to do so in the future.

However, formal demography is also synonymous with the mathematical or statistical description of human populations, particularly their structure with regard to age and sex, and the components of change, such as births and deaths, which alter their structure over time. Seminal works in this field include Nathan Keyfitz's *Introduction to the Mathematics of Population* (Keyfitz 1968), Roland Pressat's *Demographic Analysis* (Pressat 1972) and Henry Shryock and Jacob Siegel's *The Methods and Materials of Demography* (Shryock and Siegel 1973). Demographic concepts and methods include alternative measures of population growth, standardised rates, cohort and period measures and analyses, synthetic measures of fertility and replacement, life tables and expectancies, stable populations and demographic models, all of which are underpinned by issues relating to data availability. More recent volumes on methodology and concepts have been produced by Hinde (1998) and Rowland (2003).

This chapter attempts to demonstrate the impact of information and communication technologies (ICT) generally and geotechnology in particular on demography, a discipline which, as we have seen above, is formally considered to be a scientific, quantitative and data-based subject with little consideration for the spatial dimension. The next section discusses the emergence of scholarly interest in the demography of place and space and the use of geographical concepts and methods to examine the interconnections and differentiations between and within different spaces. Section 7.3 examines the impact of technological change on population mapping. Whereas this section is concerned with visualisation, the next three sections consider developments in data availability and accessibility, the emergence of a new subdiscipline known as geodemographics, and new analytical methods and modelling. Some conclusions are presented that summarise the progress made in understanding the significance of location and spatial relations, but also in investigating spatiotemporal relations. The chapter is written from an unashamedly British perspective and illustrated with several figures from the author's own work.

## 7.2 Spatial Demography

The temporal dimension can be used to distinguish different subareas of demography. *Historical demography* is the quantitative study of population history that was developed and popularised in the 20th century by the French historian Louis Henry (Henry and Fleury 1956). Unlike contemporary demography, it relies on data from the period before statistical tools like censuses were introduced and therefore involves the use of documents like parish and civil registers, inscriptions on gravestones, church records of christenings, marriages and burials (parish registers), voter or citizenship rolls, legal documents (such as records of wills and deceased estates or land tenure records), taxation lists, muster lists for militia service and similar documents. Wrigley (1966) provides a useful introduction to English historical demography.

Besides historical demography and demographic analysis using censuses and surveys, there is a field of demography that looks to the future through the creation of *population projections* using mathematical models. The earliest population projections were usually produced using a cohort component model which, in the case of a single region, involved the estimation of the population at the beginning of a projection period, the projection of the number of births during the future time period and the survival of those already alive or born during the period. Early examples of uniregional models include those developed by Bowley (1924) in Britain, Weibol in the Netherlands (de Gans 1999) and Whelpton (1936) in the USA. Leslie (1945, 1948) rewrote the uniregional model in matrix notation; others demonstrated how the model could be expanded to include net migration, either in the form of flows or rates (Plane and Rogerson 1994).

It was the development of multiregional demography from uniregional modelling in the mid-1960s, requiring the proper specification of interzonal migration flows rather than net migration balances in projection models, which led to the development of a new subfield known as *spatial demography*. Andrei Rogers (1966, 1967, 1968) pioneered the development of the Leslie matrix for a multiregion system and the creation of multiregion life tables (Rogers, 1973). Thereafter, an alternative approach to the Rogers' multiregional survival model known as accounts-based modelling was developed by Rees and Wilson (1977) during the 1970s. Philip Rees and Alan Wilson first constructed accounts-based models for (census-based) transition data (involving the migration of those in existence at one point in time who were living at another address at an earlier point in time) before applying similar techniques to (register-based) movement migration (counts of moves taking place in a period irrespective of existence at the beginning or end points) (Rees 1984).

These multiregional modelling approaches were critical from a geographical perspective because they demonstrated recognition not only of the importance of spatial variations in the natural components of population change, but also of the role of migration, both interregional and international, in connecting different places and having a significant impact on population dynamics. In particular, Rogers provided the theoretical rationale for the use of gross migration flows rather than net balances in population models (Rogers 1990). In other words, it was with the developments in multiregional demography (Rogers 1995) that comparisons between demographic structures and relationships between areas of origin and destination became more significant, not least because of the increasing importance of migration with regard to fertility and mortality in explaining population dynamics.

This is not to say that there were no parallel developments taking place in population studies, especially with the subfield of *population geography* coming of age. In fact, the case for population geography had been made by Trewartha

(1953) and, in the mid-1960s, John Clarke identified population geography with the spatial variation in the composition and distribution of population and stated that "the growth of population is related to spatial variations in the nature of places" (Clarke 1965, p. 2). However, as Woods (1979) suggests, it would not be entirely accurate to describe population geographers as being concerned only with population distributions and demographers as just population statisticians unconcerned with a sense of place. Research in both population geography and demography fell within the ambit of 'population studies'. State-of-the-art research in population geography in the UK and the Netherlands at the end of the 1980s (before GIS became established) is exemplified in a collection of papers edited by Stillwell and Scholten (1989) and shows the key topics: multiregional population projection models; patterns and trends in the components of population change; migration characteristics of the labour force; immigration and racism; mobility of the elderly; demographic change and housing needs; residential mobility; impacts of housing supply changes. Since then, space has remained a crucial element for demographic studies and the number of applications in spatial demography has grown as more data have become available and as new software for spatial analysis has been developed (Rey and Anselin 2006). Moreover, geographical information science (Longley, et al., 2001) has itself become established as a discipline within which the number of demographic applications has been increasing. Examples of the growing popularity of geographical information systems (GIS) or new spatial demographic analysis methods (like multi-level modelling or geographically weighted regression) can be found in socioeconomic and ethnic segregation, welfare and deprivation, labour market conditions, health and education inequalities, household consumption, crime and community safety, and population and environment linkages, as well as the more traditional areas of fertility, mortality, marriage and migration. However, it is critical to recognise that developments in GIS and in modelling have tended to occur in parallel, with little evidence from spatial demography to suggest that they have become more integrated. Geographical information systems have remained the tools with which to visualise the basic demographic data, the outputs from historical modelling and the results generated by population projection models. The next section indicates some of the key developments in visualisation.

## 7.3 Population Mapping and the Impact of Geotechnological Change

Visualisation has been crucial for analysing spatial data and communicating information since John Snow's mapping of the places of residence of people infected by cholera in London in 1854 (Fig. 7.1), which led to the detection of a contaminated water pump in Broad Street (Snow 1855). Distribution maps like this were produced manually until the early 1970s, including Skoda and Robertson's famous 'isodemographic map', created using a physical analogue model based on metal balls and adhesive tape. It represents a population-oriented rendering of the 1966 Canadian census divisions, while keeping all of Canada together in a contiguous mass and preserving recognisable division and province outlines (Skoda and Robertson 1972).

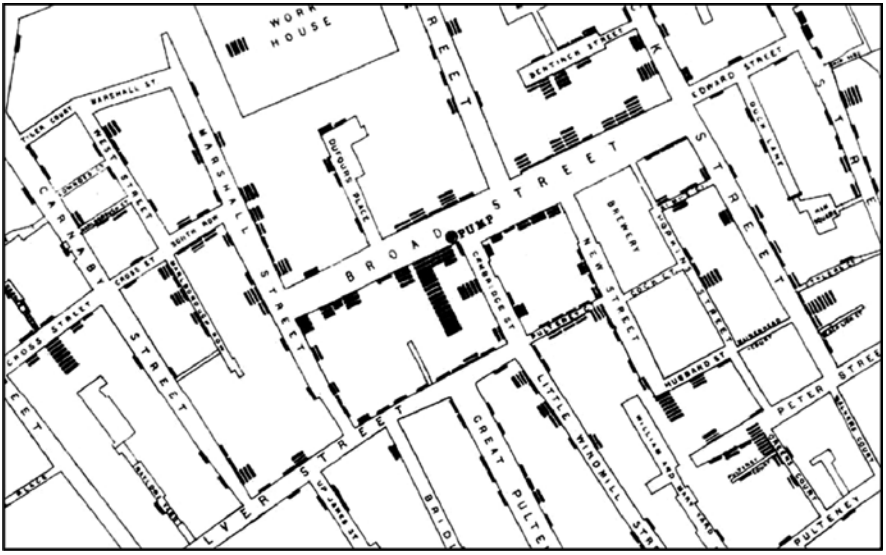


**Fig. 7.1** Detail from John Snow's 1854 map (source: Snow 1855)

The developments in computer mapping that occurred during the 1970s transformed the quality and versatility of mapping as a tool for demographic research. Waldo Tobler was in the vanguard of this movement, developing his notion of 'analytical cartography' that involved the application of mathematical concepts and methods in map production (Tobler 1976). Others in the USA, like Norman Thrower, Duane Marble, Judy Olson and Mark Monmonier, developed their own areas of expertise. The dramatic changes in computer technology that began to take place with computer automated mapping initiated a revolution in population distribution mapping. Plotters and line printers on mainframe computers enabled researchers to produce maps from computer files using packages like *SYMAP* and *SYMVU*. Figure 7.2 is an example from my own PhD thesis (Stillwell 1979), in which *SYMAP* was used to depict the distance decay in migration from each county in England and Wales based on migration data from the 1966 Census. In the mid-1970s, *SYMAP* was one of the few mapping packages available to spatial demographers and population geographers.

Specific mapping programs like *PopMap* were developed. *PopMa*p is an integrated software package developed by the United Nations Statistics Division, with support from the United Nations Population Fund. It offers graphics, spreadsheet and mapping facilities with an integrated geographical database, making it appropriate for the planning and administration of population activities with an important geographical context. Exciting innovations took place during the 1970s and 1980s with the development of computer programs for cartograms (Tobler 1974, 1986) which were used to depict population distributions. Danny Dorling's algorithm for creating cartograms based on a uniformly shaped symbol (usually a circle) scaled on the basis of population size and placed in the centre of every polygon was created

**Fig. 7.2** Out-migration field for the North Riding of Yorkshire, 1961–65 (source: Stillwell 1979)

in the early 1990s (Dorling 1993, 1994) and used to produce The *New Social Atlas of Britain* (Dorling 1995). Figure 7.3 is an example of the application of Dorling's code to create cartograms for comparing migration efficiencies for those at retirement age (60–64) by city region in the UK and Australia (Stillwell et al. 2001). Effectiveness measures net migration as a percentage of the component gross flows involved for each city region. Tobler was also one of the first to develop software (*FlowMap*) for displaying migration flows utilising lines of differing width to depict directional movement (Tobler 1987). More recently, Tom de Jong at Utrecht University developed a software package with the same name to display flows of goods and people (de Jong and Floor 1991). Its capabilities were extended in subsequent years to include procedures for spatial clustering based on flow patterns, network

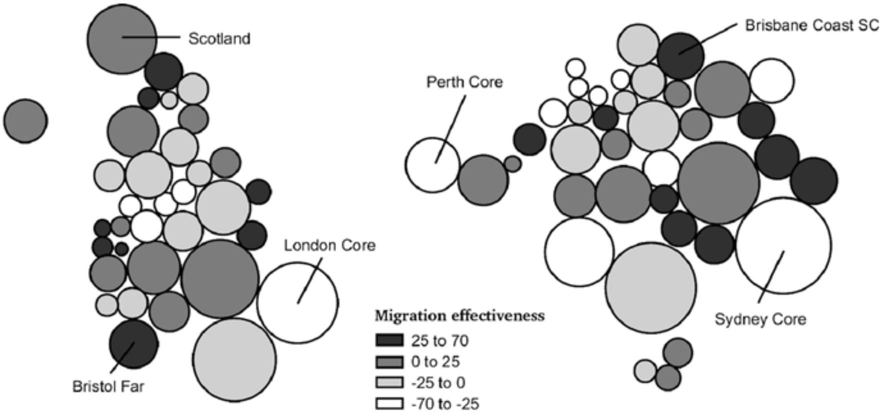


**Fig. 7.3** Cartogram representation of migration effectiveness [as in key and text] of people aged 60 to 64 by city region, UK and Australia, 1991–96 (source: Stillwell et al. 2001)

distance calculations, accessibility analysis and gravity modelling (de Jong et al. 1994; Geertman, et al., 2003).

More generally, the development of geographical information systems like *Atlas-GIS*, *MapInfo* and *ArcInfo*, and subsequent desktop versions, transformed the quality of map display through the use of a range of different types of mapping, from choropleth mapping of demographic indicators (Fig. 7.4) to maps with proportional symbols (Fig. 7.5). Geographical information systems not only provided the means for rapid visualisation of demographic data, but have also been used to map more sophisticated spatial demographic indices, such as location quotients, indices of migration effectiveness and indices of ethnic diversity. The last is illustrated for London wards in 2001 in Fig. 7.4. The areas with the darker shading are those whose population structures are most ethnically diverse. Geographical information systems also enable the integration of data, either through the overlay of different variables to show areas meeting particular conditions or through computing new variables from existing attributes, for example the calculation of migration rates using populations at risk as denominators. Moreover, GIS facilitates the visualisation of changes over time. Figure 7.5 illustrates the spatiotemporal evolution of average annual net migration for Family Health Service Authorities in England and Wales based on NHS patient re-registration data between 1980 and 1982 and 1988 and 1990 (Stillwell 1994).

More recent developments in geographical visualisation are reviewed in Slocum, et al., (2005) and include a range of new techniques, such as three dimensional mapping, map and graphical animation, knowledge discovery in databases, electronic atlases, multimedia systems, virtual reality and interactive visualisation. Only two ‘demographic’ examples of these new techniques are used here because of space constraints. The first (Fig. 7.6) illustrates the use of the 3D mapping function in MapInfo to emphasise the pattern of travel to work in Leeds by different social classes, based on Special Workplace Statistics from the 2001 Census (Stillwell

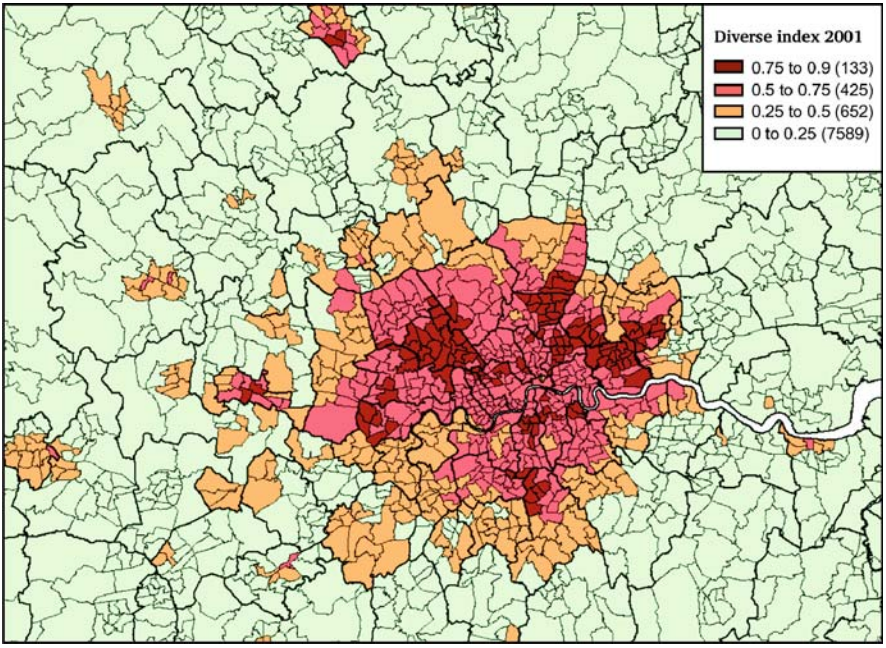


**Fig. 7.4** Ethnic diversity index for wards of Greater London and surroundings, 2001

and Duke-Williams 2003). This map series shows how professional and managerial workers (classes I and II) tend to commute to the city centre from the northern suburbs or districts adjacent to Leeds, or live close to the city centre, whereas skilled non-manual and manual workers (classes III(NM) and III(M)) tend to originate in the outer city wards and have a southerly orientation, as do those doing partly skilled and unskilled jobs (classes IV and V).

The second example is an interactive, web-based dynamic population pyramid developed by the Office for National Statistics (ONS). It allows the user to observe the changing age and sex structure of the population of England and Wales between 1961 and 2007. The user can either play the animation by clicking the play button on the right hand side or clicking on either the left or right arrow at either end of the slider bar under the pyramid. Furthermore, by placing the mouse over the pyramid the user can drag and click over one or more age groups to display information about that age group on the right hand side of the image. Figure 7.7 displays the demographic structure of the population in 1961 and 2007, highlighting the decline in the proportion of teenagers from 15% of the total population in 1961 to 12.6% in 2007.

The impact of ICT and geotechnology on the visualisation of spatial data has been as remarkable in demography as it has been in other disciplines. The pace of change is unrelenting, with the new developments taking place in grid technologies, web mapping, interactive web services and the advent of Google Earth and Google

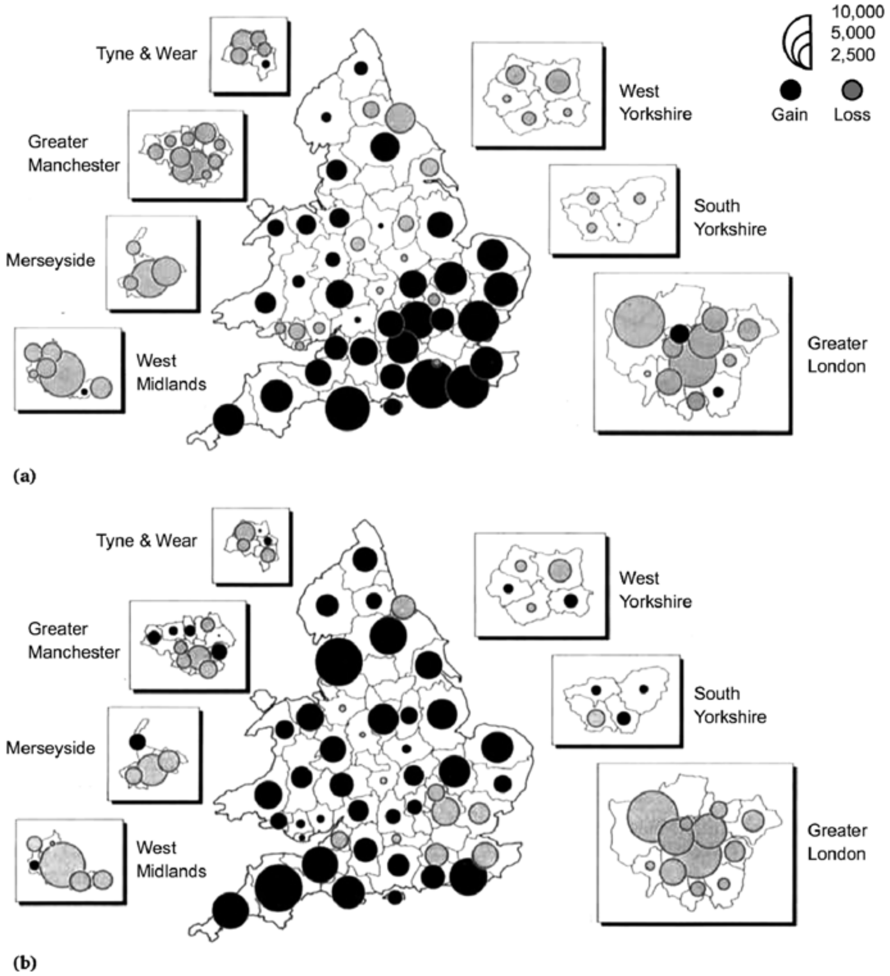


**Fig. 7.5** Average annual net migration by Family Health Service Authorities: (**a**) 1980–82 and (**b**) 1988–90 (source: Stillwell 1994)

Maps. The changes reviewed in this section have been matched by changes in the supply of and access to demographic data. These are considered in the next section.

## 7.4 Demographic Data Availability and Accessibility

The immense technological change over the last 30 years has impacted on data availability and accessibility as well as on mapping and visualisation. The volumes of demographic data being collected have risen enormously and they are becoming more available to the research community. This is partly due to the desire to collect more information about the attributes of the population and partly due to the

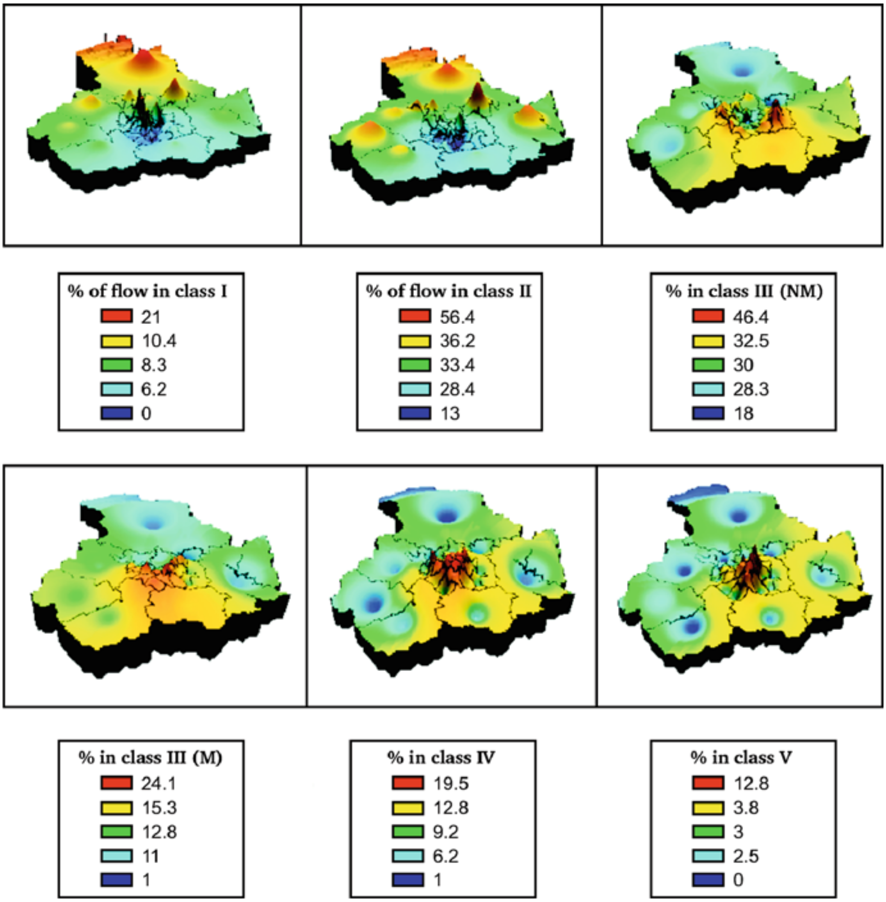
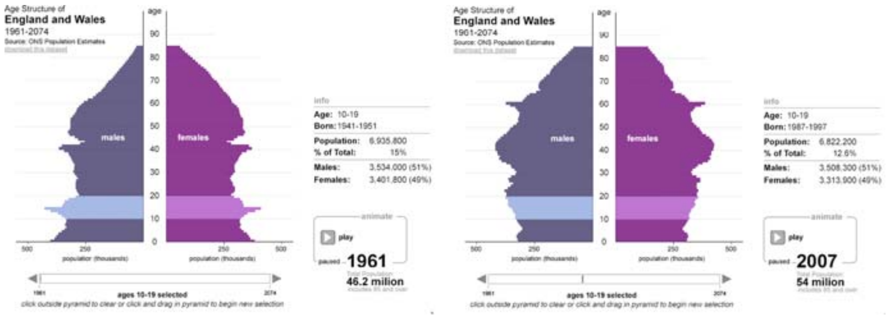


**Fig. 7.6** Proportions of commuters to central Leeds from other wards and surrounding districts by social class, 1991 (source: Stillwell and Duke-Williams 2003)

need for demographic data at finer levels of spatial resolution by those charged with delivering services and planning local communities. In some instances, this may involve data at the level of postcode units, households or individuals, although in the UK, for example, there remain confidentiality constraints to control the risk of disclosure with censuses and other types of public sector data. Demographic data come from three types of source: censuses, surveys and registers. In some countries without population registration systems, like the UK, the census remains critically important as a source of information for central government and local authorities, as well as a rich source of data for academic research.

### 7.4.1 Census Data

In the USA, the first census was undertaken in 1790 by the Census Bureau, an organisation which has subsequently played a pioneering role in the use of technology



Age: 10-19
Born: 1941-1951
Population: 6,935,800
% of Total: 15%
Males: 3,534,000 (51%)
Females: 3,401,800 (49%)
1961
46.2 million

Age: 10-19
Born: 1987-1997
Population: 6,822,200
% of Total: 12.6%
Males: 3,508,300 (51%)
Females: 3,313,900 (49%)
2007
54 million

**Fig. 7.7** Interactive visualisation of national demographic structure (source: http://www.statistics.gov.uk/populationestimates/svg_pyramid/ew/index.html)

since Hollerith founded what was to become the IBM Corporation. The US established a digital map base for its 1990 Census – the TIGER (Topologically Integrated Geographic Encoding and Referencing) system – which was used in both data collection and output. The 1970 and 1980 Censuses in the USA pioneered the use of topologically structured geographical base files – the DIME (Dual Independent Map Encoding) system for census organisation and output (Barr 1996). In Great Britain, the first census was in 1801 and recent censuses since 1966 have been decadal – in 1971, 1981, 1991 and 2001. The British census is the single most important source of small area sociodemographic data available. It is a good example of how GIS have been used in the census process and how the volume of information being collected and made available has increased. The Geography Area Planning System (GAPS) was used to automate the process of deriving the enumeration districts for data collection in the UK 2001 Census (Martin 1999a), which was the first to generate output for a different set of areas. The system for creating 'output areas' was fully automated and applied systematic and consistent criteria throughout the country. Its development became possible through the availability of increased computing power for automatic zoning methods (Openshaw 1977) and of coordinate referenced and postcoded data based on the Ordnance Survey Address Point product. In simple terms, the system created 175,000 Output Areas in England and Wales, each with around 125 households and populations which tended towards homogeneity, normally comprised of whole unit postcodes, and whose shape was reasonably compact and followed natural boundaries where possible. Comprehensive user guides to the 1991 Census in the UK have been produced by Dale and Marsh (1993) and by Openshaw (1995). Rees, et al., (2002) provide an authoritative guide to the 2001 Census Data System.

Although demographic researchers now have access to data for much smaller areas, the need for statistical disclosure controls using a series of measures, including the small cell adjustment method (SCAM), has restricted the value of the data, particularly the migration and commuting flows contained in the Origin-Destination Statistics (Stillwell and Duke-Williams 2007). The latter sets of interaction flows are one of the additional products of the last three censuses. Other new products are the Samples of Anonymised Records (SARs), introduced in the UK as one of the outputs of the 1991 Census, which offer a considerable degree of flexibility for multivariate analysis of individuals (Dale 1998). The SARs comprise a set of records relating to individuals and (where appropriate) households, with personal data such as names and addresses removed. Some fields in the records retain the full original coding, whereas others are recoded in order to prevent disclosure of information for identifiable individuals. There is a variety of spatial variables in the SARs, including residential location at the time of the census, location of address one year ago for migrants, and country of birth. Some locational variables are simple aggregates of more detailed base values. For example, 'county' in the 1991 Individual SAR is aggregated from the more detailed SAR area variable. The 2001 Small Area Microdata (SAM) improves on the spatial resolution used in the licensed versions of the 2001 SAR data. The new 2001 Controlled Access Microdata Sample (CAMS) files also offer improvements over their licensed counterparts. In particular, the 2001 Individual CAMS offers considerable scope for interaction-based analysis of migrants because the file is available on a UK basis and has an increased sample size compared to that of the 1991 Individual SAR.

In the UK the Joint Information Systems Committee (JISC) and the Economic and Social Research Council (ESRC) have invested in a Census Programme, the only one of its kind in the world, that allocates funds to a series of data support units. These provide the academic community with access to the various census datasets discussed above and guidance on how to use them. The data support units include:

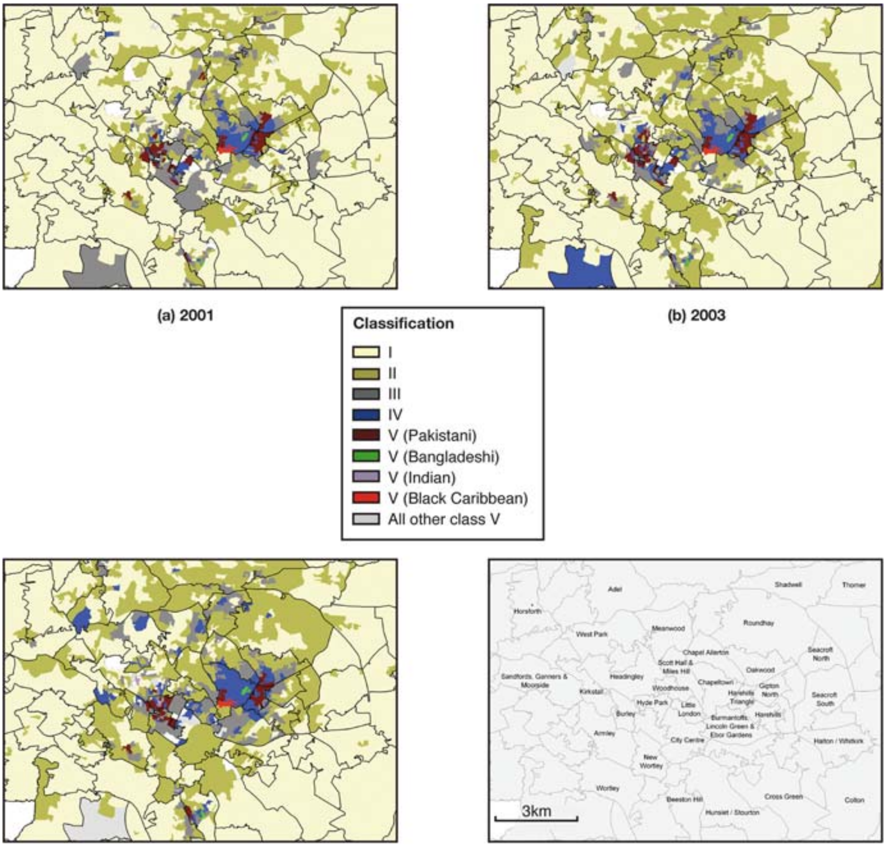
- the Census Dissemination Unit (CDU) at MIMAS, University of Manchester, which supports the Census Area Statistics and postcode lookup tables;
- the UKBORDERS service at EDINA, University of Edinburgh, which supports digital boundary datasets;
- the Centre for Interaction Data Estimation and Research (CIDER) at the University of Leeds, which supports the migration and travel to work statistics;
- The Cathie Marsh Centre for Census and Survey Research (CCSR) at the University of Manchester, which supports the Samples of Anonymised Records;
- the Centre for Longitudinal Study Information and User Support (CelSIUS) at the London School of Hygiene and Tropical Medicine, which supports the Longitudinal Study; and
- the Longitudinal Studies Centre Scotland, which supports the Scottish Longitudinal Study.

The first three of these units have web-based information systems that enable users to access data very quickly and download data files for further analysis and mapping. CASWEB is the software interface for the census area statistics, UKBORDERS allows users to download sets of digital geographical boundaries, and WICID, the web-based Interface to Census Interaction Data, enables users to build queries and extract sets of flow data by origin and destination (Stillwell 2006).

### 7.4.2 Administrative Sources

While population censuses are accepted as providing the most comprehensive and most reliable demographic data in the UK, there are many potential non-census datasets that originate from administrative sources and involve the collection of records arising from transactions, registrations or service delivery. These datasets are collected for administrative rather than purely research purposes and many of them are collected by government departments. In Spain, registration statistics provide detailed insights into population dynamics at the municipality level (Garciá Coll 2005), as they do in other European countries. Jones and Elias (2006) have completed a selected audit of administrative datasets in Britain, most of which are used to provide stock information. In some cases, registration data have a much simpler structure than census data and are only available at a relatively aggregated spatial scale, but are particularly valuable because they are produced regularly and frequently contain a geographical identifier. In other cases, the information has to be generated from the primary unit data using time-consuming data matching and manipulation algorithms. One key example of administrative data of value to spatial demographers is the registration system that records National Health Service (NHS) patients, whose migration is recorded when they change their doctor. The NHS Central Register (NHSCR) at Southport records movements of patients between Health Authority (HA) areas in England and Wales. The Office for National Statistics has developed systems for capturing the reporting of re-registrations of patients between areas. The advantages and shortcomings of the data have been identified by several authors, including Stillwell, et al., (1992) and Champion, et al., (1998). NHSCR data (an example of which is given in Fig. 7.5) have been used more recently for a major migration modelling study commissioned by the central government, which will be discussed in more detail in Section 7.6.

New administrative datasets with great potential for spatial demographic research are regularly becoming available. One example is in the education sector in the UK. Various data sets are collected and held by the Department for Children, Schools and Families (DCSF) within a centralised ‘data warehouse’. These include the National Pupil Database (NPD), local authority data, school level data, school workforce data and geographical data (Ewens 2005; Jones and Elias 2006). The NPD was established in 2002 and contains linked individual pupil records for all children in the state school system. The database is updated annually through the Pupil Level Annual School Census (PLASC), which collects data from each education authority in England and Wales. Each pupil is given a unique pupil number (UPN) and has an associated set of attributes: age, gender, ethnicity, special educational needs, free school meal entitlement, key stage assessments, public exam results, home postcode and school attended. The georeferencing of each pupil’s residential location enables much more detailed examination of the relationship between academic achievement and deprivation than has been possible in the past (Stillwell and Langley 1999) and opens up possibilities for new analyses comparing ethnic residential segregation with ethnic segregation in schools (Johnston, et al., 2006). Although PLASC data only relates to schoolchildren, it can be used to detect changes in the geography of ethnic minority communities over time. Figure 7.8 shows the dispersal of ethnic minority populations in Leeds from areas of initial concentration in Chapeltown/Harehills and Hyde Park over the last five years (Harland and Stillwell 2007). Figure 7.8 is based on a classification system used by Johnston, et al., (2006) allowing residential zones across the city to be identified according to the proportion of the host White British population and the proportions of different ethnic minority groups who live there. The zones used are output areas (OAs). Each OA can be classified using five types of area based on White and non-White proportions. At one end of the spectrum, category I refers to areas where over 80% of the population is White British, whereas at the other end, category V involves a non-White proportion that is greater than 70% and where one non-White group is in the majority. The three other categories fall between these extremes: category II has a White British majority of between 50 and 80%, category III has a White British minority of between 30 and 50% and category IV is where the White British minority is less than 30% but where


(a) 2001

(b) 2003

(c) 2006

(d) base

**Fig. 7.8** Ethnic minority dispersal in Leeds by output area, 2001, 2003 and 2006 no single non-White group is in the majority. Figure 7.8 demonstrates the extent of dispersal by OA, particularly the increasing transition of OAs from category I to category II.

### *7.4.3 Surveys*

Surveys are the third main source of demographic data. Large surveys such as the Labour Force Survey (LFS) and the International Passenger Survey (IPS) provide reasonably detailed data on the population of the UK, but are of limited value because their sample sizes allow only restricted spatial coverage. However, in many cases survey data are particularly valuable because of the cross-classification possibilities offered by primary unit data, even though the geographical dimension may be limited. A significant number of different surveys provide national if not regional data: the British Household Panel Survey, General Household Survey and National Travel Survey are key examples. Longitudinal data sets such as the Longitudinal Study (LS) and the Birth Cohort Studies provide particularly rich sets of data for demographers that include some spatial detail. Fielding's study of migration and social change and his conception of the South East as an 'escalator region' (Fielding 1989) were based on analysis of the LS between 1971 and 1981 (Fielding 1992).

In addition to these more official types of survey undertaken by public sector organisations, in recent years there has also been a proliferation of consumer surveys in which questionnaires are used to gather information from a sample of consumers. Each questionnaire may be sent directly to the sample group through the mail or the information may be obtained through in-person or telephone interviews. Consumer surveys are frequently undertaken for commercial or marketing reasons and a new subarea of spatial demography has developed around them in recent years.

## 7.5 Geodemographics

Geodemographics has been referred to as the "classification of small areas according to their inhabitants" (Rothman 1989, p. 1). Geodemographic systems have been constructed on the principle that people living in the same locality are likely to have similar socioeconomic or lifestyle characteristics and therefore these places can be categorised on this basis using some form of geographical clustering technique. The development of geodemographic classification systems made possible by technological improvements has become big business over the last three decades, resulting in the creation of a number of general purpose systems, such as ACORN from CACI and MOSAIC from Experían in the UK (see reviews by Batey and Brown (1995) and Birkin (1995)).

Traditionally, these systems have used residence-based population census data to provide indicators of demand. One important development has been the use of more non-census variables, including those from lifestyles databases derived from consumer surveys, as mentioned in the previous section. Lifestyle companies (such as Consumer Surveys Ltd, NDL and Experían) like to claim that no information in their databases is more than three years old (Sleight 1997). Debenham, et al., (2003) have argued that these proprietary systems still tend to remain entirely focused on the indicators of demand in a given area and pay no attention to characteristics associated with areas being workplaces. Workplace-based indicators, such as employment size and composition, capture dimensions of economic activity on the supply side. Furthermore, little attempt has been made hitherto to extend the type of variables beyond stock attributes, or to take into consideration measures of change on either the demand or the supply sides when selecting variables to add to the cluster analysis.

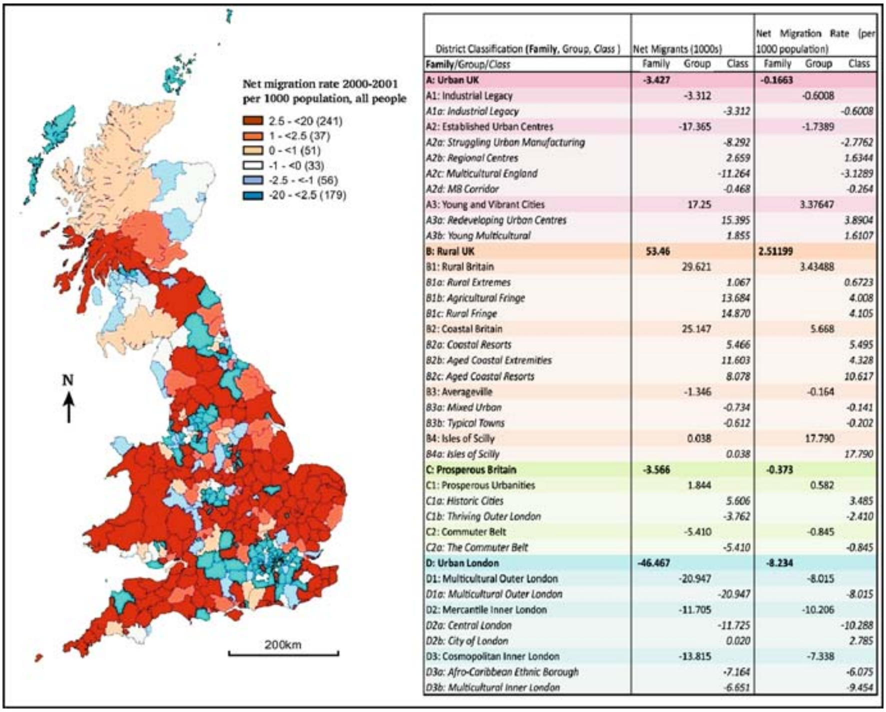
The development of geodemographic systems has not been without considerable debate over the relative merits and robustness of the classification process and the quality of the underlying data. The standard statistical blurring of census data in the UK to ensure confidentiality has introduced errors and the suppression of data "runs counter to many business applications in which an objective is to identify individuals or households with particular characteristics as precisely as possible" (Martin 1999b, p. 79). Likewise, Webber (1989) reveals that the inclusion of non-census data is not without problems. Another area of major concern faced by geodemographers has been the modifiable areal unit problem (MAUP) and the ecological fallacy. Openshaw (1984) defined two related components of MAUP. The 'scale problem' is "the variation in results that can be obtained when data for one set of areal units are progressively aggregated into fewer and larger units for analysis" (Openshaw 1984, p. 8). The 'aggregation problem' is associated with the fact that, at any given scale, the areal units can be grouped together in different ways. The ecological fallacy is concerned with the misrepresentation of an individual by assuming he or she must have the characteristics of the population in the spatial unit or 'cluster' used to aggregate the individual data. Harris (1999) rejects Cathelat's (1990) assertion that the demographic, economic and physical criteria of the cluster must totally classify the social individual. However, concern with these issues has led to consideration of alternative solutions, including the work on fuzzy geodemographics (Openshaw 1994; Feng and Flowerdew 1999; See and Openshaw 2001).

The development of geodemographic classification systems has not been confined to the private sector. In the UK, the Office for National Statistics (ONS) has produced its own Area Classification of clusters of geographical areas according to key characteristics common to the population in that grouping, derived using census data (Office for National Statistics 2005). The classification is used by government departments and academics for analysis and comparison, but can also be used by members of the public or schoolchildren to find out about where they live and how their area compares with the rest of the country. Classifications have been created at different spatial scales: local authorities, wards and output areas. Vickers et al. (2003)report on the methods used and results produced from a project undertaken in collaboration with ONS to create a classification of the UK's 434 local authorities, based on 56 variables from the 2001 Census Key Statistics. A three-tier hierarchy of clusters for the UK was generated, with a top tier containing five clusters called

Families, a second tier with 13 clusters or Groups, and a third tier with 26 clusters known as Classes. The classification is shown in the table on the right hand side of Fig. 7.9. The data in the table and the map provide an example of how such a geodemographic classification can be used in a research context to examine spatial patterns of net migration.

Figure 7.9 uses the Vickers, et al., 2001 area classification of districts in Great Britain as a framework for visualising the spatial variation in net migration rates, based on census migration data from the Special Migration Statistics for 2000–01. The map depicts very clearly the major losses of population through migration from the country's metropolitan areas and the gains experience in rural Britain. However, as the figures in the accompanying table signify, there are interesting exceptions within the four major divisions. The City of London is gaining, for example, whereas the rest of Urban London is losing, and while old established urban centres are losing population, the Regional Centres class is gaining in aggregate terms. In contrast, the two classes of the Averageville group both have net migration losses, whereas the Rural UK family in which they are classified has a massive net gain.

A classification based on the 223,060 output areas in the UK has also been produced (Vickers and Rees 2007) and is available as a National Statistic via National Statistics Online. It is also available as an interactive map via the Output Area



| District Classification (**Family**, Group, *Class*) | Net Migrants (1000s) | | | Net Migration Rate (per 1000 population) | | |
|---|---|---|---|---|---|---|
| **Family**/Group/*Class* | Family | Group | Class | Family | Group | Class |
| **A: Urban UK** | **-3.427** | | | **-0.1663** | | |
| A1: Industrial Legacy | | -3.312 | | | -0.6008 | |
| *A1a: Industrial Legacy* | | | *-3.312* | | | *-0.6008* |
| A2: Established Urban Centres | | -17.365 | | | -1.7389 | |
| *A2a: Struggling Urban Manufacturing* | | | *-8.292* | | | *-2.7762* |
| *A2b: Regional Centres* | | | *2.659* | | | *1.6344* |
| *A2c: Multicultural England* | | | *-11.264* | | | *-3.1289* |
| *A2d: M8 Corridor* | | | *-0.468* | | | *-0.264* |
| A3: Young and Vibrant Cities | | 17.25 | | | 3.37647 | |
| *A3a: Redeveloping Urban Centres* | | | *15.395* | | | *3.8904* |
| *A3b: Young Multicultural* | | | *1.855* | | | *1.6107* |
| **B: Rural UK** | **53.46** | | | **2.51199** | | |
| B1: Rural Britain | | 29.621 | | | 3.43488 | |
| *B1a: Rural Extremes* | | | *1.067* | | | *0.6723* |
| *B1b: Agricultural Fringe* | | | *13.684* | | | *4.008* |
| *B1c: Rural Fringe* | | | *14.870* | | | *4.105* |
| B2: Coastal Britain | | 25.147 | | | 5.668 | |
| *B2a: Coastal Resorts* | | | *5.466* | | | *5.495* |
| *B2b: Aged Coastal Extremities* | | | *11.603* | | | *4.328* |
| *B2c: Aged Coastal Resorts* | | | *8.078* | | | *10.617* |
| B3: Averageville | | -1.346 | | | -0.164 | |
| *B3a: Mixed Urban* | | | *-0.734* | | | *-0.141* |
| *B3b: Typical Towns* | | | *-0.612* | | | *-0.202* |
| B4: Isles of Scilly | | 0.038 | | | 17.790 | |
| *B4a: Isles of Scilly* | | | *0.038* | | | *17.790* |
| **C: Prosperous Britain** | **-3.566** | | | **-0.373** | | |
| C1: Prosperous Urbanities | | 1.844 | | | 0.582 | |
| *C1a: Historic Cities* | | | *5.606* | | | *3.485* |
| *C1b: Thriving Outer London* | | | *-3.762* | | | *-2.410* |
| C2: Commuter Belt | | -5.410 | | | -0.845 | |
| *C2a: The Commuter Belt* | | | *-5.410* | | | *-0.845* |
| **D: Urban London** | **-46.467** | | | **-8.234** | | |
| D1: Multicultural Outer London | | -20.947 | | | -8.015 | |
| *D1a: Multicultural Outer London* | | | *-20.947* | | | *-8.015* |
| D2: Mercantile Inner London | | -11.705 | | | -10.206 | |
| *D2a: Central London* | | | *-11.725* | | | *-10.288* |
| *D2b: City of London* | | | *0.020* | | | *2.785* |
| D3: Cosmopolitan Inner London | | -13.815 | | | -7.338 | |
| *D3a: Afro-Caribbean Ethnic Borough* | | | *-7.164* | | | *-6.075* |
| *D3b: Multicultural Inner London* | | | *-6.651* | | | *-9.454* |

**Fig. 7.9** Net migration rates by district, 2000–01, with summary by district classification

Classification (OAC) User Group website, where the user can choose to combine the areas classified into seven supergroups with either an Ordnance Survey map (Fig. 7.10) or satellite imagery.

This last example of interactive web mapping using two types of geographical data together with the results of a major clustering exercise is, in computational terms, a testimony to the extent to which technology, data and visualisation methods have developed since the early days of SYMAP. Advances in software for spatial data analysis have been rather more recent. Haining (1989) bemoaned the lack of tools for spatial statistical analysis in the 1980s, but since then there have been some significant developments. Generic tools like GeoDa (Anslein et al. 2006) have been created, with functionality ranging from simple mapping to exploratory data analysis, spatial autocorrelation visualisation and spatial regression, and new language environments like R, C++ and Java have emerged with which to build applications. Other tools like CrimeStat (Levine 2006) and STARS (Rey and Janikas 2006) – the Space-time Analysis of Regional Systems package that enables the dynamic exploration of spatial data measured over multiple time periods – have considerable potential for use by demographers. There have also been significant developments in demographic modelling, as indicated in the next section.

## 7.6 Demographic Modelling

Demographic modelling methods have a long tradition in population projection. Since the pioneering work of Rogers, Rees and Wilson discussed in Section 7.2, demographic population projection models have become more sophisticated as the migration component has been specified with more precision. Two particular chal-

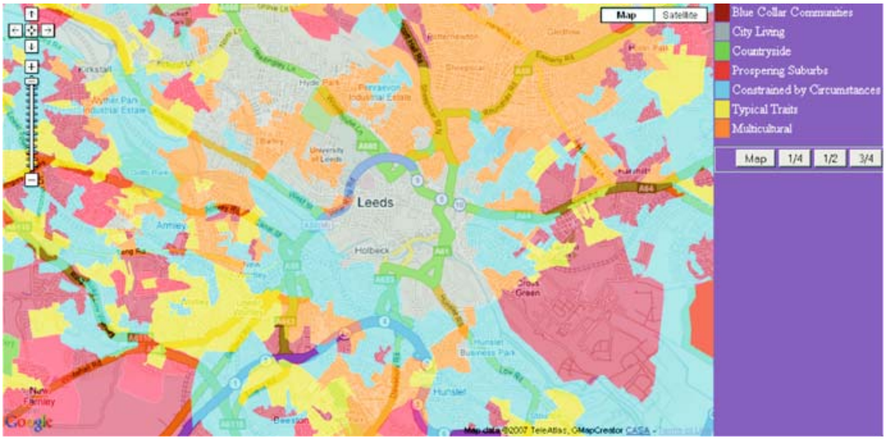


**Fig. 7.10** Detail from the 2001 Output Area Classification from the OAC website (source: http://www.areaclassification.org.uk/)

lenges have been how to incorporate some form of change into the parameters that govern the intensity and pattern of migration during a projection period and how to deal with the problem of huge data arrays when the origin-destination-time-age-sex dimensions are cross-classified in the model.

Approaches that build in temporal variance have been proposed. Plane and Rogerson (1986)discuss the use of causative matrices of ratios which link matrices of Markov intensities from one time period to another, in the same way that it is possible to extrapolate from a geometric regression based on two data points. Important work on the temporal stability of migration was undertaken in the 1980s in the Netherlands by Baydar (1983), who decomposed migration flows into an overall component or the total number of migrants in year t, a generation component or the probability of out-migration from region i in year t, and a distribution component or the probability of in-migrating to region j given origin i. Baydar then used a log-linear model to calibrate the parameters which quantify the time dependence of the different variables, and thus identified the most stable and volatile components.

The second challenge relating to the need to shrink large dimensional multiregional models occurs because a full multidimensional, demographic, subnational migration model has a separate parameter for every piece of information relating to the migration pattern. The data requirements and the computational problem are therefore very large indeed: for a system of 20 regions with 100 age groups and two sexes in any one year would involve a model with 20 (origins) $\times$ 19 (destinations) $\times$ 100 (age groups) $\times$ 2 (sexes) $=$ 76,000 flows. Van Imhoff, et al., (1997) have shown how far it is possible to simplify (shrink) the structure of the multiregional model before the resulting loss of information and accuracy becomes unacceptable.

It is interesting to observe that from a methodological point of view the multistate migration model used in demographic projections is similar in structure to the deterministic spatial interaction migration models of the type that researchers in population geography have been calibrating for several decades (Lowry 1966; Stillwell 1978; Fotheringham 1986). Both demographic and deterministic modelling approaches seem to have converged towards an approach that separates the modelling into two stages: (1) the projection of out-migration by age and sex from each region, and (2) the allocation of this pool of out-migrants to destinations. In both cases, the preferred method of calibration is by Poisson regression. In the case of demographic modelling, following van Imhoff, et al., (1997) and subsequently van der Gaag et al. (2000) the approach assumes that interregional migration is classified along five dimensions referred to by letters: O (region of origin), D (region of destination), A (age), S (sex), and T (time period). Consequently, the observed count of migrants is represented by Mijast where i and j are particular regions, a refers to one age group, s refers to males or females and t refers to one time period. The objective is to develop a model that describes each migration flow (or its corresponding rate) as the product of a limited number of parameters and then to examine the relative significance of the parameters. This approach seeks to answer questions such as, Are the parameters representing sex more important than those representing age? How important is the origin effect? Is the time trend significant? It also allows the significance of relationships between dimensions – the ‘interaction effects' – to be identified, for example between particular origins and destination regions or between certain age groups and sex. The Generalised Linear Modelling (GLIM) framework provides a suitable context for estimating the parameters of this type of model, although it can take a long time to calibrate all the parameters, despite the computing power available.

This approach differs from that adopted by a team of researchers in the UK (Champion, et al., 2003; Fotheringham, et al., 2004) who developed a state-of-the-art policy-sensitive model for the UK Government (ODPM 2002) in which separate log-linear models were fitted for each age group for males and females. *MIGMOD* (MIGration MODeller) also involves the separate modelling of out-migration from each area and the distribution of migrants between destinations, but in each case these are based on a set of determinant variables whose parameters and significance vary according to each of the flows being modelled. In the first stage, 14 age-sex group models were calibrated based on data for 139 potential determinants of out-migration. In the second stage an origin-specific distribution model was adopted, allowing the influences of 69 potential determinants of migration destination choice to be investigated on the outcomes for each of the 98 origins. Thus, it was possible to calibrate 98*14 or 1,372 separate models (for just one year), thereby generating a massive number of parameters which require special computerised routines to assist with interpretation.

Besides the population projection models (and the migration models) that have long been at the core of demography, *microsimulation* has also been a longstanding tradition central to the discipline. It has 'come of age' in recent years, facilitated by the changes in geotechnology that have occurred since its origins in the late 1950s (Orcutt 1957). As the name implies, microsimulation modelling works at the level of the individual, be that a person, household or firm, and requires very large computing resources if large populations are being simulated. Van Imhoff and Post (1998) provide a review of the differences between microsimulation and macrosimulation methods for population projection, explaining the problem that projections generated by microsimulation will always be subject to random variation, and outlining some of the microsimulation models that exist. These models include the *DYNASIM* model in the USA (Orcutt, et al., 1976), which simulated a range of demographic and socio-economic life events, the *MOSART-H* model (Brunborg and Keilman 1995), which analyses individual life courses with respect to education, marriage, births, etc. in Norway, and *KINSIM*, a dynamic microsimulation model providing insights into the size and structure of kin networks in the Netherlands. In each of the cases, there is no mention of the spatial dimension.

Geographical or spatial microsimulation typically involves the integration of census and survey data to simulate a population of individuals within households whose characteristics are as closely representative of the real population as possible (Clarke 1996; Ballas 2001). Thus, if the aim is to simulate the population of a whole city, the task of the microsimulation model is to replicate that population by creating a list of individuals with the attributes required, including a georeference. A city like Leeds requires a static dataset with over 715,000 simulated records, which can be constructed using different methods: synthetic probabilistic reconstruction models, which involve the use of random sampling; reweighting probabilistic approaches, which typically reweight an existing national microdataset to fit a geographical area description on the basis of random sampling and optimisation techniques; or reweighting deterministic approaches, which reweight a non-geographical population microdataset to fit small area descriptions, but *without* the use of random sampling procedures (Ballas, et al., 2005). Thereafter, dynamic modelling to update the basic microdataset is required. The models used for this may be either probabilistic dynamic models, which use event probabilities to project each individual in the simulated database into the future, or implicitly dynamic models, which use independent small area projections and then apply the static simulation methodologies to create small area microdata statically. One of the key advantages of microsimulation models like *SimLeeds* (Ballas 2001) is that they can be used to analyse the impacts of policy on the micro-units involved (Ballas and Clarke 2000, 2001). *SimLeeds* has been transformed into a planning support system called *MicroMaPPAS* for use by

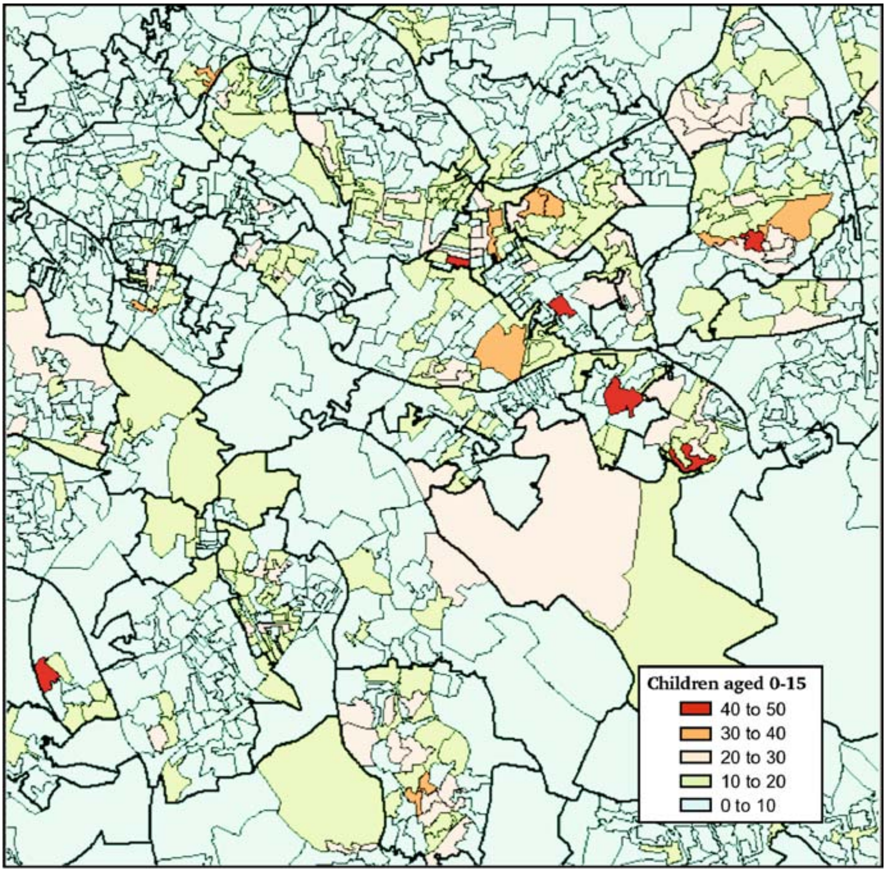


**Fig. 7.11** Simulated distribution of children in low income households, 2001 (source: Stillwell et al. 2004)

policymakers in an applied context (Stillwell et al. 2004; Ballas, et al., 2007). The microdata can be aggregated into spatial units such as output areas, postal sectors or wards, allowing the local authority providers to identify pockets of need. The example map in Fig. 7.11 shows output areas in Leeds with the simulated distribution of children aged 0–15 in households with very low income.

Spatial microsimulation can be a very computationally intensive process. In the last example, a process of simulated annealing is used to derive the simulated population, taking several hours for the model to be calibrated. Changes in computer technologies have clearly created the opportunity for this type of modelling to be undertaken for very large populations. The spatial microsimulation of the national population is now being used to exemplify the advantages of using grid technology in the social sciences (Dale 2005). The challenges that microsimulation raises for new computational algorithms, data organisation and model architecture also confront the application of agent-based modelling, another genre of model that has grown in stature over the last decade. Agent-based models have much potential for use in demographic research and also more broadly for modelling urban dynamics. *PUMA*, Predicting Urbanisation with Multi-Agents, is one example of a state-of-the-art, agent-based model that predicts land use changes based on the behaviour of agents that may be either individuals, households or firms (Ettema, et al., 2007).

## 7.7 Conclusions

This chapter has attempted to present an overview of some of the developments in demography that have been facilitated by geotechnology and which have led to an enhanced consideration of location, a much better understanding of demographic structure and dynamics in different places, and many new insights into the behavioural processes that result in linkages between different areas of the same country or different parts of the world. The emergence of spatial demography in the context of the development of multiregional population projections has been a hugely important driver for elevating the geographical dimension in demography and increasing the integration of demography and population geography. Moreover, the evolution of an entirely new subdiscipline, geodemographics, is evidence of a new-found applied demography in which the location dimension is of critical importance. Whereas spatial demography has been driven by the need for better projections for public sector planning, geodemographics is now as well established in the private sector as it is in the research community.

In both these cases, the developments have been underpinned by advances in computing technology, the availability of geographical data and the advanced application of new geographical methods to demographic information. The impact of technological change can be seen in the rapid evolution of mapping software used for visualising demographic variables, in the increased availability of demographic data accessible via the web, using more and more sophisticated web interface software, and in the emergence of new analysis and modelling methods for spatial analysis and simulation of populations and households. Not only has the last 20 years seen a proliferation of new packages for quantitative spatial analysis, but new methods and computer-based software for analysis of qualitative data have also emerged (Crang, et al., 1997). Programs such as *Nudist* and *ATLAS.ti* help researchers uncover and systematically analyse complex phenomena hidden in text and multimedia data. Demographic researchers, like researchers in every other discipline in which quantitative and qualitative data are used, have had to respond to the evolution of programming languages from Fortran and Algol to C++ and Java. They must embrace the need to create systems in which metadata specifications are an essential requirement and use the new web technologies, such as mark-up languages like XML or GML that allow internet browsers to view web-based mapping without additional components or viewers. There is no doubt that the technological infrastructure as well as the programming tools, the data management systems, the data transfer protocols, the standards and the developments in interoperability have transformed demographic research.

However, the conclusion that emerges from this overview is that geomodelling (rather than geodatabase or geomapping) has been the framework that has dominated Geo-ICT approaches in demography. Demographers have pioneered the development of new spatial models and produced algorithms for use in a range of specific contexts, sometimes utilising the database and mapping technologies to store and display the inputs and outputs of their models. Typically, these modelling methods have not been incorporated into generic GIS in a direct way; the interface between modelling and GIS referred to as the ‘missing link’ (Scholten and Padding 1990) has not been bridged. There are no proprietary GIS packages that offer specific demographic modelling methods. We have to look to the development of customised decision support systems and planning support systems for evidence of more integration between modelling and GIS, but even in this context, systems such as *MIGMOD* and *MicroMaPPAS* mentioned in the last section have made use of open source mapping routines rather than proprietary GIS. In terms of a model of integration, it is difficult to identify particular individuals other than Stan Openshaw (though I suspect he would not have labelled himself a demographer) who have championed the application of GIS in demography, or to find many conferences dedicated to this topic, or even containing strands on demography and GIS. However, there is little doubt that demographers and population geographers have recognised the value of GIS for spatial visualisation and analysis and have either trained themselves or taken courses in GIS to acquire the skills to use the tools and functions that GIS provides in handling spatial data. The demand for training has certainly been fuelled by the availability of increasingly large datasets and the need for researchers to analyse and map the information held in proprietary databases. Consequently, GIS training has become more integrated into demographic methods training.

In reflecting on the technical and methodological obstacles preventing the optimum uptake of GIS, we must acknowledge that demography, unlike its ‘big brothers’ in the social sciences (human geography, economics, sociology), is a relatively small discipline in terms of range of content. It has no place as a distinct subject in the school curriculum or at undergraduate level, although many social science degrees do contain demographic modules or materials. Demography is really only taught at postgraduate level, where it emerges as an independent discipline, but even then the number of Masters programmes remains relatively limited. It is interesting to assess the theoretical factors that Venkatesh and Davis (2000) identify in their extended Technology Acceptance Model (*TAM2*) as influencing the propensity to use geotechnologies in demography. The authors distinguish three social forces impinging on the potential user – subjective norm, voluntariness and image – and four cognitive instrumental determinants of perceived usefulness – job relevance, output quality, result demonstrability and perceived ease of use. We can deal briefly with each of these but we must recognise that Venkatesh and Davis are dealing with the application of technology in a range of manufacturing or commercial service industries, not in the more liberal atmosphere of the GIS research laboratory or the demographic research project. Consequently their analysis is probably more appropriate for considering geotechnology adoption in private consultancy or practitioner-based contexts rather than in the world of academic research. Nevertheless, I am happy to offer some considerations from my own perspective.

Firstly, I would agree that the *subjective norm*, which suggests that an intention to use a particular geotechnology is influenced by those people who are important to the researcher, has some credence in the application of Geo-ICT in academic demography. There are eminent professors who build their research teams around particular paradigms and methods and it is likely that early-stage researchers will follow in the footsteps of their mentors. This leads to the development of a particular culture which may be place- and time-specific. An example of this from my own experience as a young researcher was working under the leadership of Alan Wilson at Leeds during the ‘quantitative revolution’. The predominant paradigm at that time was systems theory and the key techniques were entropy maximising or spatial interaction models (Wilson 1970) that could be applied as logically to migration behaviour as they could to shopping or transport flows. Although there was a degree of *voluntariness* in the approaches that were used for modelling, the pressure for compliance was considerable and was reinforced by the methods that were taught formally at the time and by the availability of support and understanding of the methodology. When Stan Openshaw succeeded Alan Wilson in the 1990s, the paradigm shifted and new geotechniques based on artificial intelligence became popular. In the twenty-first century, Leeds has shifted again to being a centre of expertise in microsimulation and agent-based modelling. Thus, while the role of the champion is critical, there is also a dimension of fashionability that is also influential in the adoption of particular methods. Researchers tend to comply with the technology fashion of the day, which will change over time according to the nature of the data that are available, but also, increasingly, according to the ease of use, whether for modelling/programming or GIS. Particular centres of expertise come and go and the influence of the subjective norm on the perceived usefulness will weaken with *experience*; it is really only possible to assess whether the method does what is required satisfactorily once it has been tried and tested by the individual user. *Image* is also important in demography. A researcher who has the acquired the skills to use geotechnology, be it modelling or GIS, is respected by colleagues and becomes the focus for assisting others. This is increasingly evident as the 'quantitative skills deficit' has become more apparent and fewer students graduate with the inclination to pursue a career using Geo-ICT methods.

In terms of cognitive instrumental processes, each of the factors of job relevance, output quality and result demonstrability has an impact on the use of geotechnology. Researchers in demography will evaluate the degree to which the model or the GIS will satisfy their job goals (*job relevance*), but they will also take into consideration how well the system performs (*output quality*), making judgements about which approach is the 'best method'. A good example of this is the process of selecting the optimum clustering method in geodemographics. Similarly, the tangibility and interpretability of the outputs (*result demonstrability*) are also likely to affect the perceived usefulness of a technique in demography and therefore influence its adoption. Finally, whereas these social and cognitive processes influence usage behaviour through their impact on perceived usefulness, spatial demographers and population geographers are typically less influenced by the perceived *ease of using* geotechnologies. They are aware that human behaviour is complex and requires sophisticated mechanisms for effective simulation. However, there are other disincentives. In both spatial demography and population geography, time series analysis in the UK, for example, has not been encouraged by the continuous series of boundary changes occurring at different spatial scales. Consequently, although much good work has been done on the development of look-up tables and the use of GIS to facilitate the conversion of data from one set of geographical areas (e.g. enumeration districts) to another (postcode sectors), spatiotemporal analysis of demographic phenomena in a geographically consistent way remains a significant technical challenge, particularly at small area scales. The propensity for administrative and government authorities to make boundary changes to geographical areas at different spatial scales continues undiminished, at least in the UK. This tendency enhances the value of geographically referenced microdata that can be aggregated using GIS methods to any formal, functional or administrative spatial unit.

Looking forward to the coming decades, however, we must acknowledge that one of the major challenges confronting the world of demographic research (and policymaking) is to understand the immense changes that are occurring and will transform the demography of much of the world. These changes are taking place primarily, but not exclusively, through changing patterns of childbearing and household structure, ageing and migration, and these dimensions are interlinked on a global level. As birth rates fall and childbearing is postponed, and as more people live longer in much of Western Europe, increasing levels of international migration will probably be required to sustain economic development. In more and more regions of Europe, it is likely that population change through international migration will exceed any change brought about through internal migration. Changes in patterns of migration may have unpredictable consequences, but will inevitably be interrelated with labour market, housing and welfare issues. Demographers will need to work more closely with researchers from other disciplines to understand the trends, processes and implications more clearly. A key question is whether the research community in spatial demography will be able to harness the new ICTs that are emerging – web mapping, web services, grid technologies, for example – to advance demography in the same way that development of GIS, modelling and internet technologies have transformed the discipline over the last 30 years.

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# Chapter 8
# The Adoption of Geo-ICT in Economics: Increasing Opportunities for Spatial Research in Economics

**Jasper Dekkers and Piet Rietveld**

## 8.1 Introduction

The field of economics has developed tremendously since its beginnings in the late eighteenth century. Although this social science studies the economic aspects of human behaviour in its broadest sense, social processes were at first not addressed in a spatially explicit way, except by Johann Heinrich von Thünen (1826). More than a century would pass before economists started to recognise the importance of space and location in the study of the production, distribution and consumption of wealth. Spatially-explicit theories, algorithms and models like those developed by Weber (1929), Christaller (1933), Lösch (1940) and Alonso (1964) formed the basis for the birth and growth of various economic subdisciplines like regional economics, urban economics and transportation economics, as well as providing a theoretical basis for economic geography.

The adoption of Geo-ICT in economics has been slow and patchy, the main application being GIS software for mapping economic data. Geo-ICT is also used for other purposes than mapping, mainly for data exploration, spatial analysis and modelling in the fields of spatial economics and geomarketing. So far, spatial data have mostly been used for cross-sectional analyses. Based on analogous modelling problems with observations close together in time, mathematical tools have been developed by spatial econometricians to account for the spatial dependence of observations. We expect that the advent of dynamic location technologies and the ensuing real-time data collection possibilities will increase the demand for combined space-time methodologies and algorithms, not only for spatial economics but for science as a whole.

We begin this chapter with a short historical overview of the development of economics as an autonomous social science and the development of the various spatially explicit subdisciplines (Section 8.2). In the remainder of the chapter we focus on the field of spatial economics, starting with an attempt to define the field of study more precisely in Section 8.3. We discuss the role of Geo-ICT in this discipline by

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first describing the key Geo-ICT framework for the discipline and then highlighting three current research cases to illustrate the general use of Geo-ICT in the field (Section 8.4). In looking to the future of spatial economic research, we ask which technical and methodological obstacles have to be overcome to ensure fuller use of Geo-ICT (Section 8.5) and what economists can contribute, including a preview of new research opportunities that can be explored soon (Section 8.6). Although this chapter discusses developments in economics globally, we choose to adopt a Dutch or European perspective and use examples from our own work to illustrate current research themes.

## 8.2 The Science of Economics

### *8.2.1 Classical Economics*

The modern age of economics began with the Industrial Revolution and Adam Smith's *An Inquiry into the Nature and Causes of the Wealth of Nations* (1776), although it was still called political economy at the time. Smith was influenced by the Physiocrats, a group of Enlightenment thinkers which originated in France (see, for example, Cantillon 1755; Quesnay 1758). He strongly opposed Mercantilism, focusing on agriculture rather than on trade as the main driving force for the derivation of the wealth of nations, and arguing in favour of free trade and less government intervention. His work paved the way for the transition from political economy to economics as an independent systematic social science.

Since about the beginning of the nineteenth century, economic theory has generally distinguished between three production factors: capital goods, labour and natural resources (or land). "This 'classical triad' developed from the recognition of the three categories of participants in the economic process – landowners, workers and capitalists – associated with a triad of incomes – rent, wage and interest" (Hubacek and van den Bergh 2006, p.13). Being a landlord himself, von Thünen (1826) explicitly includes *location* as an explanatory variable for the maximum land rent per hectare by taking transport costs (i.e. distance to the market) into account. Using his land rent theory, von Thünen was able to explain the pattern of agricultural land uses around a city by looking at the maximum land rent per hectare ($R_{max}$) that a tenant can afford to pay a landlord. This can be calculated as follows:

$$R_{\max} = Z \cdot (P - (CP + CT \cdot D))$$

where:

Z = aggregate output (yield per hectare);
P = market price in € per unit crop;
CP = production costs in € per unit crop;
CT = transportation costs (freight rate in € per unit crop per mile);
D = distance from market (in miles).

The function shows that the maximum land rent a tenant farmer can afford to pay is equal to his profit (P-C). In a competitive bidding process with other tenant farmers, this means that the landlord effectively captures the entire profit in the land rent, leaving the tenant farmer with a zero profit margin. The product price is determined by the market and the production costs are equal for each location. The transportation costs linearly increase with distance to market. Using this land rent theory, von Thünen drew up a picture of agricultural land uses around a city (Fig. 8.1). Tenant farmers prefer to grow their crops closer to the city since there

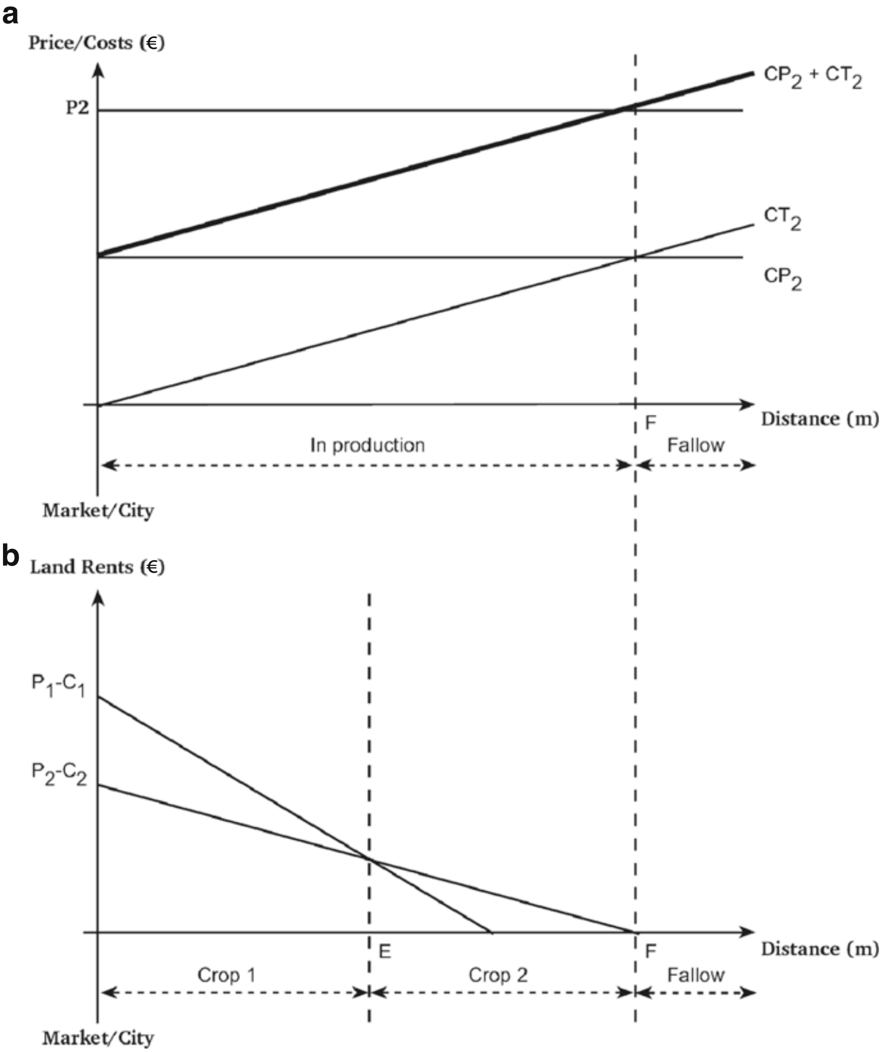

**Fig. 8.1** Relation between price, production and transportation costs, and distance to market (**a**) for crop type 2, (**b**) for two types of crops, location and land use

they will make a higher profit because of lower transportation costs. It follows that they will be willing to pay a higher land rent closer to the city. Beyond distance E, it becomes more profitable to grow crop type 2. Beyond distance F, growing crops is not profitable at all, with land lying fallow from this point on.

Von Thünen in fact constructed the first *deductive land use model*, the foundational model on which many subsequent models have been developed. His work makes him the founding father of *regional economics*. His fixed-coefficient model has been developed into a more general variable-coefficient 'bid-rent' model which permits substitution between land and other production or consumption factors (McCann 2001) and analysis of both urban and rural land prices.

### *8.2.2 Neoclassical Economics*

The term 'economics' became common around 1870 with Alfred Marshall, who is also associated with the development of neoclassical economics and the marginalist revolution: the marginal theory of value, price as a function of supply and demand, consumers' marginal utility functions and the concept of opportunity costs. Neoclassical economics probably emerged as a consequence of several changes in the environment at the time: "...the longevity of the industrial revolution, the pace of technological developments, shifts from food and fibre-based economies to mineral and fuel-based economies, and economies in the industrialised world that seemed to be almost independent of extractive industries" (Hubacek and van den Bergh 2006, p.13). Neoclassical theory, in contrast to classical theory, allows for substitution of production inputs. With this notion in mind, spatial substitution of inputs by, for instance, decreasing the distance to a cheap, abundant production input is possible. Spatial (physical) substitution was first introduced to a broader audience by Predöhl in 1928 (1925, 1928). In fact, he employed a variant of the partial equilibrium location theory as described previously by Weber (1909, English translation: Theory of the Location of Industries, 1929), whose seminal work *Über den Standort der Industrien* formed the basis for the field of industrial location theory.

Von Thünen wrote his theory at a time when agriculture still dominated society. During the 1950s, Isard (1956) placed the theoretical work of von Thünen in a broader context, arguing that the theory, in essence, only states that land will be used for those activities that will yield the highest return on investment. Following the theories of Isard, Alonso (1964) developed the *bid-rent theory*, to explain land use and land prices in an urban context. The theory assumes that land prices decrease with increasing distance from the city centre – where the Central Business District (CBD) of this monocentric city is located – since commuter costs increase. In making a bid for housing, households have to assign a value to commuter costs, the numbers of square metres of land they want to buy and other goods. The theory allows for substitution between land and other production and consumption factors. Alonso's model assumes decisions are made under maximising behaviour and is a *utility maximising model*. It is based on the American urban areas that started to develop in the nineteenth century and, because of its simple form, allowed powerful mathematical analysis (Anas 1982). For his modelling efforts in this area, Alonso is generally regarded as the founding father of *urban economics*.

Muth (1969) and Mills (1967, 1972) extended Alonso's utility maximisation model, and in doing so strengthened the foundation of the field. Many others have further developed Alonso's theory. For instance McFadden (1978) chose to pursue *stochastic* maximisation models to make Alonso's theoretical model more practically applicable in empirical models. These discrete choice models are also important in the field of *transport economics*, which deals with questions related to transport markets, transport demand, infrastructure investments, pricing and economics of transport nodes. This subdiscipline was founded in the 1950s and 1960s with the development of traffic flow theories and the use of discrete choice models for calculating the probability of choices between different modes of transport over a network.

Another subdiscipline of spatial economics, simply by virtue of its nature, is *environmental and resource economics*. The distance factor is part of the notion of local externalities of economic activities, like noise, as studied in hedonic price analyses of real estate (Bateman et al. 2002) and in the valuation of natural areas. In the latter, distance is related to travel costs as an indicator of willingness to pay for recreational visits to such areas (Freeman 1979). Bateman (1994) is the first exploration of the possibilities for using GIS in hedonic price studies.

The increase in computer power has paved the way for the development of the subdiscipline of *spatial econometrics*, which explicitly focuses on spatial dependence in econometric models (Bateman et al. 2002). Spatial econometrics as a discipline first started to grow through the modelling efforts of urban and regional economists (e.g. Paelinck and Klaassen 1979). Indeed, Paelinck is accredited for having introduced the term 'spatial econometrics' in 1974 (Bateman et al. 2002). In recognition of his pioneering efforts, Paelinck can be seen as one of the founding fathers of spatial econometrics. Much research has been done in this field since by Anselin, Florax and others (see, for example, Anselin 1988a).

Although there is much overlap between the disciplines of spatial economics and economic geography (which will become clear in Section 8.3), the main difference is that economic geography focuses mainly on describing economic observations related to concrete, geographical places, whereas spatial economics studies the economic implications of abstract notions of space and distances. However, for the last twenty or more years the disciplines have been converging and we expect this trend to continue in future.

## 8.3 Spatial Economics

As indicated above, we define spatial economics as the umbrella term for regional economics, urban economics, transport economics, environmental and resource economics and spatial econometrics. While theory based, it is at the same time an application-oriented field within economic science. Sometimes this has generated groundbreaking contributions to mainstream economic theory, including the notion of consumer surplus in welfare analysis introduced in the nineteenth century by Dupuit (1844) for developing decision rules for planning canal systems, Pigou's work on the pricing of (spatial) externalities (Pigou 1920), and the discrete choice and logit models mentioned above, for which McFadden was awarded a Nobel Prize.

In common with other broad disciplines like economic geography and planning that together with regional economics can be grouped within the field of regional science, the boundaries of the field of spatial economics are fuzzy and hard to define. Any attempt to do so would be open to dispute. Nevertheless, we need to demarcate the field to clarify at least what we include and what we exclude when we talk about the discipline. Figure 8.2 depicts how we view our field of study. The rows represent subdisciplines that are part of or related to economics. The discipline of geographic information science probably has the most indirect link of them all. The columns represent various main disciplines. The crosses indicate which main disciplines have had a great influence on the birth and development of the subdisciplines. A bold cross means that a main discipline has had relatively more influence.

Geo-ICT is not widely used in economics. In recent decades it has experienced a gradual but steady increase in use, mainly in specific strands of the discipline, particularly the economic fields that can be designated as belonging to spatial economics. It is estimated that around 50 per cent of all journal articles and conference papers published now in the field of spatial economics probably could not have been written 15 to 20 years ago. Neither the large quantities of spatial information nor the necessary tools to integrate, analyse and visualise these data were available then (van Manen et al. 2006). Now that these data are becoming more widely available, we have witnessed a gradual shift from exploratory towards explanatory research.

| | Disciplines | Economics | Geography | Informatics | Mathematics | Cartography | Planning | Environmental studies | |
|---|---|---|---|---|---|---|---|---|---|
| Spatial Economics | Marketing | x | | | | | | | |
| | GeoMarketing | **X** | x | | | | x | | |
| | Business Geography | x | **X** | | | | x | | |
| | Planning | x | x | | | | x | x | Regional Science |
| | Economic Geography | x | **X** | | | | x | | |
| | Regional Economics | **X** | x | | | | x | | |
| | Urban Economics | **X** | | | | | x | | |
| | Transport Economics | **X** | | | | | x | | |
| | Environmental Economics | **X** | | | | | x | x | |
| | Spatial Econometrics | **X** | | x | x | | | | |
| | Ecological Economics | x | | | | | x | **X** | |
| | Geographic Information Science | | x | x | x | x | x | | |

**Fig. 8.2** Spatial economics and its relations with other disciplines

It is even fair to say that in some subdisciplines, like the modelling of future land use, spatial economists have progressed beyond these stages and have reached the ‘decision making supportive stage’ (see van Manen et al. 2007a and 2007b for a description of these stages). We also see that the introduction of GIS in sciences has the potential to unite the otherwise opposing scientific nomothetic and idiographic approaches. The former approach focuses on definite truths and generalisations, the latter tries to identify and record unique properties of places. Using GIS, these two foci can be combined in a ‘place-based’ or ‘local analysis’ approach, with the goal of identifying properties that distinguish places within the context of a general framework. Geographically Weighted Regression (GWR, Fotheringham et al. 1998, 2000) and Local Indicators for Spatial Association (LISA, Anselin 1995) are two new methods that fit into this approach. The role of GIS as a bridge between opposing scientific approaches becomes apparent when we consider a GIS as consisting of two parts: the data (or database) part, that is in essence idiographic in nature, and the part representing functions, algorithms, methods and models, being nomothetic in nature (Goodchild and Janelle 2004).

Although the use of Geo-ICT in economics clearly expands the research opportunities in the field, so far economists have made little contribution to the further development of GIS as a scientific discipline. The majority of economic researchers use GIS as a modelling and mapping tool. The use of GIS is no longer an issue and is comparable to the use of statistical software packages. Bateman et al. (2002) report that for the field of econometrics, Smith (1996) and Irwin and Geoghegan (2001) argue that this can be at least partially attributed to a semantic difference in the use of the term ‘space’ between econometrics and GIS: for spatial econometrics, the goal is to specify models properly by ‘correcting’ for spatial effects, whereas in GIS space and spatial data are used to ‘create’ new insights into spatial processes and the driving forces behind them. Fotheringham (1999a, 1999b) notes that, at least until recently, GIS software packages did not incorporate many spatial-econometric analytical tools, while the ‘creative’ use of space has led environmental and resource economists to take up the use of GIS in their field of study.

## 8.4 Integration of Geo-ICT within Spatial Economics

The discipline of spatial economics clearly presents a fertile breeding ground for the integration of Geo-ICT because it already includes firmly established spatial concepts. Geo-ICT can help spatial economists to operationalise these spatial economic concepts. The existence of these concepts probably increases the rate of adoption of Geo-ICT, at least compared with disciplines that lack such spatial concepts.

### *8.4.1 Locational Information*

Within the discipline of economics we can make a distinction between theory on the one hand and methods and data on the other hand. In recent decades both domains have undergone rapid development. In the theory domain, the ideas of new economic geography, in particular, have had a strong impact on developments (Florax and Plane 2004). There has been strong interest, too, in the field of data and methods. Three types of data developments, backed by large quantities of empirical data, have fed the upsurge in testing of new methodologies and research methods. First, large single databases, consisting mainly of national surveys and large administrative databases like income tax data, are becoming increasing availability for research purposes. Second, individual databases are being linked together, creating new or enriched information. However, as issues of privacy and confidentiality come increasingly into play, this linking of databases in individual countries is moving further out of step. In the Netherlands, for instance, privacy is more of an issue than in the Scandinavian countries, where many more individual databases are already linked, giving access to detailed information about family relations, income tax, employer history, etc. Third, data on individuals has been linked to neighbourhood data using spatial coordinates. This is where the influence of Geo-ICT on spatial economics is most apparent. Remote sensing data from either satellite imagery or aerial photographs provide enormous amounts of data on the earth's surface. This allows the analysis of different facets of the economic landscape, for instance the explanation of differences in land development patterns across urban areas (Overman 2006).

This last category, supported by Geo-ICT, is also the driving force (now that the necessary data have become available) behind a development that is creating a multitude of new research opportunities and finally enables fully-developed methodologies to be tested. This development is linking microeconomic data to environmental data. Now, for example, we can calculate the optimal transport noise level by examining costs and benefits on a detailed spatial scale for an entire region. One can, for instance, econometrically estimate spatial environmental externalities like the impact of transport noise on house prices using hedonic pricing models (see, for example, Dekkers and van der Straaten 2008). Another example is linking data on individual house or land transactions to all sorts of other datasets and environmental quality features to explain what factors influence the market price of a house or a parcel of land (see, for example, Geoghegan et al. 1997; Buurman 2003; Dekkers and Koomen 2008). Until recently these database integrations have been limited to static data, but now new location technologies like global positional systems (GPS) and ultrawideband telecommunication networks have become available. Combined with the vast expansion of data storage capacity on computer hard drives and the growth of computer processing power, a whole new world of research opportunities lies waiting to be explored.

### *8.4.2 Dominant Geo-ICT Framework*

As Scholten et al. (2008) describe, there are three key frameworks for the use of Geo-ICT in science: geodatabase, geomap and geomodel. Overman (2006) claims that the most frequent application in economics is the visualisation of economic data that have a spatial component. The geomap framework may very well have been dominant in general economics until recently, but the geomodel framework is now gaining ground, certainly in the spatial economics domain where it is unquestionably dominant due to the large numbers of spatially explicit models used in this discipline. Its rise is fed by the increasing availability of spatially referenced economic data (Duranton and Overman 2005). It enables economists to add spatially explicit variables to their statistical models on a larger scale of analysis and to a higher degree of spatial accuracy. The generation of spatially explicit data can range from explicitly including the spatial dimension of census data in statistical models to more advanced data generation using specialist GIS functionality – for instance, the identification of whether observations occur at certain locations and the listing of (spatially explicit) characteristics of those observations at those specific locations. The example of a hedonic price analysis of land parcel prices and the accompanying spatial characteristics mentioned in the previous section (Buurman 2003) is an example of such an advanced GIS-supported analysis (see Bateman et al. 2002 for a broader review of GIS applications, specifically in environmental and resource economics). Statistical procedures that explicitly take space into account in models, such as the correction for spatial autocorrelation in regression models (see, for example, Anselin 1988a, 1988b), are also becoming more common for analysing spatial economic phenomena.

Now that we are approaching the ‘decision-making supportive stage’ in spatial economics, we expect the geomap framework to grow in importance again. At this stage, the goal is to improve the communication of research results to end users by showing maps next to graphs and tables. Using Geo-ICT in this way can help to make scientific findings more applicable to policymaking, for instance. Explanatory variables can be visually matched with policy options or measures. For example, the construction of infrastructure (a policy measure) improves the accessibility of a site (policy indicator), which in turn affects the value of a plot of land. Since the rapid rise of applications like in-car navigation systems, Microsoft’s Virtual Earth and Google Maps, people are getting used to interacting with non-static maps and are increasingly aware of the possibilities digital maps can offer. The first multi-user interactive group decision support systems (GDSS) suitable for spatial applications have already been developed in the form of digital tables with touch screens (see, for example, Forlines et al. 2006) (Fig. 8.3). They allow an increase in the information density of maps, which reduces the need to oversimplify the geographic presentation of scientific findings.

In the near future, the move towards real-time dynamic collection and analysis of very large quantities of location-specific data will increase the importance of the geodatabase framework in economics. Since dynamic location-based data collection methods can literally fill a database with terabytes of data in a few hours, smart data filtering algorithms will have to be devised to make this type of data capture possible on a large scale. Only the data that is of importance for the analysis should be stored, and in a compact way. We can thus conclude that although the geomodel framework is the most important framework for Geo-ICT in spatial economics, the geomap framework and the geodatabase framework are both important as well, and are likely to grow in importance in the near future.

**Fig. 8.3** A multi-user interactive GDSS application for modelling land use change

## 8.5 The Use of Geo-ICT in Spatial Economics

As noted in the introduction, the field of spatial economics has experienced a gradual shift from exploratory towards explanatory research, and even beyond that into the 'decision-making supportive stage'. Scholten et al. (2008) describe a 'Geo-ICT-Integration or Diffusion Model' for the integration of Geo-ICT in science, consisting of seven stages. It would be interesting to use this model to analyse the process of adoption of Geo-ICT in spatial economics (Table 8.1), although it is not an easy task. For instance, we could choose to monitor Regional Science Conferences to see when the first GIS topics appeared in the list of papers. However, a problem is that geographers have been attending these conferences for many years, again reflecting the fuzzy boundaries of regional science as a discipline. Although numerous publications on spatial economics using Geo-ICT have been published in the past, these were not necessarily written by spatial economists.

Historically, North America has always taken a leading role in the development of GIS, but looking at the use of Geo-ICT in economics we can conclude that Europe now performs equally as well. The key centres in this field today include Clarke University (USA), Oxford (UK), University of Illinois (USA), University of Leeds (UK), University of the Aegean (Greece), Vienna University of Economics and Business Administration (Austria) and VU University Amsterdam (Netherlands).

**Table 8.1** Integration of Geo-ICT in spatial economics following Scholten et al. (2008)

| | Integration model<br>Stage description | History within spatial economics<br>Year/period and event |
|---|---|---|
| 1 | Small group of 'champions' explore the possibilities of Geo-ICT and publish their findings | Spatial econometrics, 1991: Luc Anselin builds Stata, statistical software for correcting regression models for spatial dependence (Anselin 1988a).<br>Environmental economics, 1993/1994: Waddel and Berry (1993) and Bateman (1994) explore the use of GIS in hedonic price analysis |
| 2 | 'Champions' are invited as guest speakers in other universities | |
| 3 | Conferences fully or partly dedicated to GIS are held | First GIS Summer Institute (Amsterdam, 1988).<br>Papers on GIS become an established part of international Regional Science conferences (mid 1990s).<br>First series of socioeconomic papers presenting GIS applications at the multidisciplinary Urban and Regional Information Systems Association Annual Conference (URISA, 1997).<br>AGILE, annual multidisciplinary GIS conferences, where economic topics are also presented (from 1998 onwards). |
| 4 | Increasing demand for training in GIS from academics | Development of the first multidisciplinary Core Curriculum in GIS by NCGIA (1990).<br>UNIGIS founded, offering postgraduate distance learning MSc programmes in GIS at universities around the world. |
| 5 | Trained scientists can offer courses in GIS at their own universities. | First Senior Lectureship GIS in Europe established (VU University Amsterdam, 1990).<br>First optional course in GIS in Economics started in Masters Programme at the Faculty of Economics (VU University Amsterdam, 1997). |
| 6 | Construction of large-scale databases | Increasing availability of large databases for economic research:<br>The National Historical Geographic Information System project (NHGIS) is making US Census data from the period 1790–2000 available in GIS format.<br>The CORINE programme produces land cover data, available for Europe from 1990 onwards. |

**Table 8.1** (continued)

| | Integration model<br>Stage description | History within spatial economics<br>Year/period and event |
|---|---|---|
| | | Real Estate Monitor (ABF Research) available, containing all sorts of spatially-referenced connected datasets related to real estate, i.e. household, transaction and neighbourhood characteristics, building permits, house values, income and general demographic statistics, and more. Most data is available from 1996–2000 to 2006.<br>The ESPON programme (2006) aims to develop integrated tools and appropriate instruments, including a database, for territorial impact analysis and spatial analyses to improve the spatial coordination of sector policies (see www.espon.eu). |
| 7 | Full integration of Geo-ICT in both research and education | A larger proportion of new PhD students in spatial economics have already had basic training in GIS during their MSc studies (2006).<br>Integration of Geo-ICT in Bachelors and Masters courses (not yet compulsory) within the Bachelor and Master of Economics and Master of Marketing (VU University Amsterdam, 2007). |

GIS originated from cartography. In order to automate certain cartographic mapping procedures, the Canadians needed to analyse their national land inventory and built the Canadian Geographic Information System (CGIS) in 1963 under the supervision of Roger Tomlinson. One year later, in 1964, the Harvard Lab for Computer Graphics and Spatial Analysis was founded by Howard Fisher. This laboratory would play an important role in the development of GIS since many leaders in the GIS industry once worked here.

As we described in Section 8.4, the availability of spatial data stimulates the use of Geo-ICT in science. One can argue, therefore, that this situation will continue in the US, where geodata is much less costly and more readily available than in Europe, making it much easier for US scientists from all disciplines to use Geo-ICT in their research. But even in Europe spatial data is becoming increasingly available for research purposes. Certainly in the Netherlands, where relatively many highly detailed and interconnected spatial datasets covering the whole nation are produced and frequently updated, there are strong incentives to use this data in science.

The following sections describe some current research themes in the field of spatial economics where spatially-referenced data plays an indispensable role and discuss the adoption of Geo-ICT in spatial economics and the contribution by spatial economists to the further development of the field of Geo-ICT.

### 8.5.1 Spatial Economic Analysis

Land is essential for the realisation of government spatial policies. Through restrictive spatial policies and the proactive planning of land use, governments can influence land use patterns and reduce negative external effects from one type of land use on adjacent land uses. The main question from an economic point of view will be how to cope with failures in land markets. The task of a planning system is to foresee economic, demographic, political and societal developments and to anticipate the possible spatial effects of these developments. We describe three related fields of research within spatial economics where Geo-ICT is heavily used in carrying out spatial analyses. Besides an economic component, all three spatial economic case studies have strong links to planning and geography and therefore can also be classified as belonging to the broader field of regional science.

### 8.5.2 Analysis of Land Use Change

Both ex post and ex ante evaluations of spatial policies can be conducted. In this section we focus on the former. In many countries a major objective of spatial planning is to restrict the tendency towards urban sprawl in the rural areas surrounding cities, but the Netherlands is well-known for its interesting set of strict policies on preserving open space. Even the most densely populated western part of the country (called the Randstad) can be described as a collection of high density clusters of cities and towns surrounded by open spaces. Maintaining this special configuration has been a crucial issue ever since the first national policy on physical planning (RNP 1958). One very important planning concept introduced into national planning policy concerned the preservation of the central open space in the Randstad, the ‘Green Heart’ (V&B 1960). Another was the buffer zone. Green corridors no less than four kilometres wide were designated in areas subject to considerable development pressure to prevent cities from coalescing into a solid urban belt and to maintain recognisably distinct towns and cities in the landscape. Koomen et al. (2008) have assessed the success of these two Dutch strategies for protecting open space during the past ten years. Using Geographical Information Systems (GIS) and remotely sensed rasterised datasets, transition matrices were created to analyse the magnitude and patterns of land use changes (Fig. 8.4). The study shows that urban development is much less in the areas where either type of restrictive policy applies – the areas identified within the Green Heart (VROM et al. 2004) – than in the other, non-restricted parts of the Randstad, where development pressures are the highest in the country. This means that the current policies are indeed successful.

The economic effects of spatial policies and development pressure can be monetarised using the hedonic pricing method (HPM) (Rosen 1974). The HPM determines the *implicit* value of non-tradable characteristics of goods by analysing the *observed* value of tradable goods that incorporate all or part of those non-tradable characteristics (for more information regarding the hedonic pricing technique, we

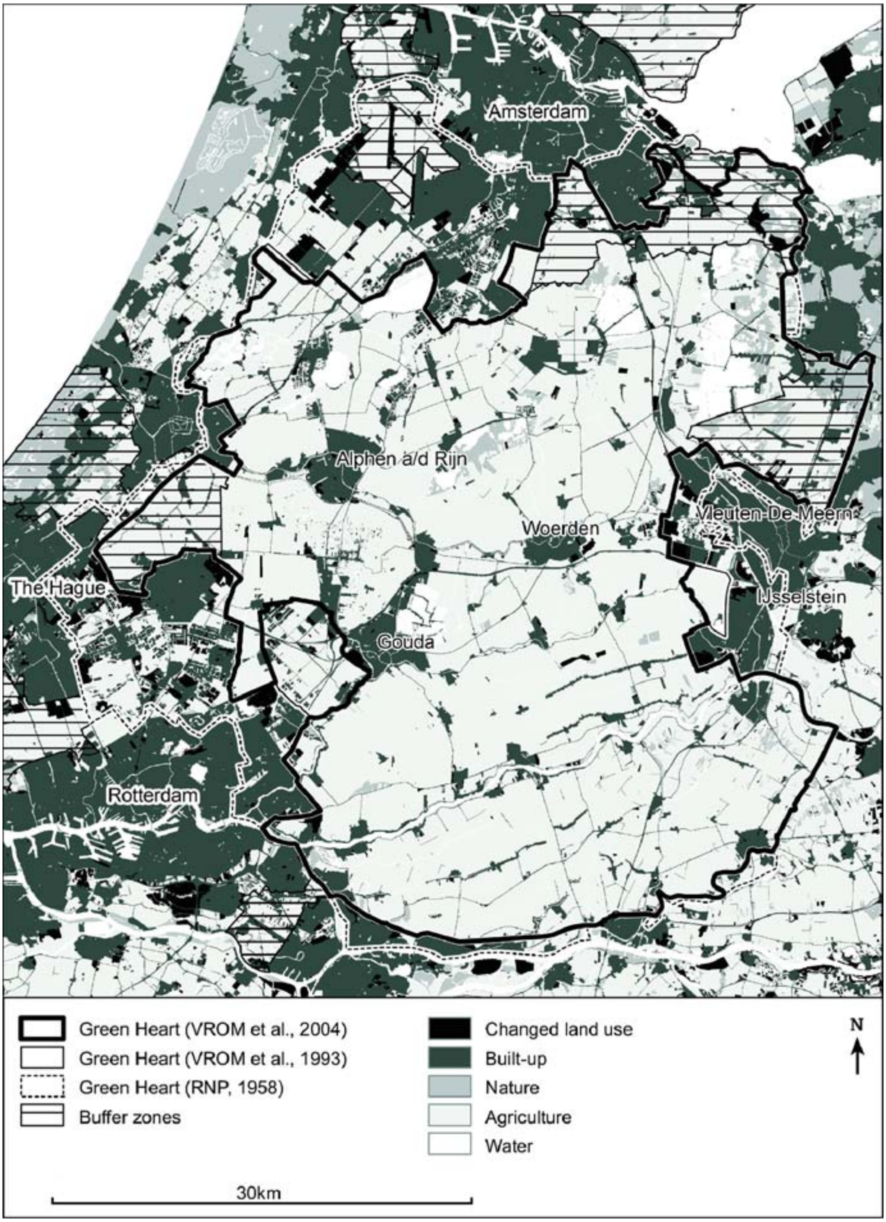

**Fig. 8.4** Land cover in 2003 in the central part of the Randstad showing the restrictive development zones. Areas where land cover has changed since 1995 are shown in *black*, irrespective of the type of change

refer to Griliches 1971 and Gordon 1990). In their study of the rural land market in the Dutch province of Noord-Holland, Dekkers et al. (2004) apply an HPM model to agricultural parcels. The analysis includes parcel characteristics that influence the land price, such as soil type, proximity to urban areas, accessibility and designation of (future) land use. The results show that an urban land use designation substantially increases the price of a parcel. Upward pressure on the price of agricultural land is also found for agricultural parcels that are surrounded by predominantly urban land uses and for parcels closer to an urban area. A nature conservation designation substantially depresses land prices. Similar results have been found by Buurman (2003).

A further analysis focusing on the rural to urban transition was carried out by Dekkers et al. (2008). They employ a linear transition probability model that uses ordinary least squares, which is based on the same HPM model of Noord-Holland, to estimate urban transition probabilities for agricultural parcels. The results show that the larger the transition probability, the larger the land price premium. The transition probability model, which is based on actual land use transactions registered at the Dutch Land Registry, can be used for modelling future land use. Another probability model for this purpose is discussed in Section 8.5.4.

### *8.5.3 Housing Markets and Externalities*

In densely populated countries, and especially in large metropolitan areas, space is a scarce good. The concentration of jobs and high level of urban facilities make polycentric areas attractive residential environments. The presence of so much human activity also causes negative externalities: the large numbers of commuters and people in a small area generates high volumes of traffic, air pollution and noise disturbance. Crime rates tend to be much higher in metropolitan areas than in rural areas, and the pressures driving urbanisation in adjacent open areas are strong. At the same time, people also like to live close to green open areas where they can go to relax and ‘recharge their batteries’. Where different stakeholders pursue conflicting objectives, land use planning tries to reconcile these diverging interests. The task is especially complex in the urban fringe, the heterogeneous landscape surrounding the bigger cities within conurbations. One of the major planning concerns here is to restrict the tendency towards urban sprawl in the rural areas surrounding cities and, at the same time, do justice to the specific value that society places on the open spaces around cities. This value and the ensuing externalities – which are in fact market failures – have received little attention in the theoretical literature on urban land use based on the seminal works of Alonso (1964), Muth (1969) and Fujita (1989). Negative externalities of urban development that strongly affect the value of open space include the fragmentation and noise disturbance effects of infrastructure and visual intrusion of man-made objects. These externalities call for corrective measures by the public sector in the form of land use interventions or pricing measures.

Economists have developed a number of procedures which, at least in the case of some externalities, provide reasonable estimates of the monetary value of some of these amenities and externalities, despite the remaining uncertainty and dispersion in values produced (see, for example, Button 1993). Tools from different science fields can assist in explaining these phenomena. More specifically, economics and geographical information science (GIS) can be very helpful since both have a hybrid nature, hovering somewhere between mathematics, (spatial) politics and ethics (van Kooten and Folmer 2004). Constructing spatial explanatory models for house prices allows the social value of open space and negative externalities like noise disturbance to be quantified in monetary terms.

Dekkers and Koomen (2008) have examined the economic value of open space by using a hedonic pricing model of residential property values. The data on sold residential properties, including price information and structural characteristics of the objects, were provided by the Dutch Association of Real Estate Brokers (NVM). The analysis was supported by extensive use of GIS, in particular for computing spatially-explicit model variables: distance to city centre, distance to the nearest motorway junction, distance to the nearest railway station, the level of urban facilities (i.e. shops, restaurants) per neighbourhood, etc. They present three local Dutch housing market case studies in the Randstad region: Amsterdam, Leiden and Het Gooi (Fig. 8.5). The three study areas differ in terms

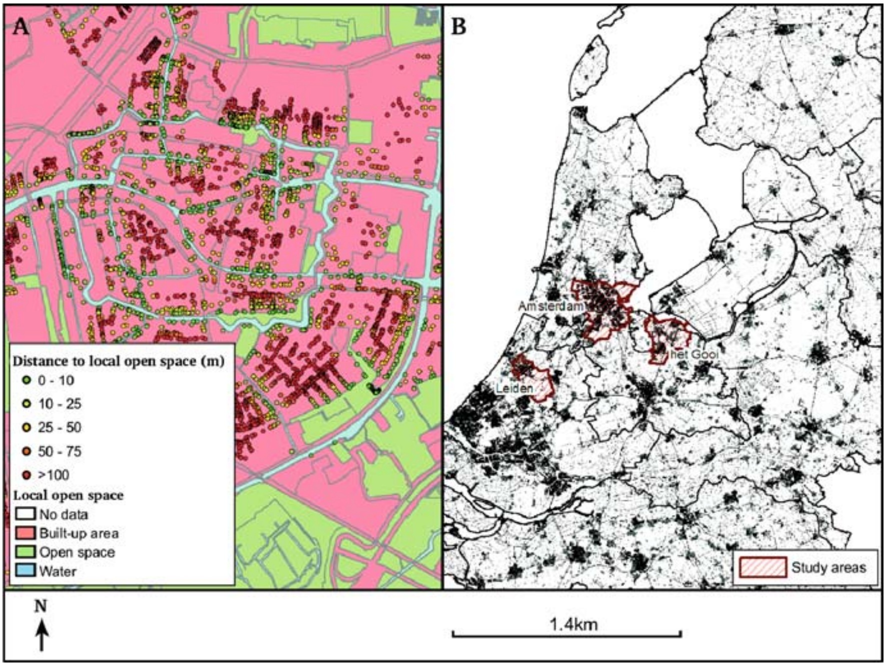

**Fig. 8.5** (**a**) Distance to local open space in the city of Leiden. (**b**) The perceptual interpretation of openness in the central part of the Netherlands. *The darker colours* denote an increase in urban land use types. Figure adapted from the Land Use Scanner model (Borsboom-van Beurden et al. 2005)

of rate of urbanisation, number of inhabitants, the amount and type of metropolitan open space available and the housing market (i.e. the number and types of houses available). In all the studies, the authors distinguish between the presence of open spaces at three different scales, ranging from views of a small local open space to the proximity of a large regional open space for recreational purposes.

Studies of the general appreciation of the landscape (e.g. Roos-Klein Lankhorst et al. 2002) show that the presence of natural land use types, relief and water make a positive impression, whereas urban development, noise and visual disturbance have a negative impact on landscape amenity. The general public essentially compares the busy, urban areas with the quiet, green countryside. As their goal is to evaluate open space from a human, user perspective, they adopt this perceptual view of open space instead of the strictly visual approach that is more common in Dutch spatial planning. Open space is thus defined as 'being free of buildings and other evidence of human presence' (for example greenhouses or infrastructure). This concept of openness corresponds roughly to the inverse of urbanism (Fig. 8.5b). The least urbanised areas in this figure can be considered to be open spaces. The authors found that the availability of local open space within 50 metres of homes has a substantial positive impact on house prices. The contribution of larger areas of regional open space to house prices cannot be established unequivocally.

Dekkers and van der Straaten (2008) apply a similar type of hedonic pricing analysis on residential property values to determine the costs of transport noise disturbance. Quite a few international studies have focused on the effect of transport noise on the value of houses (see Nelson 2004, Navrud 2002 and Schipper 1999 for meta-analysis overviews of these types of studies). Most studies, however, focus either on noise from road and/or rail transport or on noise from aeroplanes. A key point in the analysis of air traffic noise near airports by Dekkers and van der Straaten (2008) is that they took multiple sources into account, combining road, rail and air traffic noise in one analysis. They chose the area round Schiphol Amsterdam Airport as a case study since it is one of Europe's largest airports situated within the urban fringe of Greater Amsterdam, a highly urbanised area (Fig. 8.6).

The authors use Lden (Level day-evening-night) as the unit for measuring ambient noise. Lden represents the average ambient noise level during a whole year, expressed in decibels (dB). The Lden unit has a logarithmic scale on which an increase in sound of 3 dB is equal to a doubling of the sound intensity. A twenty-four hour weighting factor is applied according to the time of day in which an aeroplane causes noise: sound produced at night is weighted ten times stronger than during the day. This methodology prevents them from saying anything about the valuation of noise at different times during the day. The presence of background noise has to be taken into account in the analysis. In an urban environment, the background noise level is approximately 50–60 dB during daytime and 40 dB at night according to Nelson (2004). Morrison et al. (1999) mention a normal background noise level of 44–55 dB during the day. One way to account for this is to include a threshold value for noise sources and take other important sources of ambient noise into account. This threshold value is not fixed. To measure background noise for its Environ-

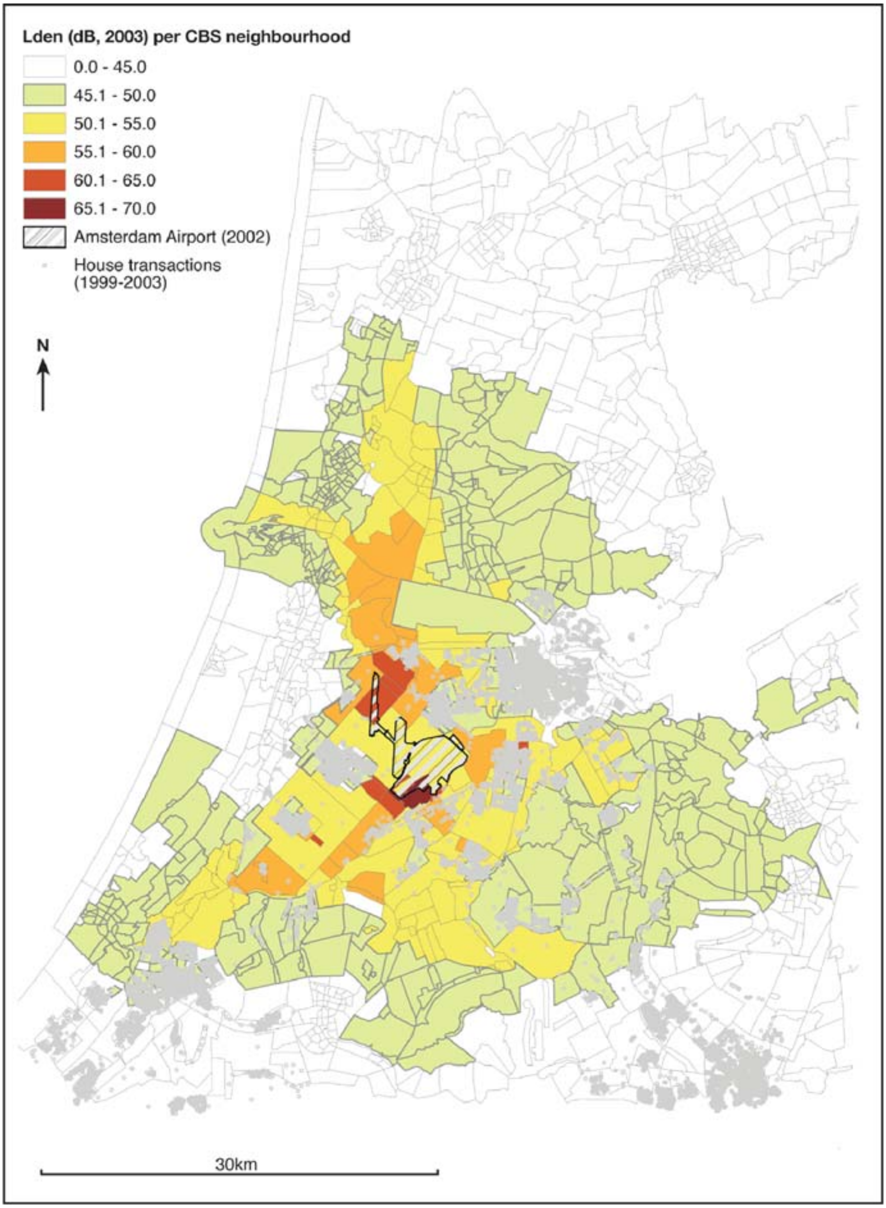

**Fig. 8.6** Lden (2003) per CBS neighbourhood, location of Schiphol Amsterdam Airport and house transactions in dataset

ment and Balances Outlooks (Dassen et al. 2001), the Netherlands Environmental Assessment Agency (MNP) uses the EMPARA model (Environmental Model for Population Annoyance and Risk Analysis). This model is an improved version of the Landelijk Beeld van Verstoring (LBV) model. In the model, a threshold value of 55 dB is used for determining houses that experience noise disturbance (MNP 2005). A study carried out for the European Commission (ECMT, 1998) claims that the threshold values below which noise nuisance should not be assigned a monetary value should be 55 dB for road transport and 60 dB for rail transport (Vermeulen et al., 2004). These threshold values are also applied in this analysis. The difference in threshold value between road/air and rail reflects the fact that people experience an equal noise level from a passing train to be less disturbing. To correct for this difference, the threshold value for rail transport noise is increased by 5 dB (Vermeulen et al. 2004). For the hedonic price analysis of the influence of aircraft noise on house prices, Dekkers and van der Straaten chose a threshold value of 45 dB, arguing that this type of noise is less constant than road and rail traffic, and thus experienced as more disturbing.

This analysis makes use of many spatially-explicit datasets. Variables on house prices, date of sale and structural house characteristics (for 1999–2003) are taken from the Dutch Association of Real-Estate Brokers (NVM). This dataset is geocoded for use in spatial analyses. Second, data on the following attributes are included for each neighbourhood: population density, the normalised number of retail outlets, the distance to the nearest railway station and the distance to the nearest motorway junction. All this data comes from Statistics Netherlands (CBS Neighbourhood statistics). Third, the noise data used are from the Netherlands Institute for Health and the Environment (RIVM) for aircraft noise, and from the Netherlands Environmental Assessment Agency (MNP) for road and rail noise. The results show that, all other things being equal, a higher noise level leads to a lower house price. Air traffic has the largest price impact, followed by rail traffic, then road traffic. We have to consider, though, that given the chosen threshold values, air and road traffic have a price impact at lower absolute ambient noise levels compared with rail traffic.

The outcomes of the hedonic price analysis can be used to estimate the marginal and total benefits of aircraft noise reduction in the area around Schiphol Amsterdam Airport. This is done by taking the model coefficient for aircraft noise and multiplying the related house price impact by the value of each house where noise levels have been reduced. The marginal benefit of a 1 dB noise reduction on the average house value (taxable value per 1 January 1999) in all CBS neighbourhoods with an aircraft noise level greater than or equal to 45 dB is 1.459 euros per house. If we assume that in 2007 a policy was introduced that led to an aircraft noise reduction in residential areas of 1 dB in 2008, the total benefit in the area around Schiphol Amsterdam Airport affected by air traffic noise would amount to 574 million euros (disregarding interest rates). If the costs of aircraft noise reduction are calculated, the size of government financial intervention to ameliorate noise nuisance near airports can be optimised. The HPM study by Dekkers and van der Straaten (2008) described above is part of a broader study by Lijesen et al. (2008).

### *8.5.4 Modelling Future Land Use*

Understanding the effects of government policy on the land market – both on actors in this market and on the market mechanisms themselves – and vice versa are crucial to comprehending the valuation of land and real estate. The valuation of land and real estate as well as spatial policy are also affected by the probability of land development or changes in land use. It is exactly this likelihood of transition between market segments with very different price levels that leads to speculation (VROM 2001; Werkgroep-IBO-Grondbeleid 2000). The urban fringe is the most dynamic area of the Dutch land market where most development takes place, and therefore also where the most transitions in land use between submarkets occur (from greenfield to built). The highest gains to be made on speculation are in this zone. The processes at work in these areas are diffuse and difficult to grasp. They present quite a challenge from a scientific point of view, but hold many potentially interesting insights from both the political and socioeconomic points of view.

As mentioned in Section 8.5.2, Dekkers et al. (2008) present a model that bridges the gap between explanatory analysis and modelling future land use. They use cadastral data on transactions involving rural land from the InfoGroMa database of the Government Service for Land and Water Management (DLG, part of the Ministry of Agriculture, Nature and Food Quality). These data are geocoded. A set of spatially-explicit variables was defined in order to explain price differences between different transactions. These variables relate to zoning schemes, different accessibility measures, distance to urban areas, soil type and fertility, etc. A GIS was used to derive all these variables. Using the hedonic pricing technique in combination with a linear probability approach, the authors were able to construct a singe-equation probabilistic land market model that delivers concrete information on the transition probability of greenfield parcels being developed in the near future.

Understanding the functioning of the land market and current land uses, especially in the urban-rural transition zone, can indeed improve our ability to model future land use change. The quantification of land use change in land use models is very important for evaluating the effects of spatial policy (MNP 2004; Borsboom-van Beurden et al. 2005) and there are many land use models available that simulate land use change. Most models only simulate urban or rural land use types. One model that can simulate different types of land use simultaneously is the *Land Use Scanner*. This economics-oriented probabilistic model uses a logit function to simulate demand for and supply of land in an iterative process. It is a grid-based spatially-explicit model and has been used for various policy-related research projects. Each cell describes the relative proportion of all current land use types, thus presenting a highly disaggregated description of the whole country. The regional projections of land use change used as inputs to the model are specific for land use type and can be derived from sector-specific models of specialised institutes. The various land use claims are allocated to individual grid cells based on their suitability. The allocation algorithm is based on economic discrete choice theory to match the spatial claims of the different land use types to the available land. The crucial variable for the allocation model is suitability $s_{cj}$, which represents the net benefits of land use type $j$ in cell $c$. The higher the suitability for land use type *j*, the higher the probability that the cell will be used for this type. Suitability maps are generated for all different land use types based on location characteristics of the grid cells described by physical properties, operative policies and expected relations with nearby land use functions. In the simplest version of the model, a logit type approach is used to determine this probability.

The model is constrained by two conditions: (1) the overall demand for the land uses is determined by the initial claims, and (2) the total amount of land which is available for each function. Imposing these conditions produces a doubly constrained logit model, which as a by-product gives the shadow prices of land in the cells. In the doubly constrained model the expected amount of land in cell *c* that will be used for land use type *j* can be formulated as:

$$M_{cj} = a_j \cdot b_c \cdot \exp(\beta \cdot s_{cj})$$

in which:

$M_{cj}$ is the expected amount of land in cell c that will be used for land use type j;
aj is the demand balancing factor (condition 1) that ensures that the total amount of allocated land for land use type j equals the sectoral claim;
$b_c$ is the supply balancing factor (condition 2) that ensures that the total amount of allocated land in cell c does not exceed the amount of land that is available for that particular cell;
β is a parameter that allows for the tuning of the model: a high value for β makes the suitability more important in the allocation process and will lead to a more mixed use land pattern; a low value will produce a more homogenous land use pattern;
$s_{cj}$ is the suitability of cell c for land use type j, based on its physical properties, operative policies and neighbourhood relations.

This approach adopts some notions of Ricardo (1817) by including soil quality as an explanatory economic component in the suitability factor. It also has some elements in common with von Thünen (1826) since it includes distance, such as distance to urban areas, in the suitability factor for several land use types (see also Section 8.2.1). Furthermore, the model includes spatial economic concepts from the bid-rent theory of Isard (1956) and Alonso (1964) (see also Section 8.2.2). Applications include the simulation of future land use following different scenarios (Schotten and Heunks 2001), the evaluation of alternatives for a new national airport (Scholten et al. 1999), the preparation of the Fifth National Policy Document on Spatial Planning (Schotten et al. 2001) and, more recently, an outlook on the prospects for agricultural land use in the Netherlands (Koomen et al. 2005). A full account of the model is provided by Hilferink and Rietveld (1999).

A recent application of this model, described in more detail in Dekkers and Koomen (2007), gives land use a major influence on local hydrological conditions, recognising that future land use is an important element in studies that focus on the upcoming challenges for water management. The application described below uses the scenario method to simulate future land use patterns. The scenario method is especially suited for long-term studies that deal with a wide array of possible developments and many related uncertainties. By systematically describing several opposing views of the future, we can simulate a broad range of spatial developments, thus offering a full overview of possible land use changes. Each individual scenario will not necessarily contain the most likely prospects, but together the simulations cover the bandwidth of possible changes as discussed by Dammers (2000).

The study area is the Elbe river catchment area that covers large parts of Germany and the Czech Republic. The Elbe catchment area has relatively low precipitation and the lowest mean water availability in Germany. As the flooding of Hamburg in 2002 shows, the region also experiences short periods of excess water, which can have disastrous effects. The study focuses on the impact of climate change on the entire water system, including the risk of water shortages or flooding. More specifically, the *Land Use Scanner* model is used to disaggregate projected agricultural and environmental developments and social changes to a more detailed geographical scale and to assess, through land use simulations, possible future water demand and possible changes in hydrology and water quality (Fig. 8.7). Land use in the study

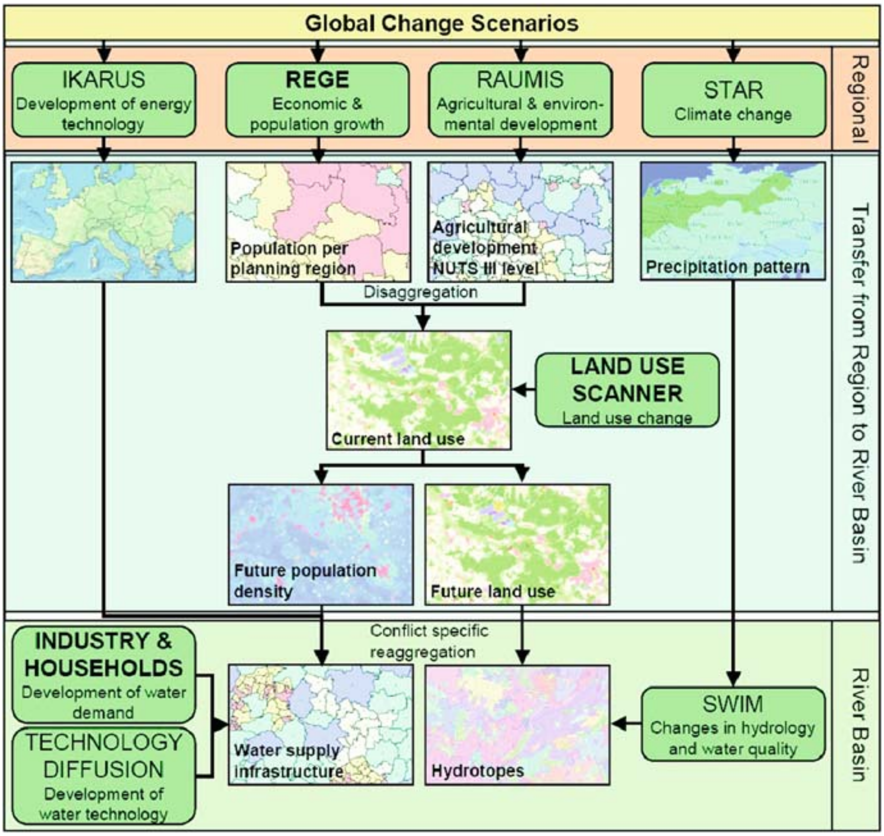

**Fig. 8.7** GLOWA-Elbe Modelling Framework and performed scale transformations (source: Hartje et al. 2005)

area was classified into 16 land use types and modelled in a 250 by 250 metre grid consisting of over 2.3 million grid cells. Current land uses from the year 2000 were taken from the European CORINE land cover database, which is based on satellite imagery. In addition, seven types of natural protection policy maps have been added to the model, as well as a map containing the agricultural yield potential for each grid cell and distance maps for road and rail trips and distances to railway stations. Three levels of administrative regions (*Bundesländer*, *Raumordnungsregionen* and *Kreise*) have now been included as the regional divisions for the different land use claims.

To get to grips with the wide range of possible future changes, a trend scenario that extrapolates current developments and policies has been defined as a reference. In a further refinement, prospective climate changes will be added to this scenario. After analysing possible social global changes, alternative scenarios will be defined that deviate from the trend scenario. The model outcomes can be presented using new visualisation platforms like Google Earth (Fig. 8.8). An advantage of visualising the results this way is that one can fly over the study area, using the transparency slide to switch dynamically between current and future land use. This is an intelligent and attractive way to let the audience see what changes occur where.

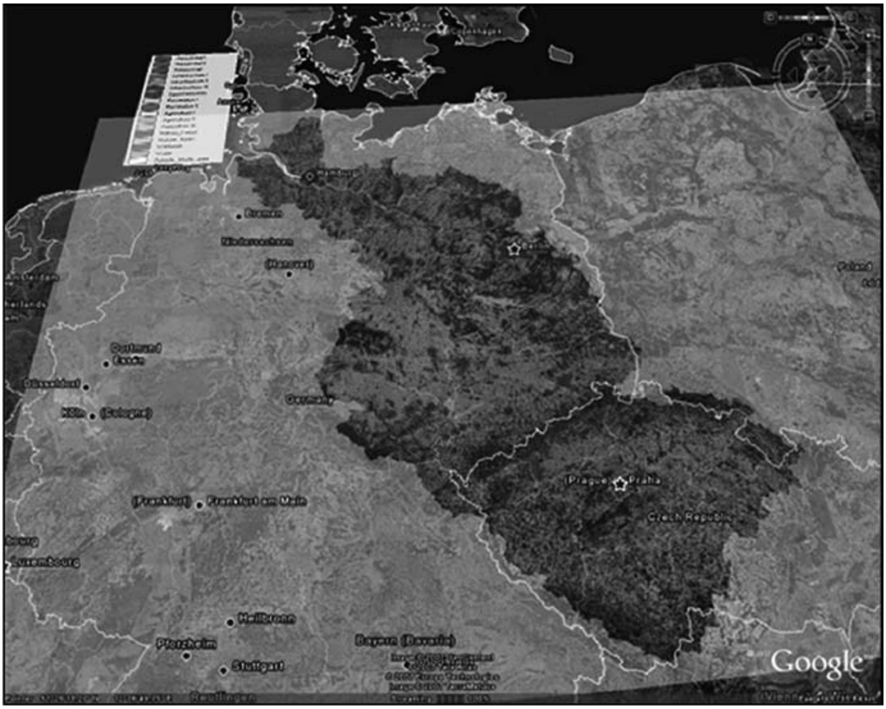

**Fig. 8.8** Land use map (CORINE 2000) from the Land Use Scanner for the Elbe river basin, projected in Google Earth

It can stimulate discussion and may help the audience to grasp more fully the implications of the model outcomes.

### *8.5.5 Adoption by Spatial Economists*

A well-known model for the adoption of new methods or technologies is the Technology Acceptance Model (TAM) (see, for example, Venkatesh and Davis 2000 for an extended version of the TAM model: TAM2). In our view this model can help to explain the penetration of GIS in spatial economics, in particular at the level of individual researchers. In the domain of scientific innovation, the common TAM notions of *perceived usefulness, perceived ease of use* and *intention to use* are certainly relevant. For example, if the dominant culture in a scientific discipline does not support the use of tools from other disciplines this may be because their perceived usefulness or ease of use is poor. However, it is clear that the model is too limited for our purpose, which requires a more macro perspective. The model is silent on the context within which adoption decisions are made and the relevant restrictions the potential adopter faces, such as the non-availability of the right technological tools and lack of access to databases. Since the market for data is not always transparent, researchers may have difficulty in keeping track of new developments. These difficulties can be overcome through formal and informal networks of researchers within research groups, but especially from different complementary groups. To make it really fruitful, the TAM model should be enriched with a network perspective.

A second limitation is that the TAM model conceptualises technology adoption as a single decision to adopt (yes versus no). However, the development of Geo-ICT reveals that a dynamic perspective is needed since the technology is rapidly developing and the broader decision context is in flux. In economics, it seems that major adoption only took place after the technology had become mature and powerful owing to developments in other domains (planning, use in the public and private sectors outside the research arena). The economics discipline may therefore be seen as a free-rider in the earlier phases of development of Geo-ICT. This was actually a rational strategy, since researchers from other disciplines were in a better position to contribute to its development at that stage. The situation has changed now, since spatial econometric approaches are really contributing to the Geo-ICT tools now being developed. What we can learn from this is that timing is an essential element in technology adoption.

## 8.6 Conclusions

This chapter has attempted to review the development of economics as a science and the role of Geo-ICT in the process. The integration of Geo-ICT in economics has been slow and limited. In general, GIS software is used for mapping economic data. Geo-ICT is also used for other purposes, such as data exploration, spatial analysis and modelling, but mainly in the fields of spatial economics and geomarketing. Compared with other scientific disciplines, spatial economics has the advantage of already having spatially-explicit theories, methods and algorithms.

In economics rapid developments have taken place both in the realm of theory and in the realm of methods and data. The emphasis with regard to new developments within the field of data and methods has been strongly oriented towards GIS. First, large single databases have become more readily available for research purposes. Second, the linking of individual databases is creating new or enriched information. And third, individual data have been linked to neighbourhood data using spatial coordinates. This is where the influence of Geo-ICT on spatial economics is most apparent.

At first the geomap framework was the most important, but since the evolution of spatially-explicit theories, especially in the field of spatial economics, combined with the upsurge in computer processing power and the increasing availability of GIS software and spatially referenced data, the geomodel framework has become by far the most important in spatial economics. We expect both the geomap and geodatabase frameworks to become more important in the near future, though, because of the trend toward decision support systems and the collection of real-time dynamic location-based data. Before all the research possibilities that this development will create can be brought within reach, some technical obstacles will have to be overcome: advanced filtering algorithms must be designed to handle the vast amount of spatial data in this type of applied research. Once this has been done, we could, for instance, investigate whether travel patterns will be influenced by the availability of in-car real-time traffic and navigation information, assuming this means optimal routes for all individual trips by the road.

The increased availability of geo-referenced data will lead to further penetration of spatial econometric approaches in the standard toolkit for spatial economic research. Two challenges present themselves. First, some of the existing spatial econometric approaches require considerable computer capacity, which puts serious constraints on large numbers of observations. This calls for the development of new approaches and more powerful software to keep pace with the supply of ever expanding datasets. Another challenge is that spatial databases gradually cover longer time periods, suggesting that in time panel data approaches will become feasible. In turn there will be demand for the integration of panel data econometrics into spatial econometrics.

A potential limitation on the use of Geo-ICT in research in general, at least in Europe, is that spatial data originating from the public domain is expensive. There are signs, however, that some governments are considering a change of policy in this respect. In the future we may expect this obstacle to be at least partially removed.

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# Chapter 9
# Spatial Planning and Geo-ICT: How Spatial Planners Invented GIS and Are Still Learning How to Use It

**Arjen de Wit, Adri van den Brink, Arnold K. Bregt, and Rob van de Velde**

## 9.1 Introduction

The term 'spatial planning' generally refers to a wide range of systematic activities designed to ensure that desired spatial goals are achieved in the future. These goals include environmental protection, urban development, different forms of economic activities, infrastructure development, water management and many others. Location is a fundamental aspect of spatial planning, as it is in other spatial sciences such as landscape architecture and physical and human geography. It is subject to, and the result of, planning activities. In spatial planning location is a composite concept. It is not only made up of physical characteristics (or phenomena), but also contains notions of form, function and meaning. This composite concept of location is reflected in the current opportunities for using Geo-ICT in planning activities, opportunities that have increased enormously since the first applications of Geo-ICT in spatial decision making in the 1960s. We claim that spatial planning has influenced the development of Geo-ICT and has boosted the development of geographical information systems (GIS) in particular. Both have maintained a close relationship ever since. But spatial planning not only 'produced' GIS; the reverse is also true: Geo-ICT and GIS have influenced and still influence the concept of spatial planning, especially its working methods and applications. Spatial planners are still searching for ways to put GIS successfully into practice.

In this chapter we explore the long and close relationship between spatial planning and Geo-ICT. We start with a description of spatial planning as a formal profession and an academic discipline before presenting several stages of the relationship between spatial planning and Geo-ICT: the use of knowledge systems, planning models and planning support systems (PSS); the development of multiagent systems and Geo-ICT applications for geovisualisation and communication; and future developments focusing on spatial behaviour and spatial preferences of people. The

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concluding section contains a reflection on the lessons that may be learned from the mutual interaction between spatial planning and Geo-ICT.

## 9.2 On Spatial Planning

There are many perceptions in planning practice and theory about what spatial planning is, or should be, and what it does, or should do. These perceptions are represented by currents in planning theory which may be philosophically, politically or economically grounded (for an overview see Allmendinger 2002). Moreover, they are culturally determined: French, British, American and Dutch planning systems are very different, mirroring the history and culture of the society in which they are embedded. As a formal profession, spatial planning has broadened enormously in scope, especially in the post-war era, and can now be said to encompass the act of planning for desired future conditions at all scales, within both the public and private sectors. As an academic discipline, spatial planning reflects on spatial decision making under circumstances of societal and environmental complexity and uncertainty. Spatial decision making is commonly based on an assessment of physical characteristics, such as vegetation, soil composition and hydrological conditions, on societal preferences regarding present and future land use, on economic opportunities, financial constraints and political realities. For the purposes of this paper we consider the related term ‘landscape planning’ to be synonymous with spatial planning.

In order to deal with the relationship between spatial planning and Geo-ICT without working through the whole range of planning methods and planning theories, we choose to use a rather ‘neutral’ definition: spatial planning is the preparation of decision-making on spatial issues at different geographical and temporal scales. The European Commission (1997) emphasises spatial planning as a public sector activity: “Spatial planning refers to the methods used largely by the public sector to influence the future distribution of activities in space.” The aims of spatial planning are described as: “Creating a more rational territorial organisation of land uses and the linkages between them and to balance the demands for development with the need to protect the environment, and to achieve social and economical objectives.” This definition emphasises the overall goal of spatial planning as a sustainable development of space, balancing and accommodating social, economical and ecological objectives. Planning activities may vary from the operational (the actual arrangement of objects and functions in a geographical unit) to the strategic (exploring possible futures, determining possible directions for spatial development). Its scale may be the neighbourhood or the continent; its time span five to 50 years. However, because most planning activities are linked to concrete policy making, scale often corresponds with governmental units, like countries, regions and municipalities, and its time span rarely exceeds 20 years.

Planners try to make uncertainty visible and to find ways of coping with uncertainty in order to produce well reasoned plans. Spatial planners may not try to predict the future, but they do want to explore the future. Furthermore, unlike most

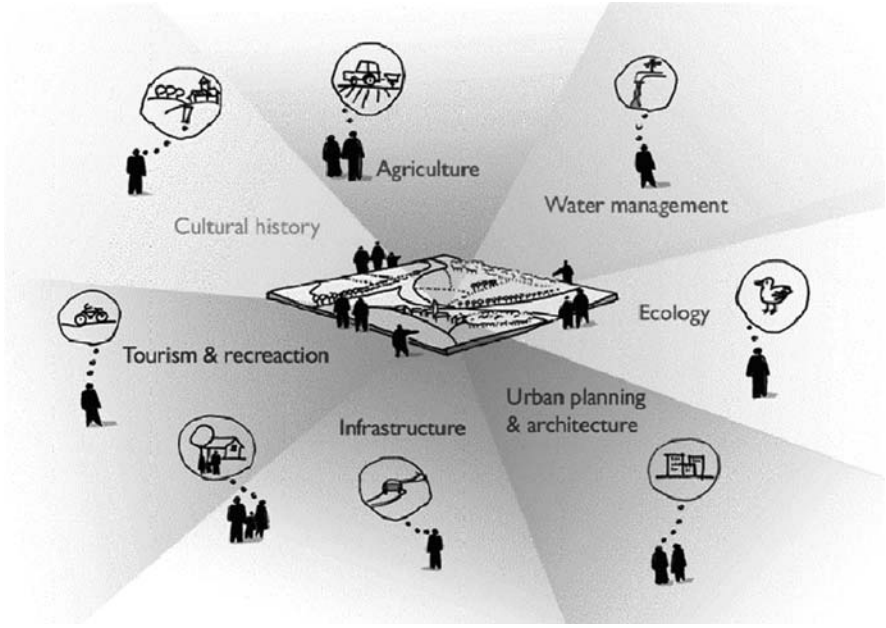

**Fig. 9.1** Spatial planning, related disciplines and relevant actors (source: Däne and van den Brink 2007, 36)

scientific fields discussed in this book, spatial planning is not a monodisciplinary activity. Rather, it can be characterised as a multidisciplinary activity that strives to be interdisciplinary (see, for example, Tress and Tress 2002). In other words, spatial planning is about integrating many forms of land use and many interests, using expertise, knowledge and information from various disciplines to find a proper balance between people, planet and profit. Consequently, spatial planning cannot function without cooperation with neighbouring disciplines, such as urban planning, architecture, water management and ecology (Fig. 9.1). As sociospatial aspects have gained in importance, spatial planners also need to consider social science aspects, such as human geography and law. In turn, the increasing complexity of planning issues has made it necessary to reconsider the planning process. Organising cooperation on planning issues between diverse actors, including experts and especially local people, has become more important.

## 9.3 Spatial Planners Invented GIS

From the 1950s until well into the 1970s spatial planning in many countries was firmly based on the modernist idea of the 'malleability' or 'makeability' of society: the belief that government could define the future by taking the right decisions and imposing them on society. This encouraged planners to make extensive 'blueprint plans'. Authors like McLoughlin (1969) championed a comprehensive, rational approach to urban and regional planning. Planning was a top-down, positivistic, technocratic and expert-driven activity. An example from the Netherlands of this way of spatial planning is the development of the city of Almere on land freshly reclaimed from the sea (Wrathall and Carrick 1983). Almere was planned, designed and then built integrally from the 1970s onwards.

Such projects would start with a large survey, covering virtually any relevant aspect. In the case of Almere, there was no need to take any present state of affairs into account since the city was built on a 'clean sheet', on reclaimed land. However, soil and hydrological conditions were of major importance and data about these conditions were extensively collected. The numbers of inhabitants, their need for transportation, facilities, recreational areas and so on were meticulously calculated, based on experiences in other cities. Using this information, the planners and urban designers developed the city from scratch, right down to the last paving stone.

Another example can be found in the land consolidation projects implemented by the Dutch government to improve agricultural production conditions. These projects required surveys of plot sizes and their suitability for different purposes, as well as data on water management and infrastructure. Later on, when more attention was paid to recreation and nature conservation, these projects were called 'integrated land development', and plan preparation and implementation required additional knowledge on recreational needs and ecological values (Buiter and Korsten 2006). The formulation of plan alternatives became the subject of a structured working method which was used to plot out and systematically compare the merits of potential solutions (van den Brink 1995).

As these example show, in the expert-based approach to planning the quality of a plan depends primarily on the ability to collect as much relevant data as possible, including information on the abiotic (e.g. soil, hydrology), biotic (vegetation, fauna) and human (e.g. land use, population density, socioeconomic) characteristics of the plan area. Many datasets on the same geographical unit were produced, representing different aspects relevant to the planning process. The planning processes involved taking all this data into account in the preparation of decision making. There was a demand for ways to structure geographical data, to generate a full overview of the characteristics of a certain area relevant to the planning situation, and to study interrelations between these different characteristics.

It is therefore not surprising that the first incentives for the development of GIS came from people who were professionally engaged in landscape design and land use planning. In 1969, the landscape architect Ian McHarg published his famous work *Design with Nature*, in which he presented a method for land suitability analysis by depicting various abiotic, biotic and human characteristics of an area as separate layers. Different layers, in fact representing different datasets, could be stacked up to combine geographical information on different topics (Figs. 9.2 and 9.3). This offered an overview of all the surveyed characteristics of the landscape and, moreover, insight into interrelations between these datasets. As Harvey (1997) describes, McHarg was not the first to apply a layer approach. As early as the 19th and early 20th centuries, starting with Von Humboldt's Kosmos (1845–1862),

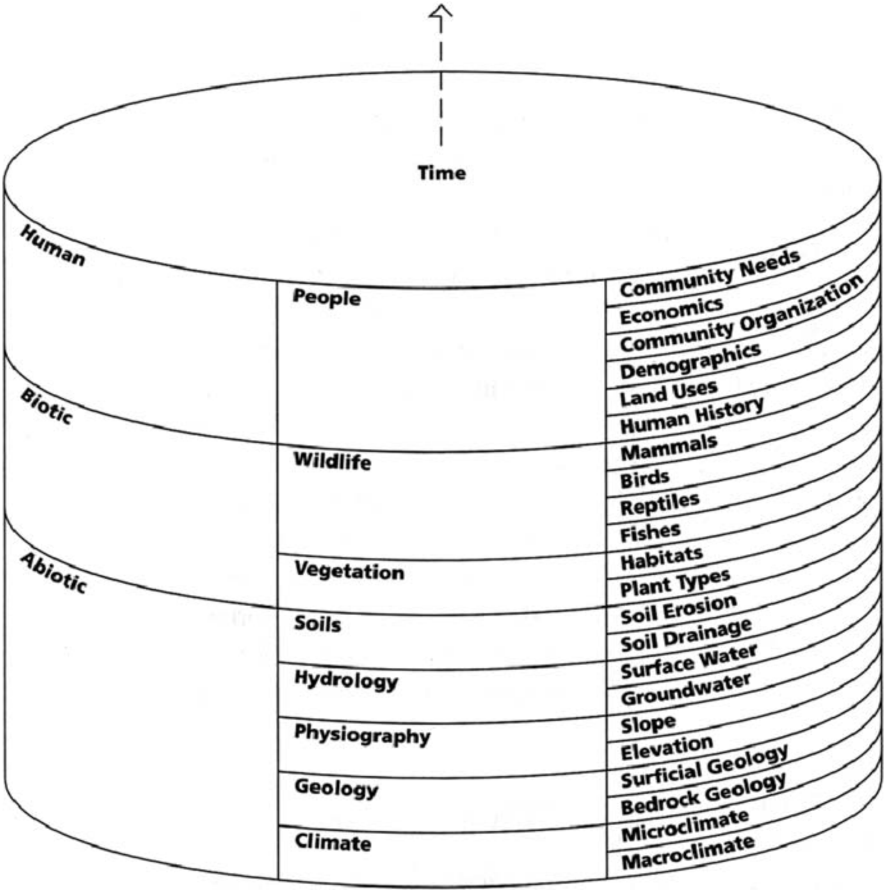

**Fig. 9.2** Layer-cake model (source: Steiner 2000; reproduced with kind permission of The McGraw-Hill Companies)

geographers had tried to get a better understanding of 'the Whole' (Hartshorne 1939) by unravelling the landscape into different layers and determining vertical relationships between the layers. However, McHarg was the first to champion the opportunities provided by the layer approach for spatial planning:

> Inventories would then constitute a description of the world, continent or ecosystem under study as phenomena, as interacting process, as a value system, as a range of environments exhibiting degrees of fitness for organisms, men and land uses. . . . Certainly the most valuable application of such inventories is to determine locations for land uses and most particularly for urbanisation. . . . Let us ask the land where are the best sites. (McHarg 1969, 197).

*Design with Nature* laid much of the foundation for the broad success of layers and overlays in GIS (Harvey 1997). Initially, individual layers were each drawn on a sheet of transparent paper. However, working with overlays manually was

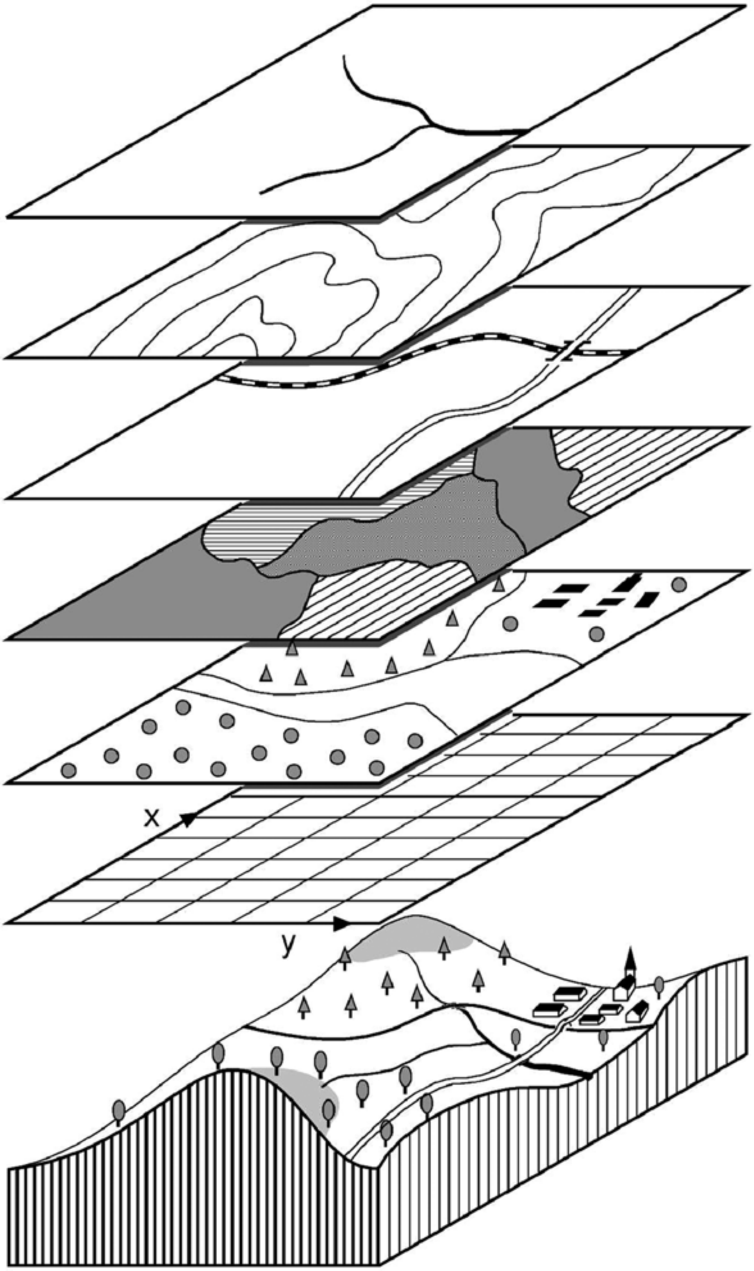

Fig. 9.3 Overlaying multiple datasets

very labour intensive and raised many practical problems. Data had to be stored in hard copy and maps had to be drawn by hand. Maps rapidly became outdated and making minor corrections would mean drawing a new map. Moreover, hand-drawn maps tend to be inaccurate due to human flaws and stretching or shrinking of paper (Heywood et al. 2006). It was therefore an obvious step to digitalise McHarg's overlay concept, and even in the 1960s there had been some experiments with GIS and overlay approaches for land inventory. The main developments were the CGIS (Canadian Geographical Information System), developed by the Canadian government since 1964, and the development of DIME (Dual Independent Map Encoding) by the US Bureau of Census since 1967 (Heywood et al. 2006, referring to Goodchild 1995).

McHarg's work inspired pioneers like Jack Dangermond, who founded ESRI in 1969, and Carl Steinitz, both landscape architects, to take GIS beyond land inventory. Dangermond (1979) developed the Integrated Terrain Unit Mapping (ITUM) methodology, extending McHarg's overlay analysis methodology to enable actual integration between layers (Harvey 1997). Steinitz conducted various case studies in the field of landscape planning, drawing on SYMAP, a programme developed in 1963 at Harvard University (Collins et al. 2001).

The first steps in Geo-ICT were therefore triggered by the needs of spatial planners and landscape architects to develop map-producing systems to store, analyse and visualise spatial data. Gradually, GIS evolved towards more user-friendly applications like ARC/INFO (1982), IDRISI (1987) and ArcView (1992). GIS techniques became more easily accessible to a large group of users in planning science and practice, and planners gradually started to learn how to use them. Indeed, the development of the city of Almere, discussed at the beginning of this section, has been monitored and planned using digital mapping systems (Alverson 1993). The Dutch National Spatial Planning Agency (RPD) and the Dutch Government Service for Land and Water Management (DLG) were the first organisations in the Netherlands in the mid 1980s that started to use GIS in the preparation of spatial policy. Scholten and van de Velde (1987) argue that the main value of the introduction of Geo-ICT into spatial planning at the regional level was the rapidity and accuracy with which maps could be produced, as well as the new possibilities for performing all kinds of analyses on geographical data. For the first time planners were able to combine attribute data with location data.

Nevertheless, in these early stages the availability of digitalised data was an important obstacle to the use of GIS. Analogue data had to be digitised before they could be used. Moreover, this was usually only done on the scale of the project at hand. The Government Service for Land and Water Management, for example, digitised hard copy topographical maps, but in the beginning of the 1990s it also started to demand that data suppliers (i.e. research institutes) deliver their data in digitised form, although at this stage these data were often hard to compare and exchange or to integrate at a higher geographical scale. Gradually, more digitised data became available, not only for specific projects, but in the Netherlands as in many other countries also on the national level. More and more attention was paid to the accessibility and comparability of these data and clearinghouses for geodata were established in many countries (Crompvoets 2006) and government regulations were put into force to guarantee the quality of the data. An example of this is the European Union's INSPIRE directive, which was adopted in 2007.

## 9.4 Planning Support Systems and Land Use Models

The increased availability and quality of spatial data and the rapidly increasing technical opportunities for data storage and processing fuelled new attempts to integrate and model data on a large scale as a way of improving the quality of spatial decision making. This can be seen as a second wave in the development of large-scale spatial models. Earlier, in the 1970s, comparable attempts to develop various large-scale urban land use models had failed. In his *Requiem for Large Scale Models* Lee (1973) analysed these unsuccessful attempts. He stated that most of these models were theory driven and rarely problem driven. A characteristic feature of these models was that important steering variables (to be influenced by spatial policy) could not be changed and that they generally lacked transparency and simplicity, which meant that only a very limited number of researchers contributed to their development. This lack of interaction not only stunted their development but also hindered their application.

Awareness of such problems led to the development of 'planning support systems' (PSS) (Harris 1989), a broad range of geo-information tools and technologies specifically designed for supporting spatial planning, as opposed to earlier general systems (GIS, spatial decision-making support systems) which may be used in spatial planning (Geertman and Stillwell 2003, Vonk 2006). PSS may be dedicated to exploration, analysis, prediction or visualisation of current and future spatial developments, and discuss issues associated with the need to plan (Batty 1995, as referred to in Vonk 2006). Therefore, various types of PSS have been developed for different stages and tasks in spatial planning.

An example is STEPP (Strategic Tool for integrating Environmental aspects in Planning Procedures; Carsjens and Ligtenberg 2007), which combines several environmental influences (smell, dust, noise, fire, explosion hazards, air and soil pollution) with the sensitivity of humans, flora, fauna and abiotic elements into integrated environmental quality maps. By adapting the parameters of the model, the effects of land use changes on environmental quality can easily and quickly be analysed. It supports decision making by exploring and analysing different planning policy options on land use change. Another example of a PSS is the WARUMEC system developed in the early 1990s by the Staring Centre (now Alterra) in the Netherlands (Roos-Klein Lankhorst and Verweij 1999). The system is designed as a quick scan instrument for planning support in an early stage of the spatial planning process. It consists of three modules: condition, suitability and quality (Fig. 9.4).

The module 'condition' contains data on the present physical state of an area. The module 'suitability' allows the user to calculate the suitability of land for a wide range of land use types. The suitability assessment is done by using expert rules

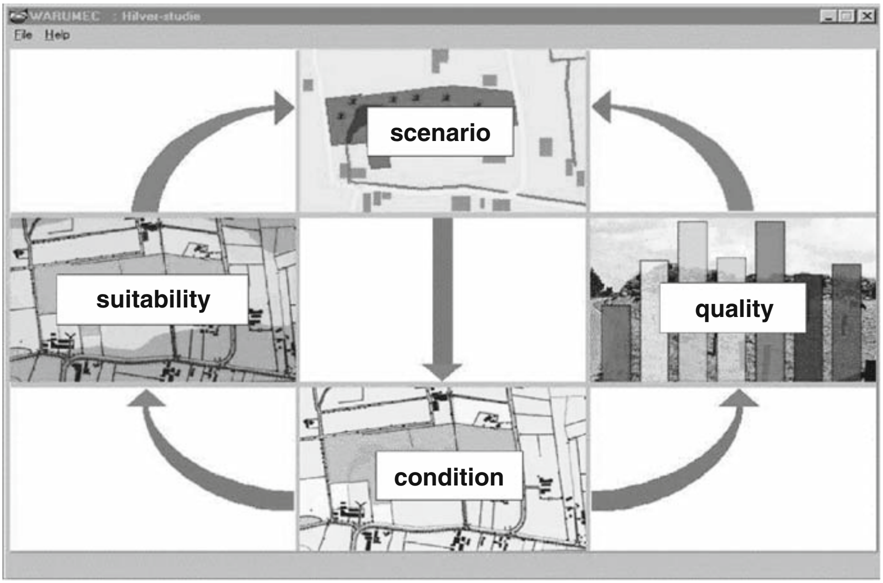

**Fig. 9.4** The WARUMEC spatial planning support system (source: Alterra)

derived from various detailed studies and experts from the research institute. The last module, the ‘quality’ module, allows the user to calculate a number of hydrological, environmental, ecological and economic quality indicators for a study area. The system supports the planning process by calculating the change in qualities of the region in different plan scenarios, which represent possible projected or planned land use types. Although the system was user-friendly, fast and very well stocked with spatial data and expert knowledge, it was not used much because the users (i.e. policy makers) had little trust in it, thinking the results of the calculations were too good to be true, and because the system itself was poorly maintained.

Lee’s warnings were still highly relevant, despite the increased computational power of Geo-ICT. However, Lee also stated that when models are specifically designed for policy evaluation, it is particularly important to construct them in a transparent way and to opt for simplicity wherever possible. Complex models with large numbers of dependent and independent variables are often simply not used because nobody understands and trusts them. These recommendations underpin the philosophy of the Land Use Scanner (Scholten et al. 1999), which was developed in the 1990s as a policy analysis model. This model integrates techniques for spatial analysis with a very broad range of spatial data which are registered per grid cell of 500 x 500 metres. The input of the model is based on forecasts at national or regional scale, which are translated into variables that refer to population, the number of households and, related to these, housing needs, employment, the need for office space and commercial zones, and the spatial needs of land-based agriculture.

The results of the Land Use Scanner can be interpreted as the expected spatial claims (per grid cell or aggregations of grid cells) of the various types of land uses. The added value for ex ante policy evaluations lies not so much in the prediction of land use, but in the tracing of spatial conflicts and implications of land use changes. Processes of urbanisation, urban condensation and development along the main infrastructure, and also farm expansion versus nature restoration and conservation, can thus be translated into spatial patterns and consequences.

The Land Use Scanner has been intensively used for spatial policy analyses for over ten years now. Practice shows that the added value of Geo-ICT for this is in the opportunities it provides for integration, visualisation and communication of knowledge and information about spatial processes and patterns. (Dekkers and Koomen 2007; Koomen et al. 2008). Figure 9.5 shows a ‘difference map’ of the future built-up area in 2040 compared with the current built-up area in the western part of the Netherlands. The forecasts are based on a ‘concentric growth’ scenario, which results in new urban development that is located in the proximity of existing urban areas, preserving open spaces such as the Green Heart.

## 9.5 Visualisation and Communication

In the previous sections we showed how the development of Geo-ICT, and GIS in particular, was driven by spatial planners’ need for knowledge about the physical environment. The approach to spatial planning was technocratic and positivistic. Experts based their plans on solid, factual and quantified data, using the opportunities provided by Geo-ICT to support their planning activities. Over the years spatial planners adopted a more sociocratic and political approach. Planning theorists drew attention to the political context of spatial planning (Fischer and Forester 1993), the communicative aspects of the planning process (Healey 1996) and planning as a participatory process (Forester 1999). Expert knowledge was no longer sacred or dominant as stakeholders and their interests came to play an increasingly important role in participatory planning processes. As a consequence, the way Geo-ICT supported spatial planning also changed in what can be characterised as a shift from ‘decision support’ to ‘discussion support’, which pays more attention to visualisation and communication. The image is no longer the representation of the results of the planning process, but an integral part of the planning process itself, because the image has the capacity to evoke and clarify discussions between the stakeholders.

Technocracy and sociocracy can be considered as two opposing types of planning ideals (Faludi and van der Valk 1994). Table 9.1 sums up the main features of each. In the technocratic view, planning is a process that occurs in different phases in a set chronological sequence: from definition of the problem, by formulating objectives and drafting plan alternatives, to realisation of the best alternative. In the sociocratic view there is a cyclical process of searching and learning. The key question is not whether a plan is completed in an integral manner, but whether the perceptions that

**Fig. 9.5** 'Difference map' produced by running the Land Use Scanner on a predefined growth scenario (source: SPINlab VU University Amsterdam 2008)

**Table 9.1** Basic tenets of steering and planning: technocracy and sociocracy (after Faludi and van der Valk 1994, 11)

| Features | Technocracy | Sociocracy |
|---|---|---|
| Planning controlled by | One steering centre | Coalition of parties |
| Type of process | Social engineering | Joint learning |
| Role of experts | Central | One of many |
| Degree of centralisation | High | Low |
| Type of plan | Blueprint | Indicative |
| Importance of plan | Normative, dominant | Relative |
| Perception of effectiveness | Conformance | Performance |
| Course of process | Linear | Cyclical |
| Role of science | Positivistic | Critical and pragmatic |
| Image of the future | Closed | Open |

are agreed upon are considered feasible by those involved and having a stake once action is taken (consequences of the plan).

We should point out that technocracy and sociocracy are not binary categories like black and white or right or wrong. Rather, they are groups of dimensions that lend colour to the differences in planning systems and provide a tool to help understand why planning systems tend to differ between one situation and another. A second observation is that technocratic is not the same as technical. The latter term is neutral; sociocratic planning often depends on technical solutions to the problems it encounters.

With regard to modelling, this shift towards sociocratic planning is reflected in the development of ‘multiagent systems’ (Ligtenberg 2006; van Leeuwen, et al., 2007). Whereas ‘classic’ land use models take current physical characteristics of the landscape as their starting point to determine possible future land use, multiagent systems attempt to model *actors* (the ‘agents’) in this landscape to determine the impact of their behaviour on land use. Every agent is in itself a model, which has properties like autonomy, social abilities, reactivity and sometimes even mentality and emotion. The agents sense their environment, including other agents, and act on it over time in pursuit of their own agenda. Multiagent systems, therefore, are used to simulate interactive multiactor spatial planning processes. Figure 9.6, for example, shows the total suitability for new urban development generated by three groups of actor agents (farmers, nature conservationists and citizens).

The dependence of sociocratic planning on technical solutions can be illustrated further by the use of Geo-ICT for visualisation and communication in participatory (i.e. sociocratic) planning processes. New techniques, such as map tables and 3D virtual reality viewers have been developed to facilitate communication on spatial information to the participants of a spatial planning process and to avoid unfocused design discussions, unjustified expectations, and expensive and unchangeable planning decisions.

MapTable, developed in the Netherlands by Alterra and Rijkswaterstaat (the Directorate-General for Public Works and Water Management), is designed to bring

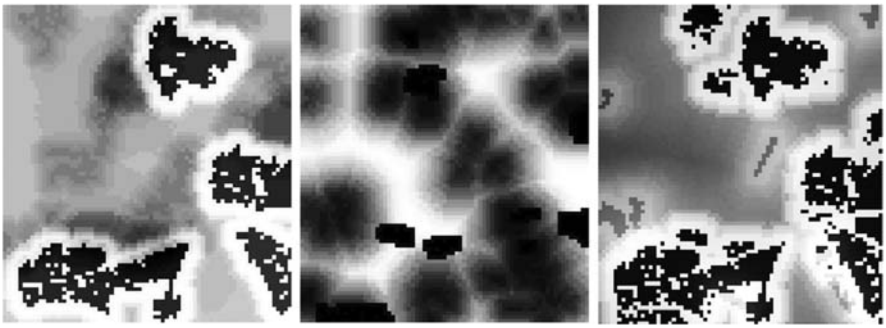

**Fig. 9.6** Multiagent system application, showing total suitability for new urban development generated by three groups of actor agents (at t=0). *Dark grey* indicates low suitability, *light grey* a high suitability (source: Ligtenberg, et al., 2009)

stakeholders together to discuss a new spatial design. Participants' knowledge is combined with a large spatial database and process models. Maps are displayed on a large computer screen embedded in a table, around which participants can gather and propose adjustments by drawing directly on the map (Fig. 9.7). The system can immediately calculate the impacts of their proposals, for example the effects

**Fig. 9.7** MapTable in action (source: Jandirk Bulens, Alterra)

of certain landscape adaptations on the water level of a river. Test cases show that MapTable is a useful and efficient tool for brainstorming, visualisation and collaboration, although its ease of use still requires improvement (Bulens and Ligtenberg 2006). Similar systems, although with different functionality, are Tangitable by Geodan and VU University Amsterdam (Scottà et al. 2007) and Virtual Maquette by the Technical University of Eindhoven (de Vries et al. 2006).

Virtual reality viewers and other 3D geovisualisations are generated from 2D geographical data and include additional 3D objects, which lend perspective to the visualisation (Fig. 9.8). They are flexible tools, allowing the visualised data, point of view, scale and interaction with data to be changed via an interface (viewer). Such visualisations present spatial information that is inherently 3D in its natural format, which reduces the number of cognitive steps stakeholders have to make to understand a visual representation. The technology for building 3D geovisualisations, including their photorealism and visual quality, has been gradually improved over the past 20 years. Their power to influence the perception and decisions of people, and therefore to influence participants in the planning process, is widely acknowledged (e.g. Appleton and Lovett 2005). Nevertheless, knowledge on how to use these geovisualisations in the planning process is relatively scarce. Using geovisualisations in participatory spatial planning without being certain of their suitability can lead to the dissemination of unintentional misleading messages that may result in counterproductive processes. Such consequences can seriously damage the involvement and support of participants in the whole planning process. Planners therefore need to learn about when and how to use these powerful tools.

The INTERREG IIIC project 'Participatory Spatial Planning in Europe' (van den Brink et al. 2007) has yielded a number of interesting insights of importance for the practical application of geovisualisation in participatory spatial planning. It showed, for example, that geovisualisation acts as a catalyst for developing new forms of par-

**Fig. 9.8** Example of a virtual reality viewer: the case of the Groningen Lake City Project (source: Boetze and van Uum 2007, 129)

ticipatory spatial planning. Besides, traditional forms of information transfer have had their day and much spatial information is freely available via the internet. This implies a different way of thinking and working. The project also showed that geovisualisation raises the question of which spatial information is necessary to come to a decision and how this information should be represented and communicated. Geovisualisations have great potential to reveal people's sense of place and their attachment to it, although it is difficult to say which geodata and geovisualisation best serve this purpose.

Nevertheless, the project proved that geovisualisation is an effective educational tool for stimulating dialogue between citizens and decision makers. This is particularly true in countries where government authorities have little experience of participatory processes or are reluctant to engage in them for fear of losing their grip on the outcome or because the organisational culture formed over many years leaves little room for active citizen participation. On the other hand, no concrete answers could be given to the question of how participants actually perceive the new tools. Further research is needed on comparing traditional and innovative forms of information and knowledge exchange in planning practice, and on their effects on stakeholders and planning process. Finally, the project showed that the successful application of geovisualisation requires considerable input of time and money as well as organisational change. It is not the technology that is expensive, but the adjustment to working practices required to actually put this technology to good use. Moreover, the expert – 'geo specialist' for example – is still needed to translate proposals made by stakeholders during public meetings into a new representation or image of the future situation. And organisational arrangements need to be made that allow governments to adequately respond to these proposals.

## 9.6 Future Developments: Mapping Emotions

In the near future, web-based applications may offer possibilities to better understand people's preferences and behaviour. A consortium including the Technical University of Eindhoven and the City of Eindhoven has conducted an experiment in which members of the public volunteered to track their daily movements through the city to obtain a better understanding of the 'sense of the city'. On their way, the volunteers took notes and pictures of what they see, what they like or dislike, illustrating how they experience the city. Their routes, notes and pictures are presented on the website.[1] In this case, Geo-ICT is used to collect and visualise data on people's preferences and spatial behaviour. The challenge for spatial planners is to find ways to use such data for planning purposes.

In general, the World Wide Web is playing a tremendously crucial role in today's society. Recent statistical research shows that in 2006 over 80% of Dutch

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[1] See www.senseofthecity.nl.

households have access to the internet. Also, governmental services are increasingly offered online (CBS 2006). A random exploration of Dutch spatial issues on the internet turns up many informative websites about spatial transitions and spatial decision making at the national, provincial and municipal level. It is the anonymous character of the web that Bulmer (2001) finds most promising. Traditional methods of public participation quite often involve a confrontational atmosphere that can discourage participation. Besides, the limited time and the actual geographical location can restrict the possibility of widespread attendance. Participation over the internet dissolves barriers like time, location and confrontation (Bulmer 2001).

To sum up, the internet is regarded among scholars as a very useful tool for organising, presenting, communicating and discussing spatial information. It is claimed that it makes spatial planning more democratic, more accessible and more bottom-up. What seems to be missing, however, is a true web-based interactive platform in which geospatial information is visualised to achieve better participation, better process results and, in the end, a better spatial transition. In this regard, the launch of Google Earth and Microsoft's Virtual Earth on the internet is considered to be a very promising development by researchers and policy makers. As one researcher has stated in the journal *GIS Development*, "... Google had simply given access with Google Earth. Access to geographic information in a fairly democratic way in the hands of everyone (having Internet), without discriminating on the basis of who is who – government, staff, academician, student, NGO, private sector, defence staff, etc. It has made any restrictive regime – of withholding geographic information – a big joke" (Gupta 2005).

## 9.7 Discussion

We have seen how GIS evolved from the efforts of landscape architects in the 1960s and has developed into a full scientific discipline. We have illustrated this with examples of Geo-ICT applications used for spatial planning over the years, from very basic land use models via more advanced models with map representation to integrated systems supporting discussion, providing attractive visualisation and communication tools that are available now or will be in the near future. At the same time, we have seen that spatial planning has been transformed from a positivistic, technocratic process into a more participatory and sociocratic activity. Developments in both spatial planning and Geo-ICT, and the interactions between these disciplines, are shown side by side in Fig. 9.9.

Although Geo-ICT and spatial planning appear to be closely interrelated in scientific development, researchers conclude that the use of Geo-ICT in spatial planning practice lags far behind expectations (Brail and Klosterman 2001; Geertman and Stillwell 2003; Uran and Janssen 2003; Couclelis 2005; Vonk 2006). The literature contains a number of reasons for this, both in the Geo-ICT sector and in planning practice. The Geo-ICT sector is said not to provide the tools spatial planners need in a form they can deal with: "Most current tools are far too generic, complex,

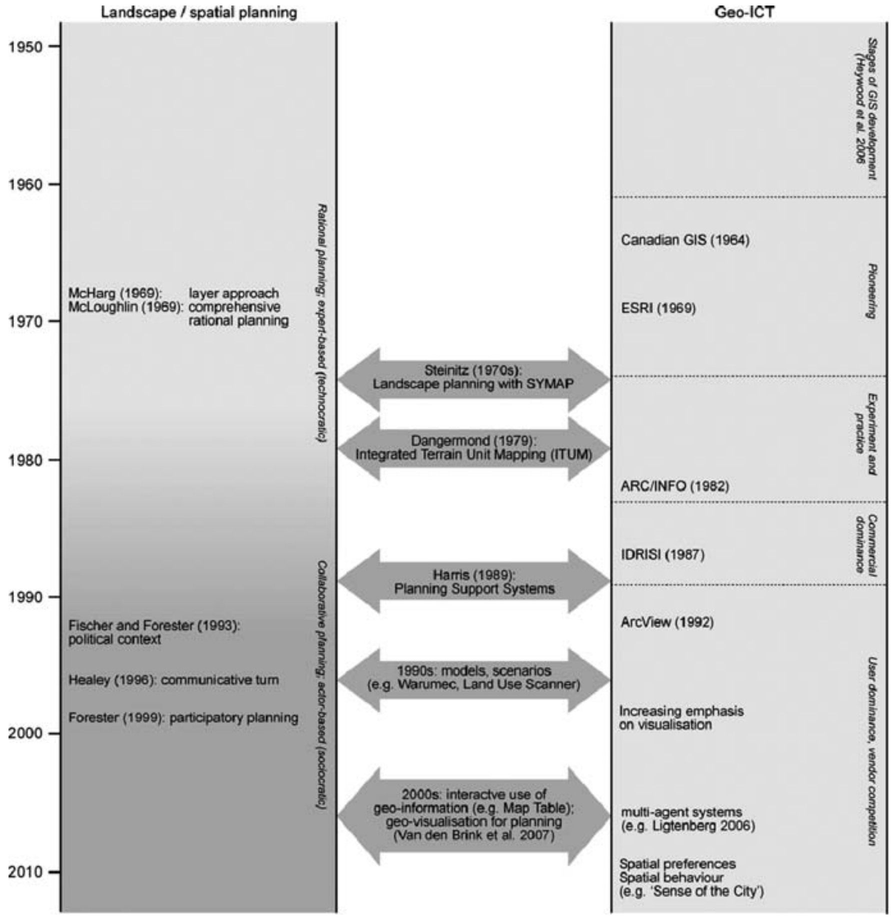

**Fig. 9.9** Development of, and interactions between, spatial planning and Geo-ICT since the 1960s

and inflexible, incompatible with most planning tasks, oriented toward technology rather than problems, and too focused on strict rationality" (Vonk 2006, 44). Or, as Couclelis (2005, 1359) puts it, "models are based on science; planning is about policy". Planners, on the other hand, "remain at best distrustful, or at worst downright antagonistic toward highly systematic and computer-based models" (Geertman and Stillwell 2003).

Vonk (2006) observes that PSS designed primarily to inform the actors involved in planning are applied widely, but PSS designed primarily to support communication and analysis are not. He distinguishes three main categories of bottlenecks to widespread usage and acceptance of PSS: little awareness of the existence and purposes of PSS; a general lack of experience with them; and little intention of using them. These bottlenecks are expected to be at least partially valid for computer-based tools in general.

In terms of the ‘integration or diffusion model’ presented in Chapter 1, Geo-ICT in spatial planning seems to have trouble jumping from stage 6 (‘large-scale databases’) to stage 7 (‘full integration’). We believe technical obstacles are hardly the problem here, considering the many possibilities presented in this chapter. What is preventing the full integration of these disciplines are the methodological differences between spatial planning and Geo-ICT, the related data obstacles and the lack of competence in making use of the possibilities.

### *9.7.1 Methodological Obstacles*

The scientific approaches and applied methods of both disciplines have grown apart since Geo-ICT emerged from the planners’ need for data and automated spatial analysis methods in the 1960s. Whereas Geo-ICT developers have focused on quantitative data, spatial planners are increasingly applying qualitative methods. Out of the rational approach to spatial planning in the 1960s and 1970s, deriving plans mainly from physical characteristics of the present and the desired landscape (to be defined by planners), a planning practice has emerged which engages much more with people’s opinions, values and interests, and which is searching for ways of involving the public in planning.

Planners are searching for interaction between quantitative object knowledge and qualitative process methods. Geo-ICT experts often develop tools based on a technocratic, rational image of spatial planning, which does not satisfactorily support the sociocratic, political situation with which spatial planners are confronted. Because of this discrepancy, Geo-ICT products which may in themselves be of good quality are not accepted by spatial planners. At the same time, we must conclude that many planners make little effort to explore what Geo-ICT has to offer, probably due to their focus on process rather than data. They have little knowledge of the possibilities and do not feel motivated to invest in software, data and education.

### *9.7.2 Data Obstacles*

With regard to data obstacles it is important to note that the role of data in planning processes is changing. Whereas in the technocratic planning tradition data was usually collected and accepted by the planners, in the contemporary, more sociocratic planning paradigm data is collected by multiple actors and is also much more contested. Data is interpreted differently and used strategically by participants in a planning process. Hence, Geo-ICT tools providing or processing these data are not automatically accepted. Moreover, other data is required. Sociocratic planning requires not only data on physical characteristics of the area to be planned, but also data on people’s interests, behaviour and preferences, and on the cultural or historical meanings of places. Such data are not systematically collected.

On the other hand, there may be too much data. At first sight this may seem rather contradictory, but a lot of effort is put into collecting more detailed datasets, which reflects the processes of individualisation and fragmentation in society. More detail does not automatically lead to 'better' spatial decision making. Besides, the collected data usually only describe the actual situation and give less insight into land use dynamics. These dynamics, and also the increasing importance of the third dimension and the blurring distinction between indoors and outdoors, demand new concepts of data collection. There is a growing demand for process-oriented data that can support social, governance and business processes. Process monitoring will probably be one of the key factors in this change of orientation. It is therefore important to find new ways of balancing spatial planning, data and Geo-ICT applications.

### *9.7.3 Competence*

A planners attitudes towards Geo-ICT is partly determined by their education. If attention is paid to Geo-ICT in planning education now, this may result in a gradual increase of interest in Geo-ICT in planning science and practice. A quick scan of Bachelors and Masters study programmes on spatial planning at five Dutch universities (Utrecht University, University of Amsterdam, University of Groningen, Radboud University Nijmegen and Wageningen University) shows that three universities offer their bachelor students an obligatory introductory course on GIS or modelling (see Table 9.2). Remarkably, at two universities a course on Geo-ICT is

**Table 9.2** Geo-ICT in academic planning education in the Netherlands (based on QANU 2008)

| University | Programme | Course on Geo-ICT (size in ECTS) | Geo-ICT as a required qualification |
|---|---|---|---|
| Amsterdam | BSc Planning | Geographical Information Systems (6) optional | Yes |
| Groningen | BSc Human Geography and Planning | Introduction to GIS (5) | No |
| | BSc. Technical planning | Introduction to GIS (5) | |
| Nijmegen | BSc Human Geography and Planning | Modelling: design and application (6) | No |
| Utrecht | BSc Human Geography and Planning | GIS/Cartography (size unknown)<br>Human Geography track: obligatory<br>Planning track: optional | No |
| Wageningen | BSc Landscape Architecture and Planning | Introduction Geo-information science (6) | Yes |

obligatory for bachelor students of human geography but not for planning students. Masters programmes offer no obligatory Geo-ICT courses.

All universities offer courses on methods and techniques, both in the Bachelors and Masters programmes. Such courses incorporate Geo-ICT applications and let students reflect on the possibilities and limitations of Geo-ICT. Two universities mention “analysing and simple mapping with GIS” or “applying digital technology” as a skill in the list of qualifications that students should acquire in their Bachelors programmes (see Table 9.2). One of them mentions it also as a Masters qualification. Conversely, there is a Masters programme on Geographical Information Management and Applications offered by a consortium of Dutch universities, which includes spatial planning as one of the application fields of Geo-ICT.

These results do not give the impression that Geo-ICT, and GIS in particular, are firmly established parts of planning education. They may even be considered as an evidence base for the current situation in which spatial planning and Geo-ICT have grown apart. On the other hand, as spatial planning has become more process oriented, they may also stimulate the geosciences to pursue a new course.

## 9.8 Conclusion

Considering the examples of the possibilities presented in this chapter, Geo-ICT experts and spatial planners appear to be heading in the right direction to overcome these obstacles. We observe three general trends which are in line with developments in spatial planning. The first is a change of the *target group* of Geo-ICT. ‘Traditional’ GIS used to focus on expert users. Now, more attractive visualisation, increasing attention to aspects of communication and easier accessibility of data and applications are making Geo-ICT more accessible to the public and enhancing the interaction between Geo-ICT experts, planning practitioners, decision makers and the public. Applications are becoming more widely applicable and can be tailored by users to suit their own needs. The most obvious examples of this, of course, are Google Earth and Google Maps, which are by now incorporated into many websites and web-based computer tools.

Second, there is a shift in the *subject matter* with which Geo-ICT deals. Whereas Geo-ICT traditionally focuses on land use and the physical characteristics of the earth, more recently it is increasingly dealing with people and their spatial preferences and behaviour in space and time. We described multiagent systems, which assume that land use is changing through actors’ choices and consequently focus on these actors in the first place. The various examples of using geovisualisation to support discussion between actors and web-based tools like ‘Sense of the City’ show that Geo-ICT developers are increasingly interested in people’s opinions about their environment, rather than on land use itself.

Third, with respect to the *Geo-ICT frameworks* presented in Chapter 1, we observe a gradual shift from an emphasis on geodatabases and geomodels to geomaps. Whereas data used to be the limiting factor, in recent years an abundance of data has been built up and made accessible. The modelling technology to process and analyse these data is available. The task now is to making data and results more meaningful to planners, decision makers and the public by further improving aspects of communication and visualisation. This stronger focus on the geomap framework may raise planners' interest in GIS and lead to further improvement of GIS tools through the incorporation of their feedback. It raises new questions: How can behaviour and preferences be made visible through geo-information? How can we cope with the contestability of data? How, and to what extent can data on spatial preferences of individuals be generalised and used to serve planning for society? These are questions to be answered by Geo-ICT specialists, spatial planners and participants in planning processes together. By learning from each other, they can bring Geo-ICT and spatial planning closer to each other again, as they used to be in the early days.

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# Chapter 10
# Geo-ICT: Connecting Physical and Virtual Geographies

**Josef Strobl**

## 10.1 Introduction

Geo-ICT, loosely defined as ‘computer-based technologies and methods applied to georeferenced data’, is a rapidly growing area spanning the full range of applications from everyday, spatially aware visualisations to dynamic modelling of complex processes. ICT and Geo-ICT are rapidly gaining momentum as an indispensable research methodology in physical geography as part of the wider field of geography, environmental science and other explicitly spatial sciences. Researchers in the geosciences and environmental sciences regularly make observations and representations of natural environments, models of physical processes over different timescales and simulations of alternate futures scenarios.

Quantitative methods, and subsequently computer-based tools, were adopted into physical geography at an early stage of their development. This fact has several interdependent roots. First, because of the repetitive nature of topographic map analysis and aerial photo interpretation, which are standard tasks in physical geography, algorithmic automation was attempted to achieve standardised results (e.g. Evans 1990). Subsequently, statistical analysis became more important, first in climatological research and then in other areas, such as terrain analysis. Geostatistical techniques imported from exploration geology became popular as alternative interpolation approaches and later for mapping value distributions over rugged terrain. Another entry point for ICT into physical geography was the emergence of remote sensing techniques for land cover classification and later for multitemporal analysis of vegetation, snow cover and other indicators of physical processes. A final example is the rapid adoption of ICT to support the drafting of maps. As in many other disciplines, early GIS applications provided ‘automated mapping’ capabilities

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to support existing workflows and not to realign analytical workflows according to Geo-ICT capabilities. Some limited progress towards a rethinking of workflows was achieved through ambitious programmes targeted at geomorphological, geoecological or ‘geoscientific’ mapping (e.g. Vinken 1986).

These examples of Geo-ICT making inroads into the traditional set of methods, and becoming standard techniques for most researchers, indicate a slow but steady paradigm change, which is still under way. Early physical geography relied extensively on personal observation and field mapping. This approach was limited to in-depth studies of some areas and a few comparative analyses because travel, the availability of prominent vantage points, the size of the study area and limited observation time imposed severe practical constraints on the scope and scale of field studies. It is not surprising, therefore, that the use of models representing the study area quickly became popular, and topographic and other physiographic maps as analogue models were soon adopted as core tools. Physical geographers were, and some still are, adept at creating models (e.g. geomorphological maps) from field observations and aerial imagery and interpreting and analysing maps to obtain deeper insights into the processes leading to the observations documented in these (map) models. Models (maps), as simplified representations of certain aspects of reality, serve the analytical needs of a given research topic. The emergence of Geo-ICT has led to a change in modelling, but not necessarily in research topics as such. As analogue models have increasingly been replaced by digital (data) models, maps have now essentially become communication tools.

Interestingly, as indicated above, early applications of Geo-ICT in physical geography often followed a rather conservative approach by attempting to replicate well established analogue techniques in the digital domain. A German research initiative to develop a ‘digital geomorphological map’ (Stäblein 1978; Dikau 1992) contributed enormously to the evolution of digital geospatial tools and skills in physical geography. Ultimately, though, it did not go anywhere because it became obvious that the map itself did not justify the huge resources being invested in its creation and the researchers attempted to legitimise their effort by shifting the objective to developing ‘applied’ maps. One outcome was the move to the concept of a ‘digital geoecological map’ (Duttmann 1993; Duttmann et al. 1993; Huber 1994), but again the main point was missed; the focus was too much on producing a map at a time when visual models were already being replaced by structured digital data models.

This example clearly demonstrates an important point that is valid for many disciplines moving towards ICT-based frameworks: just using digitally supported tools while adhering to established concepts and workflows often falls short of the full potential ICT has to offer. Just using Geo-ICT with a focus on automated map production instead of replacing the visual graphics of maps, as the core conceptual model, with a much more flexible and powerful spatially explicit data model clearly misses the point (Raper and Livingstone (1995) clearly recognise this fact). Geo-ICT not only changes the tools, but changes concepts and research approaches as well.

## 10.2 Physical Geography as a Location-Based Science

Obviously, physical geography is an intrinsically location-based science. Knowledge and new insights are mostly derived from spatially organised observations by inductive reasoning. As in other areas of geographic enquiry, and unlike non-spatial analysis, empirical research is not based on mutually independent observations ('statistical independence'), but rather looks for patterns and spatial autocorrelation. Spatial patterns are considered to be the results of physical processes leading to the given spatial distribution of observations. Insights and the knowledge resulting from them are based, among others, on:

- localised and regionalised occurrence of phenomena or values;
- gradients (rate of change) between positions;
- directional flows at locations.

Hydrographic runoff is a simple example of the explicitly spatial modelling nature of many types of geographical analysis. First, elevation values distributed across a study area are registered, then local gradients (slope) are derived from the ratio of distance against change in elevation, the azimuthal distribution indicating the local direction of runoff. These data can be used to establish a runoff pattern of streams, delineate catchments and estimate hydrographs (amount of runoff over time at a point along a stream).

While physical geography covers a wide range of natural science and environmental topics, location, either as an absolute or relative position, is common to all of them. Analyses and models aim to explain patterns, distributions and processes through:

- location on the globe (e.g. latitude);
- elevation above a set datum or local reference point;
- position relative to forces like gravity, radiation, runoff, weather/climate;
- position relative to relevant spatial factors (e.g. lithology);
- position next to similar, different or particular things (e.g. gradient, clustering).

Physical geography is widely taught as 'Earth Systems Science' (Kump et al. 2003) within the wider framework of the environmental sciences. Empirical observations serve as indicators for patterns and then processes in our natural environment. One principal objective is to explain this physical environment in order to support its management.

The main target areas for Geo-ICT in this context are land surface analysis (landform types, geomorphogenesis, role of terrain in processes), land cover analysis as an indicator for land use, boundary layer analysis (weather, climate, water) based on observations of status and change, and advanced physical process modelling.

The teaching of physical geography is often broken down into compartments, or separate 'spheres', like geomorphology, climatology (atmosphere), hydrography (hydrosphere), biogeography, etc. (Holden 2004). For most applied research questions, several of these compartments need to be integrated, examples being the assessment of natural risks (hazard mapping), agricultural yield potentials and suitability zoning for different land uses. This integration of various factors is achieved by georeferenced overlay operations, a key method in analytical Geo-ICT.

For a truly applied perspective, risks, potentials and allocation zones need to be related to management actions because government and the general public will need to know about the potential impacts and outcomes of decisions and actions. Scenario-based analyses provide a decision-support interface to structural and process models, making model structures and parametrisation explicit to all users.

The general role of Geo-ICT in physical geography can be divided into three stages:

1. mapping and visualisation, and (spatial) statistics
2. spatial analyses – i.e. location-based integration, zoning, etc.
3. dynamic process models

All of these applications are universally based on georeferenced data and explicitly spatial processing, which are obviously necessary for methods applied in a location-based science.

## 10.3 Geo-ICT Frameworks

As the aim of this book is to assess and compare the uptake and impact of Geo-ICT across a range of 'location-based sciences', this three-stage framework is used here to discuss the longer-term development of Geo-ICT in physical geography:

1. Geomap: visualisation-oriented and mapcentric ('map analysis');
2. Geomodel: spatially explicit explanatory models;
3. Geodatabase: slowly emerging, but still mostly single-purpose.

As briefly mentioned above, the Geomap paradigm of mapcentric workflows was characteristic of the early stages of ICT use in this discipline. Efforts were frequently directed at more efficiently producing better maps, with maps serving the dual purpose of representing and communicating information. As always, when two separate tasks have to be achieved within one approach, compromises are necessary. Today the foundations are in place for focusing the mapcentric paradigm exclusively on communication tasks, with representation and storage taken over by geodatabases.

Explanatory modelling, the Geomodel paradigm, does have a well established tradition in Geo-ICT. Part of this, though, is not fully spatially explicit and based on non-spatial statistical techniques like bivariate or multivariate methods to explain location-based correlation regardless of the relative position of observations. As for truly spatially explicit models, two major approaches have become established: geostatistical modelling to explain patterns and distributions through stochastic processes, and physical process models as discussed below.

The Geodatabase paradigm is being developed in two stages. First, it indicates a shift from the above critiqued visualisation-oriented mapcentric approach to Geo-ICT, with its rather limited potential, towards a representation-centric data modelling paradigm. The latter aims at establishing geospatial data models that support different application logics, scales and temporal states; put simply, representing more dimensions and facets in a data model than would be feasible on any one map.

Data modelling typically follows the ANSI SPARC approach (as outlined in Peuquet 1994, 2002) where one or more external models (user views, application logics) are mapped onto a unified conceptual model whenever possible. The resulting multipurpose data models are the key foundation for making geospatial data available for multiple uses within distributed interoperable service frameworks. Practically speaking, this would mean that standard representations of physical features (e.g. terrain surface, hydrographic networks) would be accessible as online services. Applications requiring access to these features in different scales and semantics can directly work with these service-based representations. While most conceptual and technical questions have been resolved through Open Geospatial Consortium (OGC) specifications, practical applications beyond prototype demonstrators have yet to fully emerge. In short, the Geodatabase paradigm is only slowly making its way from project-oriented desktops towards standardised interoperable service infrastructures.

## 10.4 Sensing and Representing Physical Spaces

In order to analyse the current status of natural environments, assess the processes that formed them and predict future scenarios, adequate models representing reality need to be built. These models are based on direct measurements and indicators. While traditional physical geography research was largely based on topographic maps and field recordings, substantial progress has been achieved through satellite positioning and remote sensing technologies.

‘Geographical’ remote sensing had its origins in the recording of land surface reflectance patterns and the extraction of semantic information by image processing and statistically based classification techniques. The resulting land cover maps are interpreted as indicators for land use to explain the spatial arrangement of functional types of uses, such as economic activities. The revisit capability of remote sensing platforms soon led to a focus on multitemporal analyses, with land use change becoming the dominant object of interest.

The development of remote sensing techniques has for decades been aimed at enhancing what could be ‘seen’. Improvements in spatial, temporal, spectral and digital resolution led to an ongoing quest for ever more detail and higher resolution ‘objects’ in each domain, sometimes seemingly forgetting that remote sensing will continue to interpret an electromagnetic response as an indicator for the presence of real world features and not as a direct measure of a sometimes elusive entity like a land use instance.

### 10.4.1 Satellite Positioning

Starting from the concept of 'location-based sciences', determining and recording positions is obviously a critically important task for generating empirical evidence. Early work relied primarily on entering locations by 'visual referencing' in topographic maps. Whenever such a map was not available in sufficient quality or when precise locations were needed, terrestrial surveying techniques like triangulation or trilateration were employed.

Easy availability and high accuracy for positioning was achieved with the advent of GPS and other GNSS (Global Navigation Satellite Systems). Field mapping (e.g. with ruggedised tablet computers), spatial sampling and movement recordings all leverage the ubiquitous availability of positioning services. Although GNSS services have been taken for granted since the mid 1990s, they have revolutionised fieldwork, particularly in the geographical sciences where location is a defining factor for all observations, and where ground-based mapping had been a huge effort fraught with difficulties and inaccuracies (see Cornelius et al. 1994 for an early assessment).

### 10.4.2 Sensor Networks

More important than simply gathering position readings is combining them with values at those locations. Sampling networks for atmospheric or hydrological variables have long been a key tool for observing fluctuations in these domains. These stations were typically installed and operated at substantial cost for the long-term monitoring of physical phenomena.

Recently, due to progress in sensor technology, positioning services, communication and power supply sensor networks can be applied in a much more flexible and possibly ad hoc way. Spatially distributed sampling can now be carried out with stationary or mobile sensors connected through wireless (sometimes peer-to-peer or self-organising) communication networks. This opens up new opportunities for monitoring physical environments, greatly facilitated by OGC standards developments in Sensor Web interoperability (OGC 2006).

Early tracking of mobile sensors (e.g. telemetry for animal habitat research, as documented in Bogel (1996)) led to more sophisticated approaches (Fuller 1995) and now opens up opportunities eloquently compared to a 'digital nervous system for planet earth'.

### 10.4.3 Remote Sensing

For many decades remote sensing based on the interpretation of aerial imagery had been a core technique for physical geographers. In the 1980s, digital image processing of satellite imagery was accepted as the state-of–the-art technology for land use and land cover research, the latter often used as a proxy indicator for climatological phenomena, climate change and development issues.

Physical geography, though, is a 3D or at least a 2.5D science. As gravity is one of its key drivers and controls important processes, mapping the vertical dimension as well is considered imperative. Point-by-point surveys cannot easily cover large areas and photogrammetric extraction went through many generations of development (e.g. the ‘Gestalt photomapper’) and has only recently achieved a substantial degree of automation (Vexcel, Microsoft Virtual Earth).

The acquisition of remote sensing data focused on terrain and other surfaces was therefore of considerable interest to the geographical sciences. Microwave (‘radar’) remote sensing provided interesting results but was limited in difficult terrain due to its side-looking characteristics. Radar interferometry delivered excellent datasets with global coverage through the Shuttle Radar Topography Mission (SRTM) and was successfully commercialised in the NextMap environment (Intermap).

For more localised uses adjusted to different particular applications, LiDAR (‘laser scan’) remote sensing has turned out to be the most important recent technology. It can acquire terrain models as well as digital surface models over built-up as well as vegetated areas. LiDAR supplies high (submetre) resolution and, with recent developments towards full waveform analysis, competes in land cover analyses as well. From a geographical (natural) sciences perspective, this makes LiDAR the ‘technology of the decade’, with much of its promise still to be developed.

### *10.4.4 Subsurface*

Clearly, geospatial processes do not stop at the surface of the earth. Geomorphologists were always interested in digging a little deeper in order to understand how surface characteristics can be explained. Similarly, hydrologists are interested in subsurface processes, as are climatologists (e.g. using permafrost as an indicator), and of course whenever soils are relevant we clearly have to look beneath the surface.

Most remote sensing techniques (with the exception of low frequency microwave) are limited to the surface, but some geophysical techniques help with profiling some metres or more below the surface. This set of ground-sensing technologies has recently helped with creating a 3D representation for processes which for too long only could be analysed in 2D, like mass movements, groundwater hydrology, etc.

All these technical and methodological developments are mentioned here as a quick ‘supply-side’ overview of changes which are modifying and enhancing the Geo-ICT instruments available to researchers from a data acquisition perspective. New technologies are not only improving the empirical capabilities, but are also changing some of the research questions being asked and, to an even greater extent, generating new questions. Not only are temporal and spatial (scale) resolution getting finer and more direct measurements are becoming available, but simply being able to monitor much of our physical environment is giving rise to new questions.

## 10.5 Modelling Physical Processes

Observing natural phenomena, their patterns and arrangements and the changes taking place in them can all be considered to be indicators for the actual processes taking place. Observations take place at individual moments, just like ‘snapshots’ of remote sensing imagery, and tend to emphasise state over process, which has defined physical geography for too long. Similarly, the documentation of environmental factors through the use of maps communicates a stationary perspective. Only Geo-ICT enables the use of dynamic maps or animations, which represent the actual processes at work. Just as map scale controls the spatial dimension, compression (and in a few cases, expansion) of processes adjusts the temporal dimension to suit communication and understanding.

What, then, are the particular driving forces behind the main processes creating and continuously changing our physical environments? Only a few factors control change in a steady or cyclical manner:

- gravity
- solar radiation, relative to latitude, seasonal and diurnal variation
- secondary forces created by laws of physics: kinetic energy, latent heat, etc.

The analysis of numerous natural phenomena starts with modelling underlying processes. These are driven by the forces indicated above, typically moving matter and energy across a spatial domain resulting in a non-random spatial distribution of measurable phenomena. Geo-ICT play a key role in designing and operating models for various process types, described below.

Hydrographic runoff modelling across surfaces with variable morphographic, retention and friction characteristics is a generally well understood and widely applied approach (Maidment 2002; McKinney and Cai 2002; Ogden et al. 2001). Most of the required tools are fully implemented in standard GIS software and are regularly used for hydrographic characterisation of catchments, flood forecasting and flood danger assessment as well as for land use planning.

Solar energy is an important driver of natural processes. As a key input parameter into environmental and ecological models it contributes to the energy budget. GIS-based solar radiation modelling was one of the early applications to receive widespread attention owing to its broad relevance, from solar energy generation to agricultural production, and its role in the hydrological cycle (evapotranspiration, snowmelt). Modelling approaches have been developed, for example by Dubayah and Rich (1995), and are now widely available in various implementations.

More mathematically rigid models are required to analyse flows of groundwater through porous media based on Darcy’s law (e.g. Baker et al. 2003), often designed not only to quantify groundwater flows but also to determine the presence of contaminants. Atmospheric models tend to be even more complex due to their multi-scale characteristics and dynamic controls, and are currently handled in dedicated frameworks outside generic Geo-ICT.

Yet another domain for Geo-ICT based physical process modelling is exploring the diffusion of noise over complex (natural and built-up) surfaces (Li et al. 2002) or predicting atmospheric pollution (Gualtieri and Tartaglia 1998). Overall, spatial diffusion modelling for point, line and area source (frequently labelled 'non-point source') emissions has evolved into an important area in which Geo-ICT is continuously contributing to improved environmental management.

The broader area of GIS-based environmental modelling (as documented in Goodchild et al. 1993; Goodchild et al. 1996) uses physical process modelling as one important cornerstone, but generally follows an integrative approach aimed at concepts like suitability, impact assessment and evaluation of changes. These models do not merely represent processes, but start from defined objectives, use human values and relate physical processes to socially constructed spaces.

Physical and environmental modelling with a spatial focus is not without its challenges and limitations. Most models require the discretisation of continuous 'fields' (Kemp 1997a,b) into regular or irregular sample points or cells. Different computational strategies assist with either representing flows through differential equations or with localised rules (cost surface modelling, cellular automata).

Dimensionality is another issue. Geo-ICT has now moved from 2D to 2.5D ('surface') representation, but in many cases does not yet support full 3D frameworks. Current 3D data models are generally geared towards visualisation, but are not usable for dynamic modelling. As indicated above, physical processes are driven by forces (gravity) requiring more than a mere 2D model and interact across areas with significant relief (visibility, solar radiation). Therefore, the development of digital terrain/surface modelling has been and still is closely linked to physical modelling applications. A majority of these applications currently take into account single-valued surfaces (2.5D), but only very specialised solutions outside of the Geo-ICT mainstream currently support full 3D modelling.

## 10.6 Adoption of Geo-ICT in Physical Geography

Generally speaking, due to the traditional interaction with the wider natural sciences and their quantitative methodologies, some areas of physical geography were early adopters of Geo-ICT concepts and tools. This is particularly true for statistical methods in climatology and other data-intensive empirical subdisciplines, for attempts at multivariate analysis in hydrology, pedology and terrain studies, and even more so for supporting mapping through computer cartography.

While physical geography is obviously very well suited to benefit from a tight integration with Geo-ICT, in practice (and this is a personal, anecdotal observation) Geo-ICT has not been fully embraced as a core part of the discipline's methodology in many departments. Rather, it is relegated to a 'tool only' status by only using a limited part it its potential, leaving out core areas like modelling and tie-ins with key concepts.

Practically speaking, there seems to be a career dichotomy, at least in the German language domain of geography: highly qualified and experienced Geo-ICT'ers are not easily accepted into academic career tracks and tend to leave for employment in industry. Only a minority of academic leaders fully embrace Geo-ICT beyond the 'tools' level, which leaves considerable potential for full integration into theory and concepts.

Particular observations regarding this potential for growth and progress are specifically related to three issues:

1. A deterioration of common cores of knowledge and understanding in physical geography is associated with an increasing niche specialisation of many researchers. Geo-ICT, though, has particular strengths as an integrative methodology, which cannot be fully leveraged for very detailed research questions emphasising numerical analysis of overly narrow topics.
2. The use of Geo-ICT should move from the 'data handling technique' level towards full integration on a conceptual level (i.e. explicit data and process models). This would meet the need for conceptual thinking and problem-framing to catch up with measurement and analysis technologies.
3. Any strict separation between the natural and social perspectives in geography is counterproductive. As long as research questions e.g. geomorphogenetical issues per se, without links to human use and feedback from human actions, Geo-ICT will not live up to its full potential. This will be achieved from explicitly incorporating human decision making into the analysis of earth surface systems.

The future calls for physical geography to embrace and confront the creative tension between nomothetic and interpretive science (Phillips 2004) and to explicitly and fruitfully integrate these approaches by giving due attention to the natural/physical perspective of geography as a spatially explicit environmental science.

This exploration of the long-term adoption of Geo-ICT in physical geography has generally followed a standard innovation diffusion model, modified by the above-mentioned fact that full acceptance on the methodology level is still limited. One reason for this lies in the perceived dichotomy between explicit numerical modelling and field work. While the latter is obviously required for collecting some empirical data, ground truthing and validation, it is sometimes considered as superior to ICT-centric sensing and analyses. Results from field mapping and interpretation are sometimes considered fully complete research outcomes, while a similarly exclusive focus on Geo-ICT based research is (maybe rightly so) rarely accepted as valid work in the physical geography domain.

Highly complex explanatory models (e.g. for explaining the formation of a landscape) are difficult to implement. Plausible results from Geo-ICT which could potentially compete with qualitative assessment and interpretation are therefore few and far between. This is certainly an area with plenty of room for future development, with models operating across multiple scale dimensions and with a fuller integration of spatial and temporal aspects.

One interesting observation is that in a relatively short period of time we have moved from a situation in which the availability of data was a key constraint to one in which we are inundated with data. A short while ago 'map digitising' and 'field data collection' took up an extraordinary amount of effort, often leaving very little time and few resources for the analysis part of projects. For many applications this has changed substantially with the emergence of new data collection tools like the LiDAR technique. Condensing and analysing this flood of data and making sense of the huge volumes of observations – essentially, moving from data towards information and ultimately knowledge – has become the order of the day in terrain analysis. This is quite similar to the impact of multispectral remote sensing on research in land use/ land cover analysis.

However, there is still a substantial gap between theories and concepts on the one hand and methods and techniques on the other. Geo-ICT in physical geography is strong in the latter and rather weak in the former.

## 10.7 Challenges to Geo-ICT

From a physical geography and environmental sciences perspective, further progress in Geo-ICT is required to successfully tackle several current problems and issues. In order to make progress in key areas, several developments in Geo-ICT are needed to contribute towards a stronger foundation in methodology and geographical information structures.

Most topics on this wish list can be approached from a data modelling angle, assuming that only adequate representations will support application logics in an interoperable, efficient and sustainable manner. Some of these extensions to current geospatial data models are already under development or in the early stages of availability from some vendors, but generally speaking the capabilities listed below are at least partly unfulfilled requirements:

- data models for mass point data (such as surface sample points) with automated rules for scale-based dynamic extraction of points and features;
- support for hierarchical data models, which is required for working across spatial resolutions and scales and to avoid MAUP-unaware analyses;
- handling of spatial fuzziness as a data feature characteristic, also allowing for overlapping features and indeterminate boundaries;
- full 3D support, not only on a data model level, but including (consistency) rules and analytical processing;
- receiving temporal data as continuous data streams, including operators capable of real-time analysis.

Beyond these requirements that have to be tackled from a data model perspective, several analytical methods are currently not or only rudimentarily implemented in mainstream toolsets. Examples are methods for regionalisation, for feature extraction and for advanced fuzzy analysis. Strictly speaking, physical modelling is not supported in any GIS environments. Spatiotemporal dynamics from a system dynamics perspective, and flow/resistance equations are high on the wish list.

‘Solvers’ for optimisation of problems with multiple constraints like land use allocation, location/allocation, etc. (see Eastman et al. 1998) are currently emerging on research platforms and will probably be connected to GIS environments through tight coupling.

This last development already hints at one of the key areas for future Geo-ICT architectures of increasing importance for physical/environmental applications as well: distributed interoperable environments. These facilitate the development of models and analytical applications without the usual huge overhead of first setting up entire databases and the need to have all analytical capabilities installed on a local desktop. Linking a particular application logic to a remotely accessible database (e.g. a digital terrain model) and leveraging the required functionality through an OGC Web Processing Service are likely to serve as lightweight architectures for future applications in this and other areas.

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# Chapter 11
# The Role of Place and Time in the Epidemiology of Tropical Diseases

**Mark Cresswell**

## 11.1 Introduction

Environmental variables such as temperature, rainfall and humidity have a profound effect on disease. The biological characteristics of many organisms responsible for tropical diseases are such that they are sensitive to changes in the weather. Weather patterns can have a direct effect on diseases like asthma, hay fever, heart disease, influenza and mood change (Collier and Hardaker, 1995). Large-scale changes in global weather patterns like El Niño and La Niña can directly precipitate epidemics of diseases such as cholera, or indirectly by affecting vectors such as the mosquito (Diaz and McCabe, 1999; Bouma et al., 1997). These environmental conditions may be dictated by geography (and hence location) or be synchronous with annual seasonal cycles.

In the recent past much progress has been made with monitoring the environmental variables associated with disease using satellites. Diseases such as malaria (Thomson et al., 1995; 1996; Hay et al., 1996; 1997; 1998; Connor et al., 1997), trypanosomiasis (Robinson et al., 1997; Rogers and Randolph, 1991) and schistosomiasis (Malone et al. 1994) have been documented as good candidates for the exploitation of remotely sensed and other spatial information. A logical progression of this type of approach is epidemic prediction based on the forecasting of those same environmental variables rather than their monitoring

## 11.2 The Significance of Location

The very fact that a specific class of human diseases has been labelled as ‘tropical’ suggests that the early pioneers of their study were well aware of the importance of geographical location. Many of the organisms responsible for a

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variety of these tropical diseases require a specific set of environmental conditions in order to exist. Hot, moist climates with plenty of rainfall and vegetation favours insect vectors, while hot, arid and dusty conditions promote the transmission of bacterial agents responsible for conditions such as meningococcal meningitis.

Malaria is a complex disease. It is caused by the presence of a parasite (of the genus *Plasmodium*) within the body of the human host. The point of entry of the parasite is via an insect vector, the female mosquito of the genus *Anopheles*. Apart from an unwilling host, malaria needs water and warm temperatures. Water (primarily pools of water from either rainfall or irrigation) provides a location where mosquito larvae can develop and hatch. If the environment is extremely dry there will be few opportunities for mosquitoes to breed and transmission will be low. Warmer temperatures will accelerate the rate of development of both the parasite and vector such that population increase is more rapid. For these reasons, malaria is endemic in the warm wet tropics within the central Africa region. In such regions, morbidity is high but there are few epidemics as transmission is stable. This is not the case for mountainous regions, where it is often too cold. In areas where humans and infective mosquitoes rarely meet, host immunity is low and consequently the chance of epidemics is high. These fringe areas may have epidemics during years when the climate is particularly warm and wet, or when there has been a movement of infected immune hosts into a nonimmune population. Such fringe areas are critical locations and are studied with a greater intensity. Malaria epidemiology is therefore governed by a complex web of climatic and socioeconomic factors.

Studying different diseases reveals a dependency on geographical scales. Ultimately, the problem of malaria exists at a small scale (a single insect biting a human host) and even the geographical range of that single insect will be fairly limited. The same is true of meningitis, where the presence of a carrier can be likened to the malaria parasite, with close proximity to noncarrier hosts and dry air being sufficient to spread the disease from person to person. At the next scale up the movement of the human host, especially vehicular mobility and refugee situations, leads to the movement of the parasite. When host movement occurs, previously noninfective mosquitoes may become infective in a short while, allowing the disease to spread. With meningitis, people who are infected may also unwittingly spread the disease, as long as their travels keep them within areas where the environment is sufficiently dry and dusty. On a larger spatial scale, the environmental conditions necessary for the disease to exist and persist will often be the most important affecting the overall geographical coverage. Where environmental conditions are sufficiently conducive to the disease, the presence or absence of the disease will depend upon a host and only then if an infective vector is present. Mobility of an 'at-risk' population may have little impact where economic constraints prevent vehicular movement, but where natural disaster, warfare or civil unrest forces populations to migrate quickly, the potential for further disease may have a negative multiplier effect on an already vulnerable group of people.

## 11.3 The Significance of Time

Given the cyclical nature of climate and the subsequent effects this has on the agents of disease, one might expect a good relationship between both time elapsed, month of year and the number of cases of the disease noted during periods of active and passive surveillance. A good example is a historical analysis of meningococcal meningitis from the west coast of Africa (Ghana, formerly the Gold Coast) the raw data for which was presented by Waddy (1952). The data (Table 11.1) is presented as the number of cases per week during the period from November 1947 to May 1948 and covers an entire epidemic cycle.

Figure 11.1 illustrates the relationship which exists between environmental humidity and meningitis cases. In fact, analysis shows that there is around an eight-week lag between a change in environmental moisture and the subsequent effect on meningitis cases ($r = -0.83$ for all cases and observed humidity values shown in Table 11.1). Such changes in humidity occur as part of the normal annual seasonal cycle and illustrates the importance of timing in understanding epidemic cause-effect. In fact, in this part of West Africa, the annual timing of moisture change is so dependent upon time of year and synchronised to the movement of the Inter-Tropical Convergence Zone (ITCZ) that it leads to a similarly cyclical epidemic cycle for meningitis cases. Where differences exist between years it is often the amplitude of the cases of disease which can result from anomalously high or low moisture or external events such as El Niño.

Meningococcal meningitis is the only form of bacterial meningitis that occurs in epidemics (Ebrahim, 1997). Meningococcal disease is also a significant cause of mortality and morbidity throughout the World (Schwartz et al., 1989). Being able to predict who will develop the disease allows interventions to be targeted on

**Table 11.1** Meningococcal meningitis (CSM) epidemic cycle data (source: Waddy, 1952)

| Date | Number of CSM cases | Date | Number of CSM cases |
|---|---|---|---|
| 08/11/1947 | 3 | 21/02/1948 | 803 |
| 15/11/1947 | 1 | 28/02/1948 | 874 |
| 22/11/1947 | 1 | 06/03/1948 | 1492 |
| 29/11/1947 | 2 | 13/03/1948 | 1711 |
| 06/12/1947 | 2 | 20/03/1948 | 1349 |
| 13/12/1947 | 5 | 27/03/1948 | 731 |
| 20/12/1947 | 11 | 03/04/1948 | 1213 |
| 27/12/1947 | 8 | 10/04/1948 | 737 |
| 03/01/1948 | 11 | 17/04/1948 | 585 |
| 10/01/1948 | 36 | 24/04/1948 | 256 |
| 17/01/1948 | 46 | 01/05/1948 | 45 |
| 24/01/1948 | 28 | 08/05/1948 | 29 |
| 31/01/1948 | 80 | 15/05/1948 | 11 |
| 07/02/1948 | 182 | 22/05/1948 | 5 |
| 14/02/1948 | 502 | 29/05/1948 | 3 |

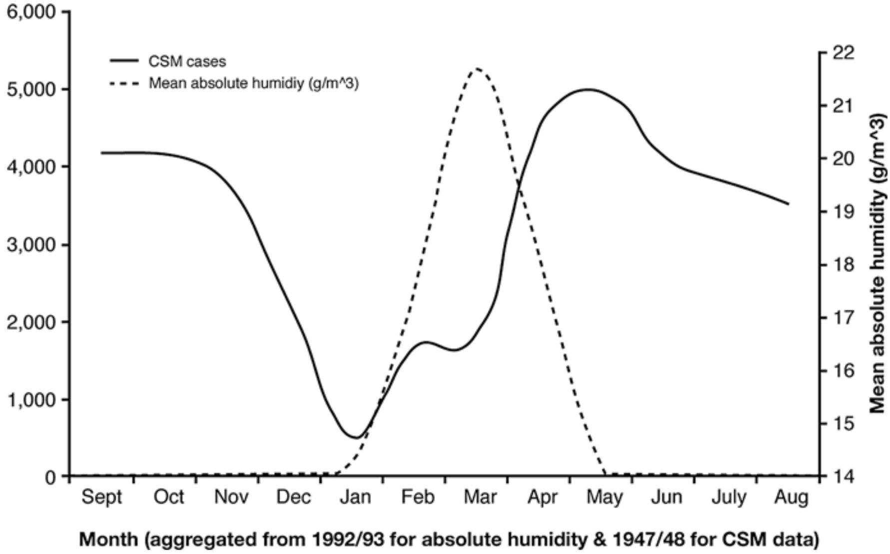

**Fig. 11.1** Relationship between observed humidity and observed meningitis cases

those populations at most risk (Schwartz et al., 1989). The first evidence of the disease in Africa appears to be from Algeria in 1840 (Scott, 1965). The high risk region of the African 'meningitis belt' was characterised by Lapeyssonnie in 1963 and originally encompassed Benin, Burkina Faso, Cameroon, the Central African Republic, Chad, Ghana, Niger, Nigeria, Sudan and Tonga. It was later expanded to the east and west, when Ethiopia, The Gambia, Guinea, Mali and Senegal were included. The population of this expanded belt is thought to be around 100 million (Greenwood, 1987). Although only 42% of the population of Africa resides in the meningitis belt countries, over 80% of the total number of cases for both 1988 and 1989 were reported from these countries (Riedo et al., 1995). Although many African countries are grouped together in the high risk belt, it does not necessarily follow that each country experiences an epidemic of the same magnitude at the same time (Hart and Cuevas, 1997). Major episodes occur every five to ten years (Ebrahim, 1997; Greenwood, 1987; Hart and Cuevas, 1997), although other authors such as Moore (1992) quote eight to 14 year cycles, with an epidemic wave following a multiyear crescendo-decrescendo pattern. Such epidemic episodes usually occur during the dry season (beginning around November), especially in the latter half of the dry season,[1] and then decline rapidly after the onset of the rains in May (Ebrahim, 1997; Schwartz et al., 1989; Moore, 1992; Greenwood, 1987; Greenwood et al., 1984, 1987; Riedo et al., 1995; Cheesbrough et al., 1995; Hart and Cuevas, 1997). Scott (1965) described January to April as the natural epidemic season, with almost all epidemics having occurred historically during the first four months of the

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[1] 1. Hausmann, B. Medecins sans Frontieres (Holland), personal communication, 1997.

year. African epidemics are large, with thousands of cases. Over 100,000 cases were recorded during the 1949–50 epidemic in northern Nigeria alone. Meningitis caused up to half a million deaths across the meningitis belt during the period 1937 to 1987, although this is likely to be an underestimate (Greenwood, 1987).

If meningitis cases are so closely linked to time of year, does this make treatment of the disease an easy task for medics? The answer is not really. The key to treating meningococcal meningitis is the administering of a vaccine. The problem is that the vaccine must be stored in refrigerated conditions and it has a limited shelf life, which means that determining the onset and cessation dates for moisture change is critical. The vaccines are expensive and should be purchased only when there is an imminent need. One way of tackling the prediction (or experimental simulation) of onset/cessation of rainfall or moist airflow is to use global climate models/general circulation models (GCMs) such as those formulated by the European Centre for Medium Range Weather Forecasting (ECMWF) and the UK Meteorological Office. Whereas the annual cycle of moisture decline starts the meningitis season, the annual rainfall cycle supports insect vector-borne diseases such as malaria. In this way, the timing of onset/cessation of rainy/dry season conditions allows us to predict likely outbreaks of malaria and meningitis across highly populated areas of Africa and Asia.

## 11.4 Social and Political Issues

It is all too easy to think of environment-mediated health and disease issues as being largely explained by physical factors such as water, vegetation, topography, etc. This is not the case, however. The at-risk populations may be significantly affected by social status (class and caste), economic status (poverty being a crucial influence), social customs (male-dominated and gender-specific factors) and religious belief. Social status is not exclusively linked to economic affluence. In the United Kingdom, the class system has often favoured middle class people who generally have access to both private and national health structures, while the working classes continue to be dependent upon state health benefits and have problems in obtaining better housing and education. In India, the caste system has often acted in a similar but more extreme way to the British class system. Those of the lower caste (so called ‘untouchables’) are unlikely to have access to any quality healthcare resources. Moreover, recent economic development in India has allowed the middle classes to become more comfortable, the gap between them and the lowest caste communities has continued to widen. Economic affluence will also have a great impact on health. People in Africa may not be able to afford mosquito bed nets to protect themselves from biting mosquitoes at night. Even if a correct and timely diagnosis has been made, the cost of drugs to treat malaria can often be too expensive for poorer communities to afford and so the disease will spread unchecked purely as a result of poverty. In some regions of West Africa, the family structure may be overtly male dominated, such that possession of a single state-supplied bed net will be for the exclusive use of the family male elder. This is at odds with our knowledge that women, when pregnant, are particularly susceptible to acquiring malaria by virtue of biological changes. It therefore becomes a social gender issue difficult for outsiders to rectify. Having increased economic power will help protect communities through access to improved healthcare, better diet, bed nets and drugs, etc. – but only up to a point. Where affluence is highest, the population might actually experience a decline in health due to the deleterious effects of lifestyle. Certainly, eating too much food rich in fats and refined sugars, lack of physical exercise through overuse of cars and public transport, consumption of drugs and alcohol and sexual habits may cause health to decline seriously. In recent times, western countries have seen a rise in childhood obesity, heart disease, diabetes and even mental health problems due to workplace stress. Figure 11.2 shows how the affluent United Kingdom population has experienced a dramatic increase in dietary overconsumption during the latter part of the 20th century. This has led to increases in obesity, heart disease and early onset diabetes.

Poverty is the number one killer in the world today, outranking smoking as the leading cause of death (BMJ, 2007, after Haines and Smith, 1997). Poverty is often defined in terms of a person's income or the amount of goods they are able to consume. The World Bank has set the international poverty line at an expenditure level of US$1 a day for every person. One dollar represents the minimum amount on which a person can fulfil his or her physical needs (World Bank, 2008). A person is considered to be living in 'absolute poverty' if his or her income falls below this

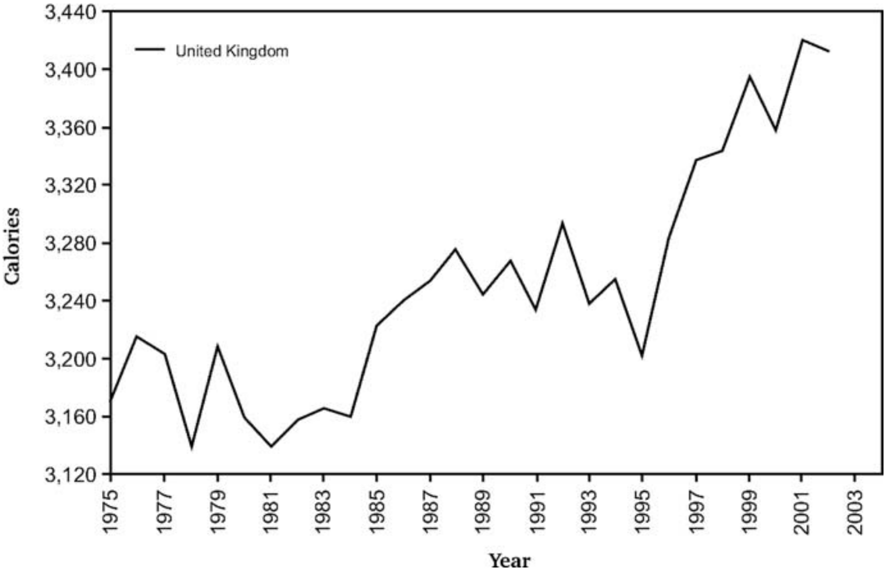

**Fig. 11.2** Observed rise in average number of calories available per day in the UK (source: WHO European Health for All Database, 2008)

line. By this measure, at the present time about 1.2 billion people are living in absolute poverty in developing and transition economies. In many parts of Africa, Asia and India we see large populations who (by the above definition) exist below the poverty line and who are entirely susceptible to tropical diseases such as malaria. Except for charitable donations they have little likelihood of benefiting from disease management systems.

## 11.5 Technologies Employed

The previous sections have established the strong relationship between place (geography), time (seasonality) and human diseases. We are in an age of new emerging technologies that allow us to model and predict outbreaks of disease in ways medical science has never known. Chief among these are remote sensing, climate prediction and computer modelling (of the disease).

### *11.5.1 Climate Models*

Broadly speaking there are three main types of climate prediction model (McGuffie and Henderson-Sellers, 1997):

- statistical
- dynamic
- hybrid – statistical-dynamic (SD) models.

An empirical (statistical) approach is to examine historical data and use it to construct predictive models of the future. A theoretical (numerical) approach, on the other hand, is to use first order principles, or established approximations to them, to attempt to calculate how the climate system should behave (Stockdale, 2000). The benefit of statistical approaches is that they do not require supercomputers or detailed parameterisation of the atmosphere to operate. They rely on empirical statistical relationships between historical sets of observations such as rainfall and sea surface temperature (SST) patterns. Currently, many skilful seasonal predictions are produced operationally for tropical regions using statistical models ‘trained’ on historical data (Palmer and Anderson, 1994). Additional seasonal predictions of the Southern Oscillation Index are produced by the *Climate Diagnostic Bulletin*, while empirical models of the Southern Oscillation extended out to as much as a year are also produced (Palmer and Anderson, 1994).

The main drawbacks for statistical models however is that they are ‘trained’ on a specific historical time series of observations such that their potential forecasts are likely to be constrained by their own climatologies. The dynamic models, however, base their predictions upon a calculation of atmospheric characteristics derived from initial conditions and a very large set of mathematical transformations and algorithms. This allows a dynamic model to predict an event that might not have been captured by the climatology of a statistical model during its historical training period, which makes the prediction of highly anomalous events more likely. Unfortunately, because of the tremendous computational overhead, and the global nature of dynamic general circulation models (GCMs), they are very expensive to run, and require large supercomputers to generate operational output. The main benefit of the dynamic models is their long-range capabilities. Statistical models can also operate over long timescales, but are unable to deal well with climate change or highly anomalous events that lie outside the training observations. Fully coupled global ocean-atmosphere models can be used to make seasonal forecasts up to six months ahead (Stockdale et al., 1998), such as those used in NINO-3 SST plumes generated at the ECMWF (European Centre for Medium-Range Weather Forecasts).

Of particular importance and interest to the climate (and health) communities is the dynamics of El Niño. In the last few years there have been major developments in the ability to predict El Niño and its global burden (Palmer, 2000). Palmer states that it is the propagating oceanic Kelvin/Rossby modes which are believed to make El Niño predictable up to several seasons ahead. He also suggests that predictability arises from a memory of initial conditions, primarily in the oceans. The commonly used model by Cane and Zebiak (CZ model) used for seasonal forecasting is described by Palmer and Anderson (1994) and can issue forecast information up to a year in advance, with a mean anomaly correlation of 0.5. Forecasts with the same model can be issued up to nine months ahead with a corresponding anomaly correlation of 0.6.

Of great interest to health workers is the lead time of a forecast. The SARCOF (Southern Africa Regional Climate Outlook Forum) meetings in Southern Africa have long been a platform for health sector workers to demand a longer lead time, such as six months. Most seasonal work has tended to concentrate on extended seasons of up to four months. It must be noted that delineation of rainfall regions created by SARCOF can involve a great deal of politics because every country is represented by their own meteorologist and decisions may not always be motivated purely by scientific rigour.

The work achieved by SARCOF has been due to the efforts of modelling groups and individuals interested specifically in Africa. Much of the pioneering work has been done in Southern Africa, perhaps for practical regions more than scientific. Much of the predictability of rainfall over Southern Africa is attributable to variability in the tropical atmospheric circulation, which responds directly to boundary forcing such as sea-surface temperature (SST) anomalies, an example being El Niño (Mason, 1997). In the case of the Southern Africa region, Mason proposes that SST anomalies as much as anything are likely to be the most useful predictor for both statistical (empirical) and numerical forecasting methods. As a note of caution, Mason suggests that statistical methods should not be abandoned yet, but rather complement dynamic models until the numerical approach is able to respond to SST anomalies more realistically.

Figure 11.3 shows some results of a study by the author to determine how well the UK Meteorological Office climate model can simulate the onset of the West African

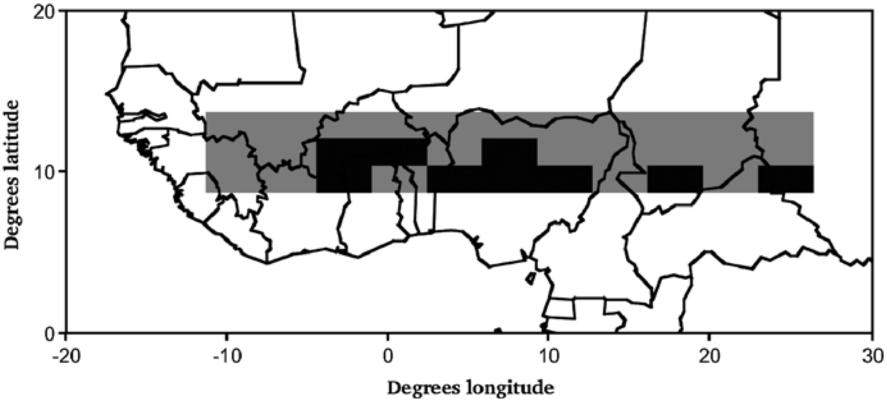

**Fig. 11.3** Map showing regions of positive skill (Brier Skill Score) in at least one of the three tercile (early, normal and late) event categories

monsoon (and hence the corresponding start and end of malaria and meningitis seasons respectively). It is clear that as a result of wet bias problems that are nonsystematic, it is difficult to achieve forecast skill in critical areas within the tropics.

### *11.5.2 Remote Sensing*

Methods that exploit the unique abilities of weather satellites to measure radiance from land and cloud tops are discussed here. Although no work has been found that already exploits satellite data of this type for daily estimation of surface humidity, the review of how such information is already used may provide an insight into its potential in the future. The early work in the field of rainfall estimation originated, not surprisingly, with the advent of the earliest satellites. It was the realisation that satellites could provide a proxy temperature estimate for cloud tops that started the work (Lethbridge, 1967). The early work by Lethbridge was based on observations received from the TIROS IV satellite. Lethbridge realised that since temperature depends on height, the thermal radiance channel of TIROS can supply information relating to the height of those cloud tops. She suggested that the lowest temperatures measured should correspond to clouds that have protruding tops, specifically high thick cirrus as well as high cumulonimbus clouds from which precipitation may have fallen, is falling, or may fall in the future. It was possible to distinguish between the cumulonimbus and cirrus clouds by examining other channels of the same instrument that return brightness. Lethbridge performed an experiment whereby cloud top temperature categories at 3 and 12 hour times from surface rainfall observations were used to estimate precipitation probability. She discovered that as the temperature decreased (from a maximum category of $\geq$260 °K to a minimum of $\leq$239 °K) the probability of precipitation increased accordingly.

The ideas of Lethbridge have been developed by a group at Reading University in the UK called TAMSAT. This group have made use of satellites launched since the TIROS craft, primarily making use of the METEOSAT geostationary satellite. It has been suggested that only geostationary satellites can be used for rainfall estimation (Milford and Dugdale, 1989). The TAMSAT method has used the period during which a cloud pixel is below a specific temperature threshold known as the cold cloud duration (CCD). At the end of 10 days, the CCD is totalled for each pixel and a calibration factor is applied to convert the CCD into a rainfall total in millimetres (Flitcroft et al., 1989). The choice of temperature threshold and the calibration coefficient is based upon many observation pairs between gauge rainfall and the corresponding CCD measured during the same time period. As a result, the threshold and coefficient information required to operationally exploit CCD is season and region specific.

Although the TAMSAT method has been used to generate 10-day (dekadal) rainfall estimate images, it has also been used for the purpose of river catchment system work (as an input to rainfall-runoff models) on a daily basis (Dugdale et al., 1991). Dugdale et al. concluded that in areas where the precipitation was chiefly convective in origin, the daily estimation from satellite data could be more accurate than relying on a gauge network with problems of low density or inconsistent operation.

So far, much of the work reviewed here has concentrated on the use of CCD information for rainfall estimation. This is indeed the greatest application, primarily because rainfall is of greater importance for many end users in Africa than surface humidity. There has been an attempt to generate an estimate of humidity (for vector-borne disease and meningitis) using Advanced Very High Resolution Radiometer (AVHRR) data from the National Oceanic and Atmospheric Administration (NOAA) polar orbiter satellite (Hay and Lennon, 1999). Hay has tried to derive vapour pressure deficit (VPD) from measurements of precipitable water in the atmospheric column derived empirically from channels four and five of the NOAA AVHRR satellite. This method is actually based on earlier work by Smith (1966) who introduced a simple empirical method for converting precipitable water to surface dew point. However, Smith found that the greatest reliability and highest correlations were attained from monthly mean data. Indeed, Hay and Lennon (1999), still using monthly data, found little difference between remotely sensed estimates of humidity and spatially interpolated station data. The work presented by Hay is not strictly of the temporal type desired by health sector workers, who require daily or perhaps dekadal estimates for monitoring and prediction. Derivation of near-surface humidity from remote sensing for meningitis studies is still a desirable but unattainable product for many health sector workers in Africa.

## 11.6 Computing and Methodological Progression

The previous sections have addressed issues of location, timing and technological advances that address these aspects of epidemiology. There are other less dramatic but equally important technical and scientific advances that must be considered. Figure 11.4 shows the interplay between competing areas of science when look-

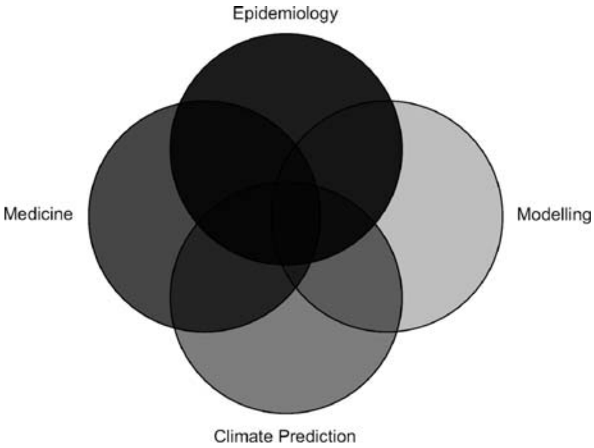

**Fig. 11.4** Venn diagram showing the relationship between modelling and treatment of disease

ing at how medical issues are dealt with. Firstly, epidemiological principles must be reflected in programmable algorithms which utilise climate and geographical information as inputs to modelling tools and methods to create output relevant to medical decision making. Figure 11.5 illustrates how this modelled medical data is used within a geographical information system (GIS) to create outputs, such as risk maps, that can be used for resource allocation and medical decision making. Note that modelling exists within this context too – but within a GIS. In addition we can see additional inputs from auxiliary information sources such as mobile computing and global positioning system (GPS) equipment.

The use of field GPS and computing devices allows critical information (such as initial case reports, clinic locations, vaccine or drug store locations, etc.) to be

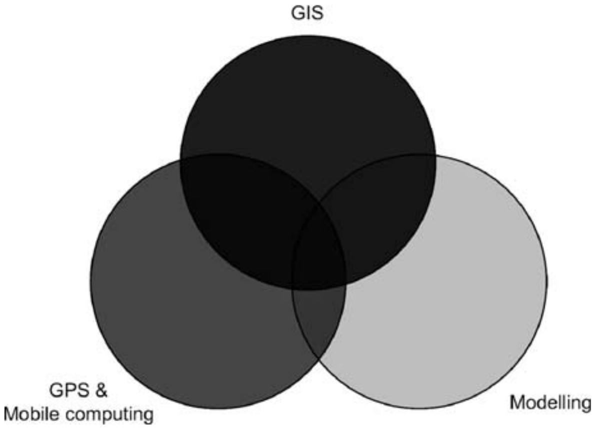

**Fig. 11.5** Final interplay between epidemiologically synthesised geographical information (inputs from Fig. 11.4) and additional socioeconomic (demographic) data within a GIS

accurately assimilated into a management GIS structure. Ultimately, field records which use this structure record both a location (latitude and longitude, and perhaps height) and a time. Using a computer system also allows more detailed data about the local environment, demographics and cultural characteristics to be recorded and incorporated into the GIS-hosted modelling phase.

Among the tools employed by spatial epidemiologists (in common with other geographers) is clustering and pattern analysis. Where a population is randomly distributed across a range of spatial scales (within an urban or rural context) one might expect occurrences of a disease by normal random chance. However, where the expected (or exceeded) number of cases exist within a clustered (geographically concentrated) zone it is usually a sign that there is some agent of causality at work. This might be an outbreak of a waterborne or airborne toxin. It might also (in the case of malaria) be the initial location within a wider region of epidemic potential, where the critical combination of infective mosquito vectors and infected hosts provides a reservoir for further transmission. Pattern analysis (as distinct from observed clustering) might provide statistical evidence that the number of cases within a boundary exceeds what would normally be expected by random chance or expected background transmission. Pattern analysis and clustering were in fact the two key methods of analysis employed by Dr John Snow in his study of cholera in early 19th century London, which led him to identify the infected Broad Street pump. More recently, geographers who study the effects of crime in urban areas (and crime detection science in general) have begun to replicate many of the spatial methods and ideas which have been employed by epidemiology for nearly 200 years. This is most commonly seen in the identification of an underlying pattern. After an event (disease outbreak or serial murders) it becomes clear why a pattern of cases/victims existed. It is the desire to analyse these patterns early on and hence stop the further spread that concerns health and crime analysts.

By using time and space, technology and robust spatial analysis methods, it might be possible to generate prior warnings of serious health risks. Knowledge of an impending malaria epidemic might allow those specific at-risk populations to be provided with the extra financial and health resources needed. Education, drugs, bed nets and extra resources to health facilities can all be provided if there is the political will to do so. Similarly, the problem of timely procurement, storage and dissemination of expensive meningitis vaccines can be better achieved if an outbreak is forecast. In this way, the burden of serious tropical diseases might be mitigated and minimised by careful and clever implementation of geographical tools and ideas. This is to be the future role of heath geography and epidemiologists: a ‘proactive’ rather than a merely ‘reactive’ approach.

## 11.7 Conclusions

The interplay between location, time and epidemiology is well established within the medical community. Where diseases can be characterised by the ecological niche demands of the organisms (insects) involved, the environmental cofactors required or seasonality (time of year), we can exploit these demands and limitations to find solutions. Mosquitoes will only be found where the environmental conditions match a specific set of geographical locations. Other diseases (such as meningitis) will only be found when the time of year allows known cyclical changes in the environment to occur.

The role of geography, as a discipline which transcends both location and time and which creates useful tools such as remote sensing and GIS, is critical for the medical community to tackle these public health issues. However, a critical constraint is the spatial scale of the data available from earth observation and climate modelling tools. While health workers operate at the host/organism scale, earth observation yields data capable of distinguishing a few square kilometres; global climate models may only distinguish to higher spatial scales of many hundreds of square kilometres and thus their value is lost at the host/organism scale. There needs to be a move towards a matching of geographical spatial scales, either by epidemiologists upscaling and/or geographical information (remote sensing and models) downscaling.

In the future, geographical location (as a reflection of environmental and/or climatic characteristics) will change. As climate change begins to become clearer in its magnitude and sphere of influence across the globe, so we shall see 'tropical' diseases moving further beyond their present geographical boundaries to new areas; and as seasons appear to shift in their duration and intensity, we shall begin to see changes in the timing and onset/cessation of particular human diseases from those annual periods we currently ascribe them to. The tools we need to combat the ever moving target of human health will continue to be those which fall within the realm of the geographical sciences.

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# Chapter 12
# Real Crimes on Virtual Maps: The Application of Geography and GIS in Criminology

**Johan G.J. van Schaaik and Jasper J. van der Kemp**

## 12.1 Introduction

The American television drama show *The District*, aired in 2000, focused on strategic and *geographical* crime analyses. Based on the approach taken by the New York Police Department in their ‘crackdown on crime’ strategy, the show used the CompStat approach. Two interesting elements of *The District* worth highlighting are the notion of using Geo-ICT in reducing crime and the high level of analysis performed by police practitioners. In this respect the show illustrates the main focus of our paper: to what extent are Geo-ICT applications used in police practice and its scientific counterpart, criminology? To answer this question we will give a brief overview of the growing significance of location-based approaches in criminology and how Geo-ICT is applied in criminological location-based research. Since there is a close relationship between the criminological (i.e. the academic) approach and police practice, we will discuss both. After first introducing the field of criminology, and more specifically environmental criminology, we will focus on technical and methodological obstacles to using Geo-ICT and end with suggestions on how to resolve these difficulties.

## 12.2 Criminology

Criminology is the science which researches crime, delinquency (or deviance), the societal reaction to crime and the process of criminalisation and decriminalisation. Traditionally, most criminological theories aim to explain what motivates people to commit criminal acts (Burke 2001). Less common are theories that try to explain the

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criminal event in its entirety: the motivation of the offender, the way in which the crime is committed (known as modus operandi) and its time and location (Paulsen and Robinson 2004).

Researchers have long known that there is variation in the spatial arrangement of crime. Although there have been spatial studies of crime for nearly 200 years, a number of key research periods have punctuated this history. Philips (1972) pointed out that hundreds of spatially oriented studies of crime and delinquency have been written by criminologists since about 1830. He recognises three major schools: (1) the *cartographical* or *geographical* school, (2) the *typological* school and (3) the *social ecology* school.

The *cartographical or geographical school* dominated between 1830 and 1870, starting in France (Guerry 1833; Quételet 1842) and spreading to England. This work was based on social data, which governments were beginning to gather. The focus was on spatial patterns on different levels and scales. The 19th century wave of studies on spatial patterns provided a series of important findings (Brantingham and Brantingham 1981), the most important of which can be summarised as follows. First, crime rates varied substantially in different *geographical* areas and these variances could be observed at many levels of aggregation: regions, provinces and counties. Second, when violent crimes and property crimes were separated, a further variation in patterning was found. Third, spatial patterns in crime persist over time and are a potentially useful predictive device for policymakers, and spatially arrayed crime data are temptingly easy to compare with spatial arrays of data about inhabitants of areas. Studies in England showed variations in crime rates between different counties, towns and villages (Plint 1851; Mayhew [1862] 1968). Generally, when such comparisons are made, areas with high reported crime rates or high levels of offender residency also seem to exhibit other problems like high population density, poverty and illiteracy. Examinations of spatial patterning of crime and/or criminal residence in small areas suggested a strong connection between the location of such places and the location of criminal targets, clusters of potential victims or some advantageous jurisdictional boundary. The *cartographical* school employed tools from the field of geography and cartography according to traditional methods, like the application of pushpins in wall maps and hand-drawn maps, which were used to visualise and analyse crime information.

The *typological school* was dominant between 1870 and 1930, in the period between the *cartographical* and the social ecological periods. The typologists focused on the relationship between the mental and physical characteristics of people and crime, without paying any attention to spatial aspects.

The *social ecology school*, which dominated between 1930 and 1970, concentrated on *geographical* variations in social conditions on the assumption that they were related to patterns of crime. The social ecologists recognised and classified areas in cities with similar social characteristics. Pioneers Shaw and MacKay (1942) produced a now classic analysis of juvenile delinquency in Chicago. The Chicago school researchers also delineated an urban model based on concentric zones in an attempt to develop a theory to explain the layout of cities (Burgess 1925). The next stage, environmental criminology, developed from around 1970. This development will be discussed in the next section.

## 12.3 Developments in Environmental Criminology

During the past few decades, interest in environmental criminology, spatial crime analysis and the investigation of offender movement patterns using *geographical* tools has grown. Brantingham and Brantingham (1981) observed a distinct break between the earlier *social ecology* school and environmental criminology. The break can be defined as 'the use of the geographic[al] imagination in concert with the sociological imagination to describe, understand and control criminal events' (Brantinghamand and Brantingham 1981, 21). According to Brantingham and Brantingham (1981) this change is characterised by at least three shifts in perspective. First, a significant shift from the tendency of academics to keep their research contained within their own specific discipline, as environmental criminologists and environmental psychologists introduced techniques and knowledge from different disciplines like geography and *geographical* information science into their research. Second, a shift from the traditional search for causes of criminal motivation, in which it was simply assumed that people are criminally motivated. The focus is now on the criminal event, to find and explain patterns in where, when and how crimes occur. Third, a move from the sociological imagination of crime to the *geographical* imagination. In summary, the field of environmental criminology includes studies of the spatial patterning of crime at different levels of aggregation (more specifically the 'journey-to-crime'), the processes by which potential offenders recognise potential crime sites and specific opportunities, and the creation and maintenance of areas of criminal residence.

Closely related to environmental criminology are the notions of environmental design and environmental management. Both of these notions gained an interest from policymakers and are, as such, of importance in understanding the development of Geo-ICT in crime science. Environmental design and environmental management are based on the work by Jeffery (1971) and Newman (1972), who proposed that the nature of the built environment can affect the level of crime both by influencing potential offenders and by affecting the ability of a person to exercise control over their surroundings. There is, essentially, a powerful belief in the ability of surveillance to help control crime. On the other hand, the concept of environmental management rests largely on the premise that certain districts may be prone to crime not only because their 'indefensibility' encourages offending, but also simply because they give the impression that their residents no longer care, and that if this is allowed to continue it will lead to further offences being committed. Wilson and Kelling (1982) describe these problems in urban America in their 'broken windows' thesis.

Environmental criminologists, designers and managers made use of theories, methods, models and concepts from social, urban, economic, human and especially behavioural geography. Behavioural geography became a focus of explicit interest in the 1960s when researchers realised that neoclassical economic assumptions borrowed for use in location theory deviated too much from reality (Cox and Golledge 1981). Questions concerning imperfect knowledge on the part of location decision makers were identified and evaluated. Concepts such as mental maps, awareness space and decision theory were adopted by environmental criminologists to explain criminal spatial behaviour (Rengert 1989).

In North America, studies in behavioural geography were focused on 'spatial behaviour', which consider the individual as an active decision maker. Choice theory, decision making, analyses of space preference, spatial learning processes, environmental cognition and cognitive mapping were subject to research. In Europe, the focus was, by contrast, on 'behaviour in space', which considers an individual as a reactor to the spatial structure of the environment. Topics such as societal, environmental and institutional constraints as well as awareness space, relative location and opportunities were studied. Pred (1981) stipulates that social barriers act as constraints on crime opportunities. Hägerstrand (1970) divides these constraints into three types: (1) authority, (2) capability and (3) coupling constraints. Much of the correctional philosophy in criminal justice is based on authority constraints with *geographical* properties. For example, imprisonment is nothing more than an authority constraint on spatial movement (Rengert 1989). The use of electronic tracking and monitoring devices based on modern Geo-ICT is an appealing implementation of an authority constraint with a *geographical* properties constraint on where a convict can be at a certain time. Geofencing and location technology can be used to monitor all the movements of prisoners in real time, both inside and outside the prison. In 2008 some governments are even considering the subcutaneous implantation of a GPS chip in the body of prisoners, such as former sex offenders, in order to track them continuously. The capability constraint is largely a time constraint and the coupling constraint identifies where, when and for how long an individual must join other individuals or objects in order to perform a criminal activity. Correctional policy can use coupling constraints to ensure potential criminals do not have the time and place to complete their criminal activity.

More recently, environmental criminology focuses on offenders (e.g. target selection and mobility) and places (e.g. features, clustering and facilities). Three main theories are employed in criminological studies: routine activity theory (Cohen and Felson 1979), the rational choice perspective (Cornish and Clarke 1986) and crime pattern theory (Brantingham and Brantingham 1981).

The routine activity theory deals with the ways that opportunities for crime arise and decline as a result of societal changes. This notion occurred to Cohen and Felson when studying the rise of residential burglary during the 1950s in the United States. The burglary increase proved to be mainly due to the fact that a lot of women started to work outside their homes, which left residences unsupervised.

The rational choice perspective deals with the ways that criminal decisions are made (Jeffery and Zahm 1993). Since rational choice deems decision making to be an economic process of weighing the pros and cons of various options, it can easily be applied to criminal decision making. In this perspective, distance to the location where a crime is to be committed is seen as a factor to be weighted in the decision-making process. For example, using this perspective has the potential to predict the next drug-selling hotspots by identifying the economically most attractive location.

Crime pattern theory deals with the ways in which offenders seek and find opportunities for crime in the course of their everyday lives. Crime pattern theory is derived from a combination of routine activity theory and opportunity theory (Ratcliffe 2004). This theory states that most people will develop a routine activity to their lives so that they will go from home to work at around a certain time, travel from work to recreational activities and then from the recreational activities to their home. The places of activities are called nodes and the routes between the nodes are called paths. Nodes and paths are part of the 'activity space' where people feel comfortable and secure and where they spend a considerable amount of time. Brantingham and Brantingham argue that offenders will have similar routine activities in their lives, but these areas of familiarity will also be the search areas for opportunities to offend. While the routine activity theory can be interpreted as an indication of victim behaviour (Robinson 1999), crime pattern theory can be considered to be the offender equivalent, indicating areas of likely criminal behaviour. The convergence of the victim and the offender in time and space can then be seen as a rational choice by the offender to take advantage (or not) of any criminal opportunity that is presented, taking into account the absence of a capable guardian/manager/handler. This concept is known as the crime triangle, illustrated in Fig. 12.1.

Knowledge of theories and concepts from environmental criminology and geography is essential to conducting crime analysis, crime mapping and *geographical* offender profiling. The application of crime mapping and *geographical* offender profiling and the employment of GIS, will be described in the next section.

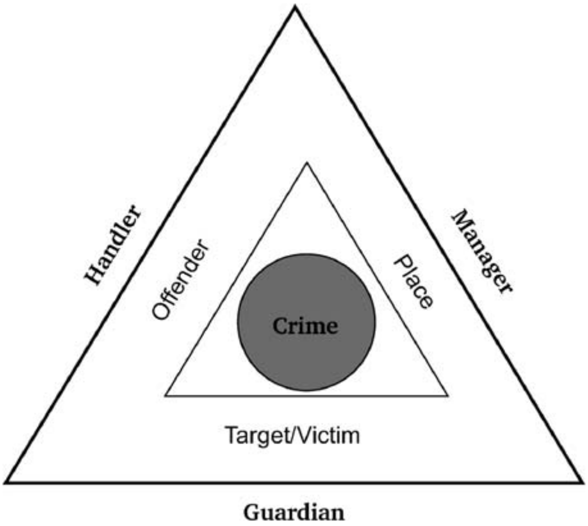

**Fig. 12.1** The crime triangle

## 12.4 Crime Mapping and the Use of GIS

Crime mapping and spatial analysis are now recognised as tools for the study and control of crime. Crime mapping is used in research as well as in policing and refers to the process of conducting spatial analysis within the range of activities of crime analysis (Boba 2005). *Geographical* information systems (presently called Geo-ICT) and *geographical* information science have developed at the same time as the field of environmental criminology and have been increasingly applied in crime research and practice.

An overview of this trend is provided by Harries (1999) and Bowers and Hirschfield (2001). Harries (1999) states that modern *geographical* information systems can be linked to developments in the 1960s, including land use analysis in the United kingdom (Coppock 1962) and the development of Canadian GIS (Tomlinson 1998). Early implementations of GIS were restricted by the memory and speed limitations of older computer systems, which limited the size of datasets and made it difficult to simultaneously manipulate multiple observations or large numbers of variables. These constraints made Geo-ICT less attractive to law enforcement agencies. Weisburd and McEwen (1997) pointed out that police departments in the USA typically lacked the computer resources and base maps necessary to support a GIS operation. GIS applications in policing took off in the late 1980s and early 1990s as desktop computing became cheaper and software became more accessible and user friendly. To date, it is likely that large departments have adopted this innovation and almost any police agency that wants a GIS can have one.

Crime mapping came of age in the ‘implementation and vendor period’ of the five stages of GIS development described by Foresman (1998). This is the period when computing costs began to fall and software became more immediately useful. It lasted until the early 1990s and was followed by the ‘client application age’. The ‘local and global network age’ is seen as the next stage. Over the past decade we have also seen more examples of police departments and research institutes commissioning customised versions of software to meet their individual needs. An example is the widely used program *CrimeStat*©, a spatial statistics program for the analysis of crime incident locations, which can be linked to a GIS. *CrimeStat*© offers functionalities for (1) data setup (linking of files and adjustment of measurement parameters), (2) spatial description (spatial distribution, distance analysis and hotspot analysis), (3) spatial modelling (interpolation, space-time analysis and journey-to-crime analysis) and (4) crime travel modelling (which is based on models used in transport geography). Other examples of auxiliary software are *GeoDa* (Anselin et. al. 2006) and tools for the support of *geographical* offender profiling like Rigel™ (*Rossmo* 2000) and *Dragnet* (Canter 2003).

A survey of police departments conducted in 1997–1998 (Mamalian et. al. 1999) showed that of 2,004 departments, only 13% used computer mapping. Slightly over one-third of large departments (those with more than 100 officers) did so, but only 3% of small units did. On average, departments had used computer mapping for 3.3 years. Crime analysts were the primary users of mapping, with relatively few patrol officers involved. The type of data most likely to be mapped were arrests and incidents, calls for service and vehicle recoveries. The most frequent applications were automated pin mapping (point data), cluster or hotspot analysis and archiving data.

Some departments used more than one package, had done some customising and were using global positioning system (GPS) technology. Sorensen (1997, 376) presented a comprehensive list of mapping and the use of GPS technology in crime mapping and analysis. Items on this list include creating police beats and redistricting (an example of redistricting is creating new districts due to new or changing neighbourhoods after a police reorganisation or after merging of municipalities), before and after intervention analysis, drug market analysis, mobility pattern analysis, offender movement analysis, journey-to-crime analysis, functional and spatial displacement and *geographical* offender profiling. Harries (1999) reports changes that may be expected in the next decade, including the application of *geographical* offender profiling, the use of high-resolution GIS and the use of complex statistical methods in spatial forecasting, aerial photography and the integration of GIS and global positioning systems (GPS).

Recently, Bangs and Weir (2007) described a survey on the use of GIS by crime analysts in England and Wales. They concluded that the application of GIS and crime mapping techniques is widespread in police forces and Crime and Disorder Reduction Partnerships (CDRPs). However, the survey demonstrates considerable variation in the availability of resources for crime mapping and types of analyses being conducted. The survey has helped to highlight a number of areas that would benefit from further development, such as GIS and crime mapping training for analysts, quality improvement of geocoded data for crime mapping analysis, time (and other resources) available for analysts to enable them to focus more on explanatory problem-solving GIS analysis, and the communication of products of crime mapping analysis to ensure that they are fed into appropriate decision-making processes. The Home Office in the United Kingdom is currently exploring ways of enhancing crime mapping skills in partnerships. The CDRP reform programme is likely to impact on the work of analysts in all partner agencies. With a focus on intelligence-led business processes, information sharing, and problem-solving analysis, crime analysis and crime mapping will be key to successful delivery of the programme. This should provide impetus at a local level for greater utilisation of GIS approaches for analysis.

Besides the previous suggested potential uses of GIS and GPS technology in crime mapping and spatial crime analysis by Sorensen (1997) and Harries (1999), Eck and Weisburd (1995) perceive some other innovative developments. These developments seek to improve knowledge about crime places in terms of theory, empirical study, practical application and research method. It may be expected that GIS computer mapping will follow the classic bell curve of innovation adoption. GIS adoption is likely to be a rapid process because the technology is simultaneously becoming cheaper and more powerful. More recently, Chainey and Ratcliffe (2005), Paulsen and Robinson (2004) and Boba (2005) provide excellent overviews of the application of spatial analysis and GIS in crime mapping. They pay much attention to issues of implementing and integrating crime mapping in research and police intelligence environments.

Boba (2005) considers crime mapping to be the process of using GIS to conduct spatial analysis of crime problems and other police-related issues. Crime mapping is seen as a subdiscipline of crime analysis and serves three main functions within crime analysis: (1) it facilitates visual and statistical analyses of the spatial nature of crime and other types of events; (2) it allows analysts to link different data sources based on common *geographical* variables, such as linking census information, school information and crime data for a common area; (3) it also provides maps that help to convey analysis results. Crime mapping is complementary to all forms of crime analysis in that it plays an important part in almost every analysis, as Fig. 12.2 shows.

The forms of crime analysis where Geo-ICT can be of added value are tactical crime, strategic crime and administrative analysis.

1. Tactical crime analysis: Crime mapping is used to identify immediate patterns for crimes such as residential and commercial burglary, auto theft and robbery. For example, spatial analysis of auto theft incidents may reveal clusters of activity at specific locations and times that might indicate a crime pattern. These clusters are generally known as hotspots, being a *geographical* area of higher than expected average crime. The analysis of hotspots may also be used to understand phenomena like displacement and diffusion of benefits.
2. Strategic crime analysis: Crime mapping is used to analyse the relationships between criminal activity and indicators of disorder over a longer period of time. Examples of strategic analysis indicators are a high volume of vacant properties or disorder calls to assist in spatial and temporal allocation of resources, such as patrol officer scheduling and determination of patrol areas. Strategic analysis is also used to examine patterns of crime at or around specific locations, such as schools, bars or drug treatment centres.

**Fig. 12.2** The crime analysis process: adapted from Boba (2005)

3. Administrative analysis: Crime mapping is a valuable tool used by police, researchers and media organisations to convey criminal activity information to the public. Websites operated by police departments and news organisations routinely post maps that depict areas of crime, along with corresponding tables and definitions.

In addition, Boba (2005) defines criminal investigative analysis as a process of constructing profiles of offenders who have committed serious crimes. Criminal investigative analysts use the elements of the crimes these offenders have committed to infer certain characteristics about the offenders, such as personality type, social and work habits. The primary purpose of criminal investigative analysis is to help criminal investigators identify and prioritise suspects by inferring the personal characteristics of likely offenders. Another specialisation of criminal investigative analysis is *geographical* offender profiling. This type of analysis focuses on the *geographical* locations of an offender's crimes (such as body dump sites, crime scenes and victim encounter sites) and is used to identify and prioritise areas where the offender is likely to live (*Rossmo*™ 2000; Canter 2003; Levine 2006). *Geographical* offender profiling has grown from the innovative combination of a number of spatial theoretical concepts, the most significant of which originated from environmental criminology (Brantingham and Brantingham 1981). It uses concepts from routine activity theory, rational choice perspective and crime pattern theory to reconstruct a pattern of offending elicited from victim information and crime scene examination (see Fig. 12.3).

The results are used to map crime sites such that each point represents a location where the offender was known to be at one point in time. Using mathematical analyses a prediction, a *geographical* offender profile, is produced based on these crime locations (see Fig. 12.4).

Finally, Boba (2005) defines intelligence analysis as the identification of networks of offenders and criminal activity as well as a tool to assist the police in apprehending those violators of the law. These networks are typically related to organised crime, gangs, drug traffickers, prostitution rings, financial fraud rings or a combination of these criminal enterprises. General intelligence analysis is con-

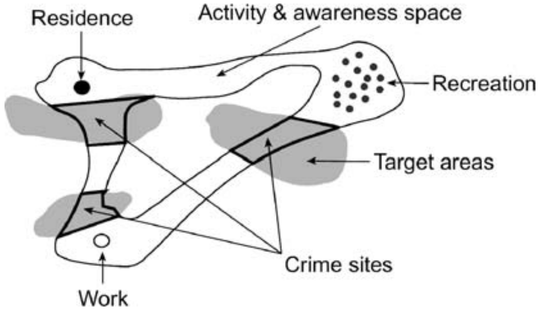

**Fig. 12.3** Crime site selection model: adapted from Brantingham and Brantingham (1984)

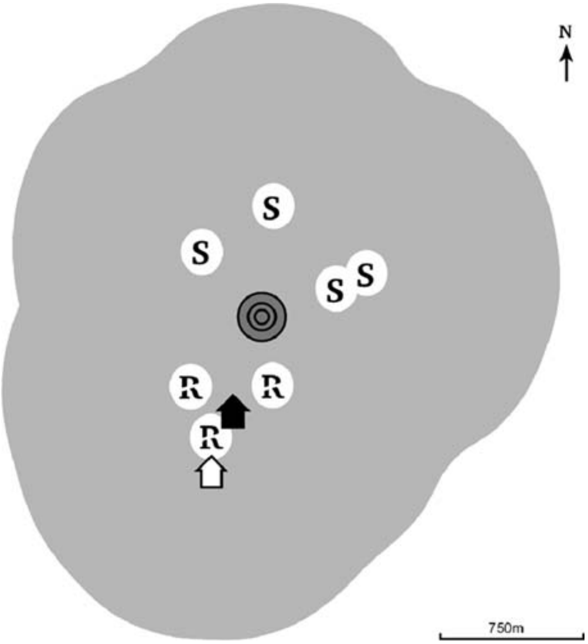

**Fig. 12.4** Geoprofile. Example of geographical offender profile of a crime series of rapes and sexual assaults. The central focus of the profile is right in the center (circled dot). The offender lived in black colored house (the white hhouse was visited durring the crime in between those loctions.) (source: Van der Kemp and Nijman 2003)

ducted within police departments and is centrally concerned with criminal activity occurring within specific jurisdictions and regional police force territories (e.g. city, county and state borders); however, police forces often collaborate with neighbouring police forces and national officials concerning criminal activity in their local areas. Much of the data examined in intelligence analysis is gathered by the police through surveillance, wire taps, informants and participant observation. The type of information examined is not limited to criminal information, but may also include the telephone conversations, travel information, financial/tax information and family and business relationships of those under investigation. By analysing these data, intelligence analysts seek to link information, prioritise information, identify relationships and distinguish areas of further investigation. It is clear that this ‘data-rich environment’ contains many spatial components which could play the role of common denominator.

In several stages of crime mapping and *geographical* offender profiling, GIS could provide the means for positioning, (spatial) data management, (spatial) data mining, spatial statistics and (advanced) visualisation and analysis. The application of geoservices and geoportals supports the sharing of functionalities and (spatial) data, improving efficiency and effectiveness in work processes. Web mapping enables the sharing and dissemination of spatial information and results of analyses with others, such as the general public, police officers, analysts, managers and researchers. Of course, consideration must be given to aspects of privacy, violation of intimacy and security.

It is recognised by Boba (2005), Ratcliffe (2004) and many others that proper education and training in theories, methods, concepts and techniques from environmental criminology, environmental psychology, geography, behavioural geography, GIS and science is a critical success factor in the application of crime mapping and spatial crime analysis. *Rossmo*™ warns (in Albert and Leipnik 2003) about ‘fast food’ crime analysis, where just a few key strokes can run a software routine, producing what has been described as ‘pretty and meaningless’ maps. Eck (1997) emphasised that crime mapping, especially the mapping of crime dots, should be accompanied by theory in order to provide meaningful information. A final and very important issue is the employment of crime data, base maps and other sources. This brings together issues of importance of police practice and criminological research.

## 12.5 Deployment of Crime Data, Base Maps and Other Sources

Data are essential to criminal research and crime mapping. With regard to data for criminal research, Brantingham and Brantingham (1984) point to several aspects and problems which are encountered by criminologists. For example, criminal laws and social definitions of crime vary from place to place and from time to time, so that apparently similar statistics may be based on very different forms of behaviour. Moreover, criminal justice statistics do not enumerate all crimes and the true number of crimes is unknown and the police can record only those offences they know about. A large number of crimes occurring each year are neither reported to, nor discovered by, the police. Because there seems to be a large number of unreported crimes at any time, a rise in the reported crime rate might reflect a real change in the incidence of criminal events or it might simply indicate a change in public reporting behaviour. The critical analysis of police statistics has long been a major concern of criminologists. Victimisation data surveys and self-reporting studies suffer from similar problems. This is known as the ‘dark number’ of criminality.

Besides researchers, practitioners also have to keep in mind the issues mentioned above when using crime mapping. Chainey and Ratcliffe (2005) argues that without actual available crime data and base maps, a GIS has no crime prevention or reduction application, because GIS is just a computer program waiting for data. Many organisations underestimate the cost of base maps and the time and effort required to geocode and map crime data. Paulsen and Robinson (2004) argue that when making crime maps it is very important to incorporate various types of information and not just to make simple point maps with only crime incident data. The beauty of GIS and crime mapping is that it allows users to analyse complex spatial relationships that cannot be detected using only point maps. Incorporating different types of information, such as contextual data about housing units, business locations, school locations or population statistics, into crime maps allows users to understand more than just where incidents have occurred; it allows analysts to create hypotheses about why crimes occur in a particular location. The data used may represent information with different spatial configurations: point data represent one place in *geographical* space, such as a physical address; polygon data represent areas, such as a beat boundary; line data represent linear objects connecting two points, such as streets, or railways; and image data represent a place or area, such as a physical area shown by a remote sensing picture or an aerial photograph.

Crime data and other data that are spatially represented can be layered, integrated and displayed in a GIS by using coordinate systems. A crime may happen at an address, but it is the conversion of this address to a *geographical* coordinate that enables its presentation on a map in a GIS. Determining *geographical* coordinates for crime records is a process that is usually performed after the crime details have been captured. Some police crime recording systems do use an approach where address and other location references are stored with their *geographical* coordinates in a look-up table in the system. Most, however, do not. Assigning these coordinates to crime records is a process that is referred to as geocoding. Geocoding is an operation that is required on all crime data if it is to be spatially displayed in a GIS. It can operate at different levels of spatial precision and thus not necessarily require all data to be matched to a precise address or location.

Geocoding can be performed on street segments or the centroid (position at the centre of an object) of a *geographical* area, such as a postcode, zip code, a police beat or a census *geographical* boundary area. In the United Kingdom, an Ordnance Survey product called ADDRESS-POINT® is used to assist precise geocoding of crime data. In certain other countries, such as the USA and Australia, street object files are used for geocoding crime data to precise spatial levels. The USA and Australian TIGER® files contain address ranges along a street segment rather than individual address references. In this case the geocoding process estimates where the crime happened along the street in relation to the address that is captured in the crime record and the range of addresses. Even though there are different approaches and levels of precision used in geocoding crime data, what is standard in all geocoding processes is that data which describe the *geographical* position of the event need to be matched to corresponding details in the file that contains these *geographical* coordinates. Such a file is often referred to as a reference file or a gazetteer.

Geocoding crime data is seldom a straightforward process because crime data pose a number of problems that are typical to these data. Some of these problems are handling abbreviations, incorrect spellings, incomplete address details, the address does not exist in a reference file or describes an area of open space. The last problem could be reduced by capturing coordinates using a personal digital assistant (PDA) equipped with GPS, GIS and base maps. Communication technology enables the user to upload the information back to the central database in real time. This mobile Geo-ICT solution is providing benefits that help improve the end-to-end process of reporting an incident to taking remedial action, particularly for using this information to quickly identify crime patterns and initiating a faster response.

While it is vitally important to understand the need for different types of data in conducting spatial analysis, it is equally important to know where to acquire this data as well as the potential problems associated with different data sources.

Paulsen and Robinson (2004) distinguishes four general categories of crime mapping data: (1) self-generated, (2) public agencies and universities, (3) free resources and (4) private companies.

Self-generated data in the form of crime incident locations and aggregated crime totals are the main source of crime data used in crime maps. Other data like beat districts and jail locations are sometimes also created by police agencies. Self-generated data is the most problematic of all data sources because of the issues related to geocoding and incompleteness mentioned above.

1. Public agencies and universities charged with gathering data are often excellent sources of data that can be used in research and crime mapping. Examples include agencies, such as tax assessors, that gather data on property values and housing statistics. Most importantly, the data that public agencies (in the USA) gather is usually available to police agencies and researchers at no cost. Universities are also an excellent source of data due to their responsibilities as both data repositories and training areas.
2. Many different types of data can be found on the internet and freely downloaded. The range of free data available from these services runs from satellite images and zoning data to census data and business locations. However, while the range of data available is often great, there are several potentially problematic issues involved with this data, notably their accuracy. Examples of free data sites are ESRI's Geography Network and GIS Lounge (Longley, et al. 2001).
3. The final source of data for crime mapping are private companies, which provide a range of GIS data. Data from private companies is usually excellent, providing accurate and extensive customisable data for end users. However, to get this accurate and customised data, users have to pay a fee.

## 12.6 Research and Practice in the Netherlands

In the Netherlands a limited number of criminologists work at universities, the Research and Documentation Centre of the Dutch Ministry of Justice (WODC), the Netherlands Institute for the Study of Crime and Law Enforcement (NSCR), the Netherlands Police Services Agency (KLPD) and the Police Academy. In the past Hesseling (1992) investigated offender mobility (*geographical* or social movement), while van Koppen and de Keijser (1997) critically reviewed the distance decay model which is frequently used as the basis of *geographical* offender profiling. Van den Eshof and van der Heijden (1990) studied 10,000 robberies and revealed a relation between the type of target and the distance covered by the person who committed the robbery.

The NSCR conducts research on the mobility and distribution of crime. This programme consists of several research projects, including the history and explanations of the spatial distribution of crime, spatial effects in criminology, environmental design and crime: spatial risk and protective factors, and *geographical* offender profiling. These projects focus on two main questions: (1) Where do we find certain types of crime? (Why there? Which spatial choices – specific location and access to locations – has the individual offender made while committing his or her crime?) and (2) What is the relationship (spatial or otherwise) between the criminal's behaviour and measures taken by law enforcement (police, department of justice and local government)?

Although psychological insights, particularly the rational choice theory, are central to the research approach, sociological methods developed by criminologists to analyse the impact of social and natural environmental factors on the individual decision maker are also used. Notwithstanding the application of several spatial concepts and *geographical* principles, the use of GIS in carrying out analyses is rather limited. Some basic GIS and base maps are primarily used to generate spatial variables, which are then analysed in advanced statistical software that deals with multivariate statistics. Unlike scholars in other disciplines, some environmental criminologists at the NSCR are also sceptical about the added value of visualisation. Some have even stated that they had never obtained new insights from drawing a crime map. On the other hand, the researchers see the benefits of having georeferenced data, like data on the ethnic backgrounds and average age in a certain area, and of the possibilities for accurately calculating the distance between different locations. Such a georeferencing system would extend the *geographical* range of findings.

While research in environmental criminology in the Netherlands and in foreign countries has progressed, the police services in the Netherlands have undergone some major organisational changes. In the vision set out in the memorandum titled 'The Changing Police', (Projectgroep Organisatie Structuren 1997), the police service was to focus on people in local communities on a small-scale, integrated and self-managing basis. In 1993 the police service was reorganised in 25 regional police forces and the Netherlands Police Service Agency was created (Fig. 12.5).

In 2008 the Netherlands still has a police service that is strongly integrated within society. Its regional orientation gives the police service a strong focus on its own regional and local environment, particularly on people in villages and local communities. At the same time it is capable of providing adequate support during large-scale events, whether alone or in collaboration with other parties such as the Netherlands Police Service Agency and municipal councils.

In the vision set out in the memorandum titled 'The Police in Evolution' (Project Vision on Policing 2006), the police service has recognised that public safety at the local, interurban and international level have become increasingly intertwined owing to the increased mobility of people, goods, money and information. Moreover, new forms of crime have surfaced over the past few decades and the safety issue has become more complex. The perceived lack of safety and the complexity of the issues involved has resulted, among other things, in increasingly broader and tougher demands being made on the police.

'The Police in Evolution' is intended to prepare the way for future developments in the profession. One of the proposed future developments is the so-called 'nodal orientation' as a necessary addition to the 'local orientation' (areas and territories),

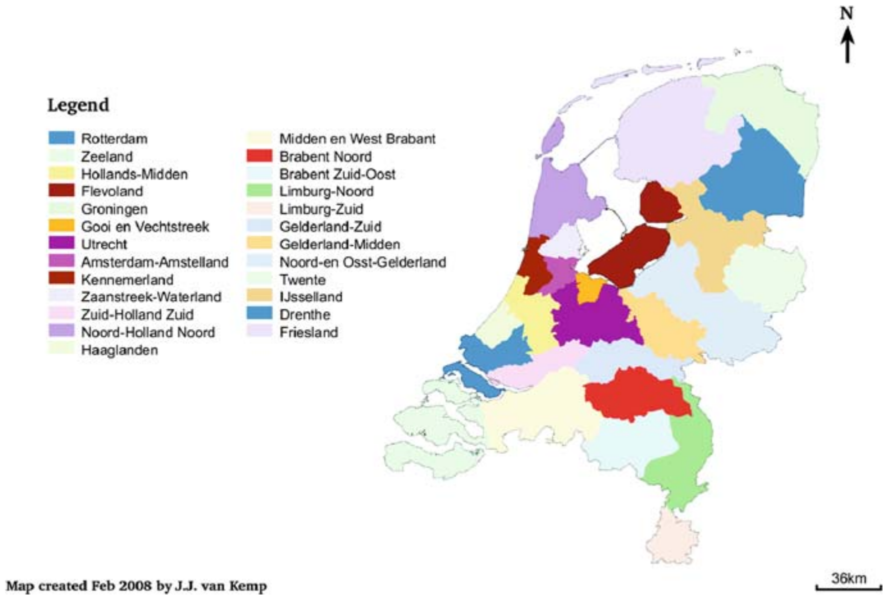

**Fig. 12.5** Dutch regional police forces

the traditional focus of the Dutch police. The newly introduced concept of nodal orientation refers to the notion of the space of flows, while local orientation refers to the notion of the space of places (Castells 1996). The space of flows is described as the flow of people, goods, money and information within miscellaneous social processes. The space of places are the area-specific physical surroundings where people live, including important locations such as the neighbourhood, the town, the ‘marketplace’ and other places where people meet. The interactions between both types of ‘spaces’ increasingly determines the nature of safety problems, while at the same time offering pointers for combating those problems.

The vision expressed in ‘The Police in Evolution’ denotes a proposed expansion of the field of attention from places to flows and it is obvious that this body of thought has many *geographical* elements. Both science and practice could certainly support putting in operation the ideas and concepts mentioned above, which, however, will require more detailed study of the usability of these new ideas and concepts.

In parallel with both research in environmental criminology and the evolution of the Dutch police, practitioners within the Dutch police force have started to discover the power of GIS and other Geo-ICT applications such as positioning by GPS, remote sensing and aerial photography. Following the deployment of GIS in just a few police dispatch centres (emergency rooms) and occasional use of GIS for the purpose of crime mapping, a police-wide project called ‘Sherpa’ was initiated in 2000. The aim of the Sherpa project was to optimally integrate geo-information into the different business processes and information systems used by the Dutch police.

The objective is to create an architecture for geo-information services and standards for geo-information (including a large set of base maps), GIS and positioning systems for the main processes: intake, law enforcement, criminal investigation, operational management, emergency aid, repression and prevention. In 2007, a new GIS (which complies with the new standards for geo-information) has been introduced at the dispatch centres of several regional police forces. The architecture Geo Information Services (Van Katwijk 2006a) describes bottlenecks and shortcomings in the main processes with respect to the use or not of spatial information and introduces several provisions for overcoming these bottlenecks and shortcomings. Special attention is paid to geoservices like user interaction (such as searching and selection), application (such as routing, hotspot and *geographical* offender profiling computations) and information collecting (such as mapping and geocoding). The standards for geo-information (Van Katwijk 2006b) are subdivided into standards for technology, semantics, presentation and standards for software and positioning. The standards are based on the widely accepted Server Oriented Architecture. For an overview of standards (in Dutch) see Bregt. (2006).

Semantic standards are strongly related to the content of geo-information. Besides a basic model for geo-information for general purposes, it is the intention of the Dutch government to develop a specific model for the public order and law enforcement domain. More specific models for the use within organisations like the police, or even parts of the police service, may be developed in future. Another development is the initiation of a signalling (alerting) service for (criminal) events and calls for service for police officers on beat. This is an example of the implementation of location-based services and the improvement of ‘situational awareness’. This promising application will probably be implemented in every regional police force and the Netherlands Police Service Agency.

Unfortunately, GIS applications for spatial analysis in criminal investigations and law enforcement have not yet been developed, despite the obvious need for such facilities. The development of a GIS for spatial analysis will not be a priority in 2009 because the mainstream ICT infrastructure of the entire Netherlands police is in urgent need of improvement. The ‘Location Services’ project for the whole police force will provide a facility for storage, maintenance and distribution of location-based reference data such as addresses, boundaries of administrative areas (e.g. regional police forces, districts, neighbourhoods and municipalities) and specific locations (e.g. junctions and hectometre poles along railways and motorways) into relevant information systems. Such information systems will be able to register the locations of criminal events and calls for service correctly, enabling geocoding if there is a need for spatial analysis or crime mapping. The Location Services may be regarded as a standard gazetteer for the entire public order and law enforcement domain.

With the availability of the standards mentioned above (including a national maintenance organisation) and the increasing availability of *geographical* datasets (such as topographical data, large-scale base maps, socioeconomic data and demographic data) from national government organisations, the Dutch police will have a sound point of departure for the development and implementation of GIS for spatial analysis and crime mapping when it is ready for a large-scale unambiguous application of crime mapping. Environmental criminologists at national and international research institutes may also benefit from this 'geo-information infrastructure' for the public order and law enforcement domain, while the police could benefit from the acquired knowledge of criminologists. Despite the well considered delay in the deployment of crime mapping across the whole police force, some regional police forces are already using GIS for spatial analysis and reporting as a proof of concept, and even in a more or less operational mode, using the intended standards or building on their own legacy GIS. For example, the Amsterdam-Amstelland regional police force has developed tools for spatial analysis, data mining, reporting and 'early warning' based on modern Geo-ICT and intended police standards. The Rotterdam-Rijnmond regional police force has developed a GIS called 'Police Statistics' (PolStat). This application contains an almost continually updated *geographical* overview of crimes within the regional police force area. At other, mostly small regional police forces a minority of crime analysts employ crime mapping more or less on their own initiative. Many of these crime analysts train themselves through 'learning by doing' and try to familiarise themselves with spatial theories of crime from environmental criminology and the basics of GIS and crime mapping. Some of the regional developments mentioned above are only loosely related to the Sherpa project and there is little interaction between practitioners and researchers (such as those at the NSCR), who tend to concentrate on obtaining data. There is some incidental collaboration and advisory input (see, for example, van der Kemp and van Koppen 2001; van der Kemp 2005), but structural collaboration with the NSCR has been limited to the Haaglanden regional police force. It must be said that at present no education and training in the application of crime mapping is offered by universities or the Police Academy or organised by the police. The issue of education and training will certainly be one of the most important key requirements and critical success factors for a large scale introduction of GIS for crime mapping.

A final interesting affair is the practical application of *geographical* offender profiling. Since 2001, both the Limburg-Zuid regional police force and the Netherlands Police Service Agency have been creating *geographical* offender profiles, although with different tools, methods and background education and training (van Schaaik 2001, 2002). The profilers involved belong to different schools of thought: the *Rossmo*™ school (using Rigel) and the Levine school (using *Crimestat*©). The possibilities for the convergence of both approaches are currently the subject of study under the 'Police and Science' research programme at the Police Academy. At the same time, criminological research is being undertaken with the aim of refining methods of *geographical* offender profiling (van der Kemp and van Koppen 2007). The behaviour of offenders is being studied from both the psychological and the *geographical* analysis perspectives to examine the choice of crime location and its impact on the assumptions of *geographical* offender profiling (van der Kemp 2004, 2007). Time will tell whether *geographical* offender profiling will be supported by and benefit from the 'geo-information infrastructure' for the public order and law enforcement domain (van Koppen, Van der Kemp and De Poot 2002).

## 12.7 Conclusions

We can draw three main conclusions from our analysis:

Different schools within criminology, in particular environmental criminology, have made use of many different concepts and models from geography at different periods for over 150 years, and will probably continue to do so in future.

1. Geo-ICT, and more specifically GIS, are implemented by researchers in environmental criminology in foreign countries like the USA and UK. In the Netherlands researchers at NSCR use GIS on a small scale, preferring the application of advanced statistical models instead of explorative spatial data analysis (ESDA). On the other hand, the benefits of having georeferenced data, such as data on ethnic background and average age in a certain area, are evident.
2. Geo-ICT, and more specifically GIS, are increasingly implemented by practitioners in law enforcement and criminal investigations worldwide, especially during the last decade. This is probably due to a mix of mutual influences, such as: (1) improved availability of Geo-ICT at lower costs, (2) better understanding of the power of geography and GIS, (3) increased availability and accessibility of geo-information like base maps, demographic data and socioeconomic data, (4) standardisation enabling the integration and exchange of geo-information, (5) legislation like the Crime and Disorder Act 1998 in the UK and (6) the foundation of innovative institutes with regard to crime mapping, such as the Mapping and Analysis for Public Safety (MAPS) in the USA and the Jill Dando Institute of Crime Science in the UK.

The use of Geo-ICT appears to be obstructed less by technical obstacles and more by a combination of issues related to education and training. There is a lack of spatial awareness and thinking at many levels (especially management), which does not create a sense of urgency for the development of Geo-ICT in police practice, while academic interest in spatial criminological phenomena is only found among a small group of researchers, none of whom are geographers by training. The lack of education and training and the lack of appealing applications makes it difficult to demonstrate the potential of Geo-ICT and spatial analyses for crime analysis, both from a research and a police perspective. The problems with sharing information are related to this. Obtaining police data for research purposes is always troublesome, but seems to be even more so if the information needs to be at the address level of victims and offenders. Besides, the accuracy of police data from a *geographical* perspective is hardly perfect.

In order to overcome the identified problems we suggest the development of a set of appealing ‘need to have’ applications, combined with a basic education and training programme drawing on related developments and best practices from foreign countries, such as embedding crime mapping within crime analysis. This would make it possible to identify the potential of Geo-ICT for both researchers and practitioners and to set up collaborative ventures. This approach could stimulate spatial awareness and thinking, reduce resistance to technological and methodological changes, and increase familiarity with the possibilities of Geo-ICT for improving analysis and decision making. Both researchers and practitioners could share and benefit from a common *geographical* infrastructure and would be able to share experiences and knowledge obtained from the application of Geo-ICT in criminology and policing.

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# Chapter 13
# Geo-ICT for Risk and Disaster Management

**Sisi Zlatanova and Andrea G. Fabbri**

## 13.1 Introduction

In order to deal with the critical issues in the application of Geo-ITC for disaster management it is important to review the main concepts of risk management and of risk-related information. As shown in Fig. 13.1, four general phases can be distinguished: prevention and mitigation, preparation, response and recovery. They are currently widely accepted by agencies all over the world, although some institutions work using national specifications. The first phase is also referred to as risk management and the last three are also referred to collectively as disaster (or crisis) management.

The terms risk management, hazard management, disaster management, crisis management and emergency management are often used interchangeably. Here, we use ‘risk’ to denote the probability of a negative, damaging outcome from an incident or a natural event (process). In applying safety/mitigation procedures and actions, planners and decision makers attempt to reduce the risk, limit the damage and reduce the vulnerability of given regions. Therefore, risk management could be regarded as the understanding, managing and reducing of risks. In practice, that should generally result in lowering vulnerability.

A hazard is considered to be a potentially damaging physical event, phenomenon and/or human activity, which may cause loss of life or injury, property damage, social and economical disruption or environmental degradation (UNISDR 2007). Intuitively, hazards are classified according to their origin. The usual classes are therefore natural hazards (e.g. floods, landslides, earthquakes, tsunamis, volcanoes, etc.) and human-caused hazards (e.g. industrial accidents, fires, terrorist attacks, etc.). However, other classifications are known from the literature. Schneiderbauer (2007) suggests four different groups: pure geogenic (e.g. earthquakes, tsunamis and landslides), geo-anthropogenic (meteorological, oceanographic, hydrological and biological), anthropogenic-technological (explosions, release of toxic materials,

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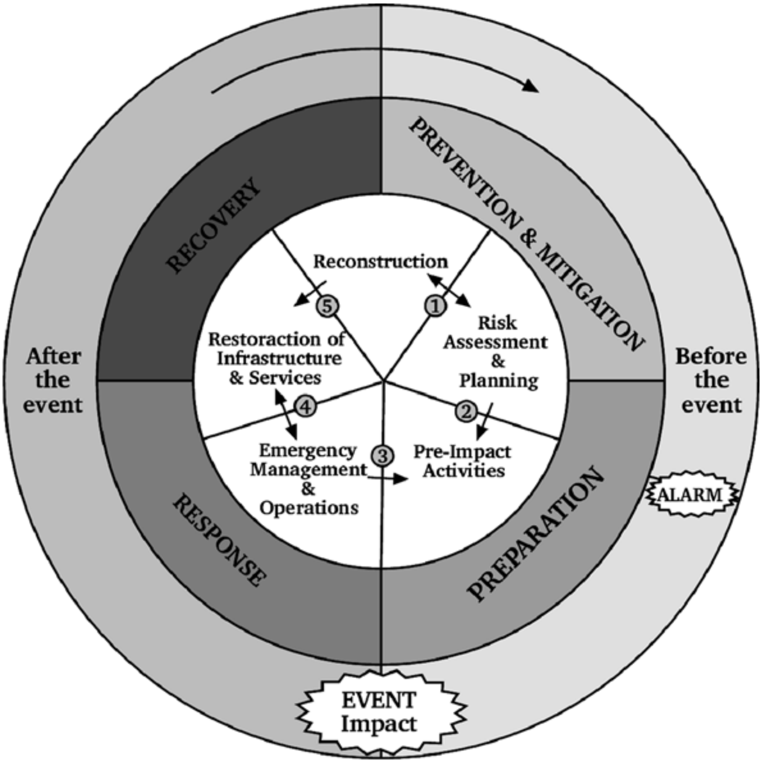


**Fig. 13.1** The disaster management cycle (source: PSC Forum, www.publicsafetycommunication.eu)

structural collapses of transportation systems, constrictions or manufacturing accidents), anthropogenic-conflict (crowd-related, terrorist activity and political conflicts). Disasters can be defined as events triggered by hazards; in effect, they are potentially negative consequences that have become reality due to the occurrence of hazard (Schneiderbauer 2007). The term disaster management is therefore related to managing the consequences of hazardous events.

The four phases of disaster management shown in Fig. 13.1 are interrelated and equally important, but they also have their own specific characteristics. Prevention and mitigation focuses on long-term measures in order to reduce vulnerability or, more rarely, the hazard. Preparation focuses on active preparation in the event of a possible emergency. The rescue services (e.g. police, ambulance and fire brigade) are trained in how to operate and cooperate in emergency situations. Response is an acute phase following the occurrence of an emergency and is the most challenging stage because of the dynamics and unpredictability of these situations. Recovery is the phase after the acute emergency, including all the arrangements for removing damages and the long-term supply of irreversible detriments.

These specific actions influence the Geo-ICT applications developed in support of the various tasks within a particular phase. For example, risk management relies on large amounts of statistically processed data. The emergency activity depends on fast response, reliable access to existing data, up-to-date field information, integration (for decision makers) and distribution of information (between rescue teams, citizens, etc.).

Furthermore, many risk and disaster management applications are hazard specific and one hazard often may trigger off others. For example, floods near industrial areas may cause technological hazards (explosions, fires, etc.), power failure may result in an explosion and damage to a dike, which consequently may transform it into a flood disaster, and earthquakes may provoke landslides. This means that the chaining of disasters triggered by a primary hazard, which then leads to secondary hazards, must be considered as likely outcomes. This chaining can involve any kind of complexity: an earthquake can cause a tsunami, which can destroy a factory, which may in turn provoke an explosion that releases toxic materials. For this reason, disaster management is often mentioned in a multihazard context.

Location identification and Geo-ICT play a major role in all the phases of disaster management. The first questions asked in call centres after a disaster has been reported is about the location of the incident and its possible ramifications. A variety of systems use maps, models, tracking logs of rescue personnel and obtained from various scanners to monitor a disaster, make forecast, estimate damages, predict risks and vulnerability, etc. (Kerle, et al., 2008; Li and Chapman 2008; Zhang and Kerle 2008). In some cases, imagery from various sensors can be quickly provided for analysis and estimation of damage caused by recent major disasters, such as the effects of the tsunami in Banda Aceh in January 2005 (see Fig. 13.2). Amdahl (2001) and Green (2002) provide numerous examples of the use of maps and GIS technology in all the phases of risk and disaster management using ESRIÒ software. Significant progress has also been made by suppliers of CAD/AEC tools and database management systems (DBMS) in providing solutions for managing disasters, predicting risk, training and simulation, and in geovisualisation.

However, the use of Geo-ICT is still rather limited compared with the potential benefits to be gained from its application in managing the many disasters that occur throughout the world. Presently, geodata is stored and used almost daily in many organisations. Geo-ICT is expanding in scope and changing in nature, especially regarding the use of the third and the fourth dimension (time). Many GIS vendors provide extended 3D visualisation tools and new visualisation environments such as Google Earth and Virtual Earth are now available, although spatial analysis is still in the 2D domain. The traditional stand-alone, desktop GIS analyses are evolving into complex system architectures in which DBMS play the critical role of a repository of administrative, geometric and multimedia data. Cell phones now incorporate functionality which used to be restricted to ultraportable computers, which are also updated with communication abilities.

**Fig. 13.2** High resolution Quick Bird images provided to the Aceh Region under the International Charter on Space and Major Disasters (Source: ICSMD)

To increase awareness in crisis situations, such Geo-ICT advances will have to be used more extensively as a basis for developing knowledge-based, multi-user and multi-risk disaster management systems, and help decision makers during the entire disaster management cycle. There are various factors which complicate the use of Geo-ICT in disaster management and these are addressed in the following sections of this chapter. The following two sections discuss existing Geo-ICT applied in risk and disaster management and review the challenges and opportunities for wider and better use of the latest technological developments. Section 13.4 of this chapter examines research and developments issues to be considered in constructing integrated multi-risk, multi-disaster systems, followed by a concluding discussion.

## 13.2 Geo-ICT Opportunities for Risk Management: Risk Maps

Risk visualisation for risk management combines risk analysis and risk evaluation (for a discussion of various risk terms see, for example, Plattner 2004 and http://www.sra.org/resources_glossary.php). In essence, risk is a human condition related to the probability that one or more natural or technological processes take place that negatively affect our daily lives, there where we are more exposed to the damage. In practice it is the spatial distribution of the natural and technological processes and the exposed socioeconomic activities that are critical to risk management.

### *13.2.1 Risk Maps – The Most Appealing Application of Geo-ICT in Risk Management*

Generally a risk map shows the distribution of risk levels, or of objects representing risk levels, across an area of concern. Such levels are plotted to assist a decision maker in taking action to avoid or mitigate risks and in responding to disasters. For instance, a map of flood risk should show the inundation levels expected as a result of likely events such as exceptionally heavy rainfalls or hurricanes.

The difficulties in generating such risk maps are numerous and multidisciplinary, ranging from the poor availability of consistent data, the need to model the hazardous processes in space and in time, the complexity of valuating human life, assets and activities, and the co-occurrence of more than one risk. Clearly, the risk mapping task involves objective and subjective aspects and representations that have to be directed not only to specialists in the risk areas, but also to non-specialist decision makers and to the general public, whose perception of risks can be an important factor in risk management. As a result, the generation of a risk map places a heavy burden of responsibility on the producer and the local administration that eventually distributes it and explains its usability.

An encouraging view of modern approaches to risk mapping is the one taken by Monmonnier in his extensive analysis of ‘cartographies of danger’ (Monmonnier 1997, 293). He points to hazard-zone mapping as a recent phenomenon that seems to focus on forecasting and monitoring, while prior cartographies used to be mainly descriptive and explanatory of past hazardous events. This means that “Most risk maps involve statistical models of some sort for estimating the likelihood of rare events such as volcanic eruptions or disastrous floods. . .and forecasting requires a representative record of the hazard’s magnitude and variability”. Moreover, “comparatively rare hazards, like volcanic eruptions are inherently uncertain” and “we cannot guarantee a future that uniformly replicates the past” (Monmonnier 1997).

It is instructive to run through a few representative interpretations of risk and risk maps. A naïve search on the internet helps to describe the present general understanding of risk maps. Typing the two keyword phrase ‘risk maps’ into a search engine immediately leads to over 30 million hits! Clearly the topic happens to be a great concern; however, there is a large variety of interpretations regarding what these maps should look like, their meaning and how they can be used.

For instance, various agencies or consulting groups offer services such as mapping of specific risks for areas selected by customers over regions of competence in a wide range of fields, including the medical field (contagious diseases), economics and industrial activities, traffic, social unrest and terrorism, and technological and natural hazards. At times, what is meant by a risk map is a graphic representation of risk levels within a decision space delimited by a risk significance axis and a risk likelihood axis. Such representation, often rather qualitative, is intended to help with structuring and prioritising actions in logical and convenient terms for an industry (see for instance www.luisepryor.com/showTopic.do?/topic=33; www.riskgrades.com/retail/treemap/treemap.cgi)

In our case, we will consider specifically the distribution of risks in geographical space for disaster management. An example of this are the risk maps made available by a company called Risk Management Solutions (http://www.rms.com/Publications/Maps.asp) that offers natural hazard risk, terrorism risk, water risk and enterprise risk services and a variety of catastrophe maps of the USA, Latin America, Europe and Japan. They are small scale maps for posters intended to assist catastrophe managers and others at conferences and meetings. Contoured values for entire continents or countries show a common measure of combined relative risk for the most typical insured hazards (termed aggregate average annual loss or AAL), a 'Risk Thermometer' for selected cities and the footprints and industrial losses for historical disasters. Clearly, such products are not meant for a close analytical scrutiny for risk management.

Let us consider a few representative websites that offer specific risk information to citizens. The Government of the Canadian Province of Alberta offers a Flood Risk Map Information System on its website http://www3.gov.ab.ca/env/water/flood/index.html. Besides introducing flood risk concepts and the Canada-Alberta Flood Damage Reduction Program, it provides flood risk maps for individual municipalities or otherwise delimited areas of concern for which information happens to be available. On another site, http://nolarisk.usace.army.mil/, the US Army Corps of Engineers provide the New Orleans Risk and Reliability Report drawn up after Hurricane Katrina made Gulf Coast landfall on August 2005. Examples of interactive maps are available with risk assessment laid over Google Earth background maps. These can be queried and instructions are given on how to read the risk maps.

Since 2005, the Manila Observatory's Center of Environmental Geomatics has constructed a website on its Mapping Philippine Vulnerability to Environmental Disasters Project (http://www.observatory.ph/vm/). It provides ample training material to calculate risks (also hazards, exposures and vulnerabilities) and provides an atlas of risk-related maps of climate, weather and geophysical risks. Another more specific site worth mentioning is on tsunami risk in Papua New Guinea: http://map.mineral.gov.pg/tiki/tiki-index.php?Page=Rabaul+Tsunami+Risk+Maps. Among the maps available on this site are the detailed Rabaul Tsunami Risk Maps of East New Britain.

To obtain an impression of how relevant risk has become in many countries, it is indicative to consider that in the last five years it has become common for many local and national administrations, universities and private consultants to construct websites to educate the public at large on natural hazards and risks. In Italy, for instance, searching for rischio idrogeologico (hydrological-geological risk) leads to over half a million hits, with many sites providing some types of hazard, vulnerability and risk maps. Naturally, these sites aim to inform the general public; more technically-oriented users looking for scientific information will have to search elsewhere.

More extensive risk map resources are available from the U.S. Geological Survey's Earthquake Hazards Program (http://earthquake.usgs.gov/) and Landslide Hazard Program (http://landslides.usgs.gov/). In particular, the USGS Geologic Hazards Team provides a list of research projects and staff where articles can be downloaded (http://geohazards.cr.usgs.gov/research.php). An example are maps on landslide recurrence intervals and probabilities in the Seattle area, Washington State (Coe, et al., 2004; Schulz 2007). The authors provide maps of landslide densities, mean recurrence intervals and exceedence probabilities for different probability models applied in that study area. However, they are to be used as a general guide to landslide occurrences and not to predict landslide hazard at specific sites.

Clearly, as we can see from these few examples, we can go from general and broad representations of risk to detailed risk maps for specific areas of concern, so that even the characterisation of all types of risk maps available on the World Wide Web would become a research endeavour in itself. As an example, we can consider a project supported by the European Commission that aimed at applied multi-risk mapping of natural hazards for impact assessment: ARMONIA. It applied state-of-the-art methodology in a case study on the Arno River Basin Authority area near Florence, Italy (http://www.armoniaproject.net/, 2004–2007). It assessed most methods and techniques for hazard and risk mapping in Europe and outside the continent.

Nevertheless, one of the problems encountered to date is that none of the risk maps analysed seem to contain measures of the credibility, uncertainty and robustness of the spatial representations. In particular, it is not clear whether the risk is represented as an aggregation of past events or as a prediction of future ones. Because of this, Fabbri, et al., (2004), Chung and Fabbri (2004) and Chung, et al., (2005) have introduced an analytical strategy to provide such measures for spatial predictions of hazard and risk maps via empirical validation techniques. Their approach will be exemplified by an application in the following subsection that presents some results based on spatial validation strategies for resolving those problems.

### *13.2.2 Examples of Risk Mapping Systems*

Risk is a condition that is evaluated by combining the presence of exposed vulnerable elements and the probability of occurrence of hazardous processes. Without the former no risk condition can occur. Risk is generally represented either as monetary loss or as a number of human casualties expected. Such values can be represented in map form to express and comprehend the significance of their distribution within a landscape containing static and dynamic human elements and activities. Simple qualitative or semi-quantitative risk maps use classes of risk such as high, medium and low, but more advanced qualitative maps provide many more values, often on a continuous scale.

An example of a risk map for surficial debris flow landslides in an area of South Korea is shown in Fig. 13.3. Most of the map has no risk values due to the absence

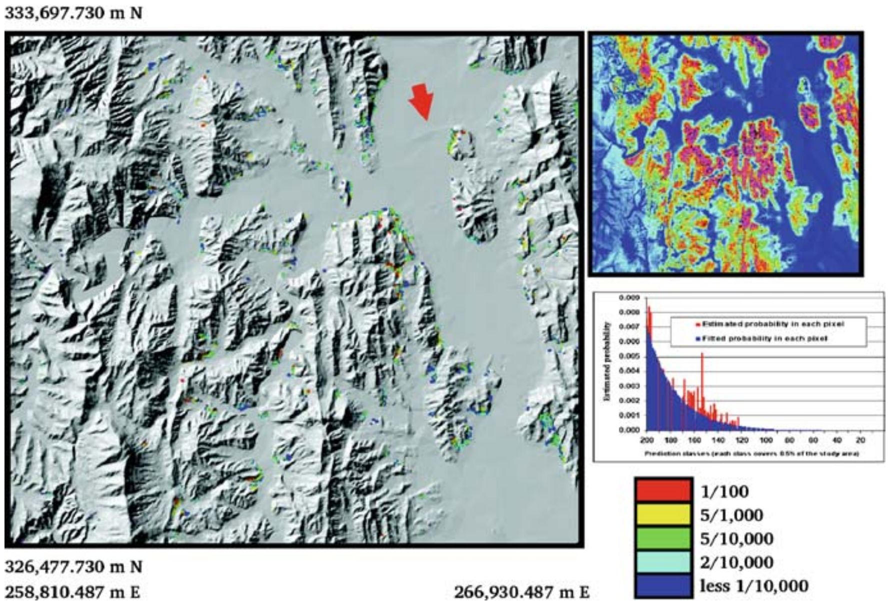


**Fig. 13.3** A 5-class population risk map of the Boeun study area (South Korea) affected by landslide processes. The classes have been mapped on a shadow relief enhanced elevation image. The landslide-hazard prediction image and the histogram of probability of occurrence necessary to compute the values for the risk map are shown on the right (after Chung, et al., 2005)

of urban settlements in those areas. The classes indicate the casualty rates expected per 5 m pixel. To understand the significance of a risk maps, it is necessary to know how it has been constructed using a spatial database, a specific mathematical model and its assumptions and the analytical strategy used for the prediction of the hazard. The Boeun study area is 58.4 km$^2$ and has about 45,600 inhabitants living in 15,000 households. The spatial database (Fabbri, et al., 2004) is a set of digital images of $1624 \times 1444$ pixels with a resolution of $5 \times 5$ m showing the digital elevation model (DEM), surficial geology, forest coverage, land use, drainage and the distribution of 420 past surficial debris flow landslides that occurred prior to 1997. In addition, several socioeconomic 'indicator' images were compiled to represent the vulnerable elements: the distribution of population density, of road networks, buildings of several types and of the drainage features and embankments. For these values in US$ for 5 m pixels and the corresponding vulnerability levels (values between $0 =$ no damage and $1 =$ total destruction) were also compiled. In addition, information became available on 44 new landslides in the area that occurred in 1998, which occupied 2,000 pixels. They caused about $200,000 of damage to man-made properties and three injuries to persons. The information on the number of pixels affected in 1998 allowed estimation of the risk level distribution in the study area.

What was done, was to apply a three-stage analytical strategy of risk assessment, keeping in mind the actual damages and casualties due to the 1998 landslides, but using only the numbers of pixels affected in 1998 to set up a computational scenario and the distribution of the 420 pre-1997 landslides. In the first stage the distribution of the 420 pre-1997 landslides was used with a fuzzy set prediction model (Chung and Fabbri 2001) to classify the study area from the spatial relationships between the landslide distribution and the digital images of the DEM, surficial geology, forest cover, land use and drainage patterns. The prediction is represented as a 200-value hazard image (using a pseudo-colour look-up table) shown on the upper right in Fig. 13.3. In the second stage, a second hazard prediction was obtained by the same model, but using only the distribution of a random half of the 420 landslides. That of the remaining 210 landslides was compared with the 200 hazard classes obtained in the second prediction to see whether the high hazard classes contain a high proportion of the 'validation' landslides. This was to obtain a prediction-rate table, also visualised as a prediction-rate curve, expressing the predictability of the events given the database and the 200 classes of hazard (200 used as default). Cost-benefit analysis can be applied to the characterisation of the curve into meaningful sections. Finally, in the third stage a realistic scenario assumed that 2,000 pixels would be affected by landslides in 1998, so that the probability of occurrence of future landslides could be estimated at each pixel of each class. The estimated probability histogram is shown to the lower right of Fig. 13.3. Those probability values have to be used to combine the first prediction map from the first stage with the socioeconomic data and images using the risk expression $R = E \times V \times H$, where E indicates the element exposed, V its vulnerability and H the probability of occurrence of the hazardous event. The combination of digital images of probability values and vulnerability/dollar values allows the risk map in Fig. 13.3 to be computed. To better communicate the risk visually, a fly-through risk map is shown in Fig. 13.4, in which a partial view of the image in Fig. 13.3 is shown.

The risk map is evidently a complex construct whose understanding is not trivial, due to the analytical steps and the necessary assumptions. One critical issue, therefore, is how credible and reliable a risk map is. The three stage strategy used to obtain the risk map in Fig. 13.3 is indeed transparent and repeatable. However, in the above application it only provides the empirical validation of the predicted hazard map using a random half of the events. Thus it does not tell us when to expect the events and it only tells us that, given the data in the database, the expected casualties in the study area are 3.14, in this case almost the same as the 3 casualties observed in 1998. More considerations on this case study can be found in Chung, et al., (2005). In this example, empirical validation techniques were used not only to demonstrate and measure the spatial support to the predicted hazard map, but also to estimate the probability of occurrence through a scenario that exploited the notion of the 2,000 pixels affected in 1998. To estimate the risk uncertainty in time and in space, however, more information will be needed in the spatial database containing the distribution of the hazardous events in time intervals and in space subdivisions, and, in addition, a number of different validation experiments. If a time division is not possible because there is no information on the time of occurrence of the past events, they can be randomly subdivided into two or more groups to obtain other validations. All such experiments will generate prediction-rate tables and curves

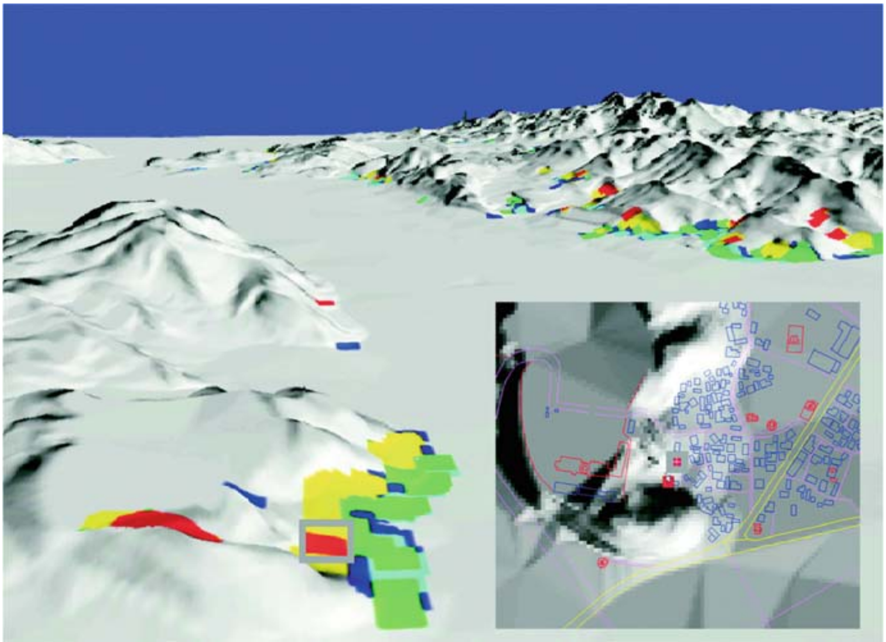


**Fig. 13.4** A fly-through is shown of the 3D visualisation of a portion of the risk map in Fig. 13.3, in which the flight direction is indicated by a red arrow. The grey box shows the location of a house where a casualty occurred. The inset on the lower right shows a vertical view of the population density database (after Chung, et al., 2005)

that can be compared to assess the uncertainty of the prediction results in the hazard map that is to be used to generate the risk map from the estimation of the probability of occurrence; in other words, this is the most critical estimation needed in risk mapping. A spatial prediction modelling software intended to be complementary to conventional GIS has been described by Fabbri, et al., 2004. The process of generating credible and convincing risk maps must be able to take advantage of the strategy described here if it is to be used to communicate risk to the public at large.

Unfortunately, in many societies it is still unclear who is responsible for producing such risk maps and which stakeholders or actors should contribute to the decision making on such maps! For instance, a study by Bonachea (2006) as part of the EC Research Network Project ALARM (Assessment of Landslide Risk and Mitigation in Mountain Areas), http://ivm10.ivm.vu.nl/webmapping/Alarm_SP_image_maps2, observed that in Europe there is no legal obligation to incorporate consideration of natural risks into land use and management policies. The only reference to such considerations is in a resolution of 16 October 1989 (Official Journal of the EU, 1989) which calls for the preparation of a statement on natural and technological risks. Worldwide, there is clearly a scarcity of hazard maps. In Spain, for instance, there are standards for information on flood hazards, but it is not clear who is responsible for preparing the hazard maps that have to show the return periods of the floods. It can be concluded, therefore, that the challenge is to include quantitative assessments of hazards and risks in future risk maps.

### *13.2.3 An Example of a Risk Map for Industrial Hazards*

In contracts to natural hazards, mapping industrial hazards is a subject of European legal enforcement. Article 12 of the Seveso II Directive requires the member states to consider, within their land use planning policies, the need of defining opportune safety distances between dangerous establishments and urban, natural and infrastructural developments. 'Dangerous' substances are those which by explosion, fire or release could lead to major accidents involving the external areas of establishments.

The Seveso II Directive is in the process of being transposed into the national legislation of all Members states. In Dutch legislation, the various provisions of the Seveso II Directive are incorporated into the Hazards of Major Accidents Decree (BRZO) and the External Safety (Establishments) Decree (BEVI). The BRZO focuses on the management of hazardous installations. The BEVI regulates the environmental quality requirements for external safety when planning land uses around hazardous installations. Decisions on land use planning and the granting of environmental permits for activities within the area hazardous establishment fall under the BEVI. The Dutch methodological approach to external safety is described extensively in the literature (Ale 2002; Bottelberghs 2000).

The Ministry of Housing, Spatial Planning and the Environment (VROM) is the competent authority for establishments of national importance, such as nuclear power plants (NPP) and nuclear waste disposal facilities. Hazardous establishments falling under the provisions of the Seveso II Directive are classified in accordance with threshold values for the quantity of stored/treated hazardous substances. Under this classification, top-tier sites are the responsibility of the provincial authorities and lower-tier sites and small liquid petroleum gas (LPG) stations are the responsibility of the municipal authorities. The urban and environmental objects and sites are classified accordingly to vulnerability categories (high, medium, low). Risks associated with an accident are estimated with respect to the type of accident being considered, its iso-risk contours and the specific territorial context. The preparation of digital risk maps to convey this information about the type of risks affecting specific areas is therefore an obvious, although recent, operational development. (http://www.risicokaart.nl/).

In the Netherlands risk maps are prepared by the provincial authorities. One such map is shown in Fig. 13.5. The Register of High-Risk Situations involving Dangerous Substances (RRGS: Register Risicovolle Situaties Gevaarlijke Stoffen) is used as informative source together with the Information System for Major Disasters (ISOR: Informatie Systeem Overige Rampentypen). ISOR has been set up jointly by the 12 Dutch provinces and contains additional information on risks, such as flood risks and vulnerable objects. Currently, it covers 11 types of disasters:

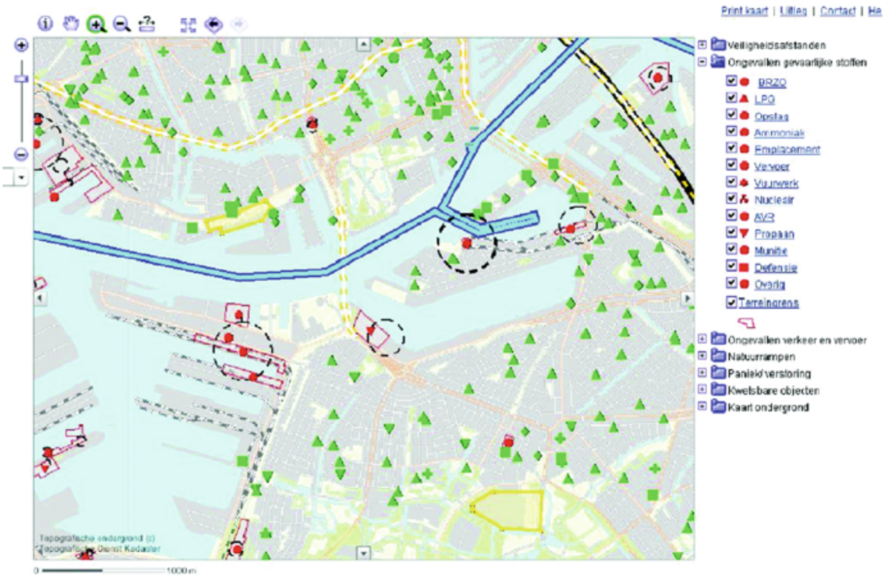


**Fig. 13.5** Example of a Risk map:. The symbols in red represent the hazardous establishments with the corresponding risk areas. The symbols in green indicate vulnerable public buildings, such as schools, hospitals, etc

dangerous substances, nuclear incidents, aircraft incidents, accidents on water, roads and in tunnels, collapse of large buildings, fire in buildings, widespread panic (or disturbance of the public order), floods and natural fires. Thanks to these developments, information on risks that was previously dispersed over many sources is being brought together in national, multi-accessible databases.

Mapping potentially hazardous establishments and vulnerable objects is a major step forwards, but it still does not help to make significant improvements in risk management and disaster management. The hazardous situations that are best represented on the risk maps are the sites whose locations or extent can be determined with accuracy, such as buildings, tunnels, stadiums, large exhibition halls, airports, parts of roads and waterways, etc. The maps give little information about the areas and populations at risk. The iso-areas are given only for hazardous establishments and the information they provide is rather limited. Iso-areas represent the individual risk at the given location, which is defined as the statistical probability that a person who is permanently present at a certain location in the vicinity of a hazardous activity will be killed as a consequence of an accident at that hazardous site. Individual risk for residential areas, hospitals, schools and the like may not exceed the legal threshold $10^{-6}$ (one in a million per year). The iso-contours indicate only that the risk within the area is larger than outside the area with respect to this threshold. Moreover, current risk maps only represent the chance and magnitude of a possible incident, but do not reflect the controllability of a possible incident. For example, it is not clear whether it would be possible to evacuate an area subject to flooding when the water reaches a near critical level.

### *13.2.4 Examples of Common Pitfalls in Risk Mapping*

There are a number of common pitfalls to using existing natural hazard/risk mapping models in risk and disaster management. Some of these pitfalls, as discussed by Chung and Fabbri (2004), are the absence of statements on the assumptions made in the prediction models, the lack of validation of the prediction results, and the absence of estimations of the conditional probabilities of future events given the characterisations of an area within a study area. Overcoming these deficiencies is a necessary but not sufficient condition. The following points are still major challenges: (1) the need for a spatial database that captures the distribution of hazardous processes, their settings and the socioeconomic elements exposed to risk; (2) the need to use models for estimating the hazard probabilities; (3) the requirements of techniques for estimating the uncertainties associated with the models and for estimating the uncertainties associated with the database; (4) the development of scenarios necessary to compute the risks; and, (5) the different techniques needed for representing the risk maps so that the risk levels and the associated uncertainties can be understood.

Until recently hazard models and risk maps have been prepared mostly for municipalities as aids in urban planning process. As such, the pitfalls listed above have not been considered critical. However, if applied in emergency response situations, hazard models and risk probability estimations have to be adapted to the development of the hazardous event and preventive measures taken during the event. Time therefore becomes a crucial factor for successfully predicting and managing the disaster. The next section concentrates on the use of geo-ICT in emergency response.

## 13.3 Geo-ICT for Emergency Response

Emergency response differs from the other phases in many respects: time is critical, the dynamics of events is higher than in normal circumstances, many people (who normally have different responsibilities) are involved, human emotions (pains, stress, panic) play an important role, infrastructure might be partially or completely destroyed, communication between different actors could be limited and even impossible, access to data and other sources of information might be obstructed, etc. Several studies have investigated factors of major importance for successful emergency response (Cutter, et al., 2003; Borkulo, et al., 2005; Diehl and van der Heide 2005; Kevany 2005; Zlatanova 2005; Brecht 2006; Zlatanova, et al., 2007). Some of the most appealing aspects related to geo-information are addressed below.

## *13.3.1 Important Factors for Emergency Response*

### 13.3.1.1 Information Awareness

Studies on past major disasters (Kevany 2005; Brecht 2006) conclude that there is insufficient information about existing resources, types of data and the availability and accessibility of data. Appropriate measures have to be taken prior to a disaster to agree on access to and availability of data. The lack of a spatial data infrastructure has been reported as a major obstacle to quick data availability and transfer. Related to this is the dynamic aspect of the information becoming available after the disaster. Frequently asked questions are: What is the position of rescue teams? Where are the shelters? What are the flood depths? Where are the landing platforms for helicopters? What is the current magnitude of a toxic cloud and how will this cloud develop over time? What is the current capacity of the nearest hospitals? Which roads are accessible and which ones are not? Because the circumstances during an emergency may change at any moment, continuous monitoring of developments and continuous distribution of information on monitored changes is necessary.

### 13.3.1.2 Collaboration and Exchange of Information

As emergency management is a multidisciplinary activity, it should be possible to exchange information between different partners at different administrative levels during the disaster. Command and control systems in dedicated centres should be built prior to the disaster or, alternatively, easily deployable components (open standard) should be developed to allow temporary management centres to be established quickly. For example, following the Hurricane Katrina disaster in the US, several ad hoc centres were created to replace the infrastructure for providing geo-information that had been flooded. Another frequently mentioned bottleneck is the issue of dynamic data management. It has been often unclear who should be responsible for the collection and appropriate organisation of dynamic data. In some cases much ‘private’ data has been donated by private companies and institutions (Brecht 2006).

### 13.3.1.3 Intuitive Interfaces

In a crisis response system heavy emphasis is placed by operators on intuitive interfaces with simple methodologies for communication and data access. Much attention has been given to the use of appropriate icons and symbols (Tatomir and Rothkranz 2005). Little importance is placed on extended functionality, or even artificial intelligence, to support decision making. In situations of stress, system operators place more reliance on their own judgment and the judgment of other human beings than they do on any form of artificial intelligence. What they want is to have a system that can be used in their day-to-day work and which they are comfortable with. The motivation behind this is directly related to the specifics of crisis response. Working with a unfamiliar system will contribute to critical delays and operator stress, which will inevitably lead to 'expensive' errors when mobilising emergency resources in response to life threatening situations.

## *13.3.2 Systems in Use in Emergency Response*

In recent years many emergency response systems have been developed for different types of disasters or for multi-disaster management that are dedicated to a particular group of responders or users. Special attention is also given to mobile systems and sensor networks for monitoring natural phenomena. All of them are intended to support decision making. In this respect it is difficult to define the scope of Geo-ICT in emergency response. The systems developed are integrated state-of-the-art technologies that include not only GIS technologies, but also computer graphics, human-machine interfaces, communications, gaming, etc. Due to the importance of location, most of the systems use vector digital maps, raster maps, images (aerial, satellite, range, radar, etc.) and 3D models for simulation and forecasting. The diversity of systems is extremely high. There are systems devoted to a particular disaster type (e.g. fire, flood, avalanches, etc.), to a group of responders (e.g. fire brigade, ambulance, police, Red Cross), or to a particular activity (e.g. early warning, evacuation, following patients to hospitals, etc.).

Generally, the systems can be subdivided into two large groups: scenario-based and demand-based (Erlich and Zlatanova 2008). The scenario-based systems concentrate on a particular type of disaster and attempt to consider a sufficient number of factors, which, when incorporated into the models, can provide the best predictions to support the decision-making process. The demand-based systems attempt to provide tools that can help in any kind of emergency. The concepts for these systems are relatively new and take account of the fact that a disaster may change its nature and may require information (or models) that are not available for the programmed disaster type. Several examples are given below.

### 13.3.2.1 Scenario-Based Systems

Numerous recently developed systems (either prototypes or operational tools) in the domain of floods, water pollution, forest fires and other natural hazards use predefined scenarios as a part of the entire architecture for forecasting the results of the process monitored. This approach allows for integrated data management (considering historical records), the creation and integration of modelling and simulation methods, and the development and adaptation (calibration and validation) of scenarios, supported by advanced optimisation tools, for forecast generation. The advantage of the scenario-based approach is the possibility of concentrating on and studying particular phenomena in depth, with the involvement of the relevant specialists, and of carefully selecting tools and components. However, such systems also have to be used by a specialist to run the different scenarios, adjust the simulations and interpret the results. Bearing in mind the complexity of the scenarios, many of the systems may become too vendor-oriented, making use of proprietary connectors and tools.

### VIKING

The VIKING project began as a cross-border collaboration between water management organisations and incident management organisation in the province of Gelderland in the Netherlands and the German state of Nordrhein-Westfalen (http://www.programmaviking.nl/). The system that has been developed in the project is a typical example of scenario-based flood disaster management systems. It has many of the functionalities of a traditional GIS. The graphic user interface is based on maps and aerial photographs and the flooded areas are interactively shown on the screen with prediction animation. VIKING enables communication between different systems (that provide the necessary information), interaction between separate procedures and cooperation between different organisations. One of the modules is the Flood Information Warning System (FLIWAS), which contains an evacuation model described by van Zuilekom and Zuidgeest (2008). Training and simulations are provided by the Virtual Cockpit, which is shown in Fig. 13.6.

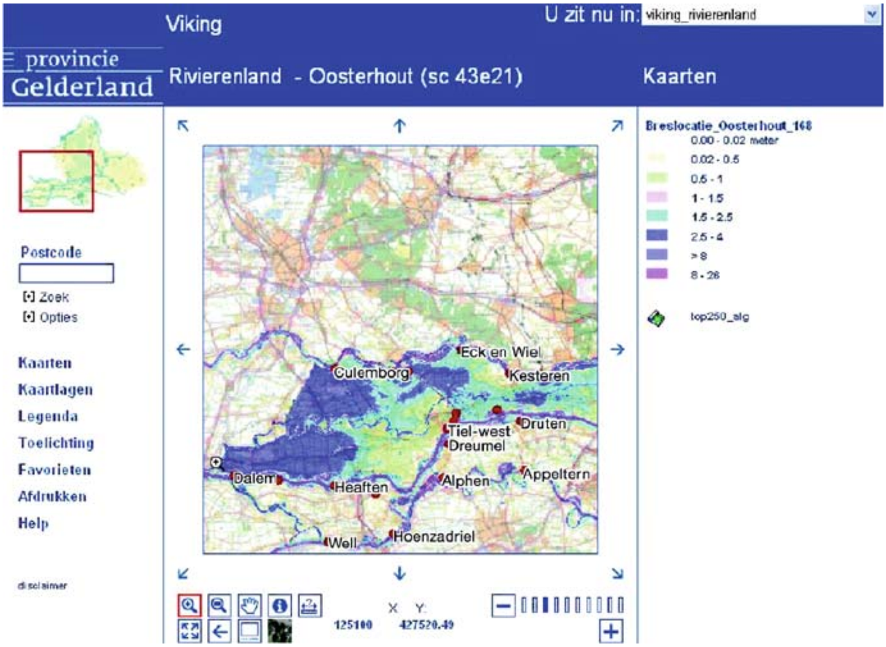


**Fig. 13.6** Viking flood warning module

### Delft-FEWS

A very interesting example is the Flood Early Warning System (FEWS) at WL|Delft Hydraulics (http://www.wldelft.nl/soft/fews/int/index.html), which has grown from a simple tool based on the combination of hydrodynamic and hydrological models into a highly functional real-time simulation program. The system uses an open shell flood forecasting system that provides essential generic (GIS) functionality for handling real-time data, data assimilation and managing forecast runs, while also allowing integration of existing forecasting modules through an open 'XML-based' interface. The modular structure of the system and generic forecasting functionality allow natural integration of the system into the flood warning process, without the requirement of extensive migration to a specific modelling environment.

### OSIRIS

Developed as one of five prototypes of the OSIRIS project (Operational Solutions for the management of Inundation Risks in the Information Society) is yet another system for flooding (Erlich, 2006). The emphasis in this case is on an interface, which can help citizens to understand official forecasts. The system allows the integration of various data, such as risk maps, flood prevention plans and rescue organisational charts. Detailed information is available at http://www.ist-osiris.org/.

### Indian Tsunami Early Warning System

The Indian Tsunami Warning Centre established at the Indian National Centre for Ocean Information Services (INCOIS) in Hyderabad opened in October 2007 (http://ioc3.unesco.org/icg-iii/documents/natreports/Indian%20National%20Report.pdf). It is perhaps the largest centre of its kind and collects information from the Indian national seismic network and other international seismic networks. The system running at the centre detects earthquake events of more than magnitude 6 on the Richter scale, which occur in the Indian Ocean in less than 20 minutes after the event. The dedicated software for the automatic location of earthquakes uses a large database of model scenarios for different earthquakes to estimate the travel time and magnitude of the tsunami. Once an earthquake occurs an appropriate scenario is selected, based on the location and magnitude of the earthquake, to adjust various predefined parameters. The scenario is needed to estimate the travel time and magnitude at various locations. At the same time, all the responsible organisations and individuals are alerted by email, fax, text messages and telephone. The use of geo-information is quite advanced. Different visualisation environments are used to display sensor information, to analyse measurements and to plot results. Areas can be identified where the population should be warned of the approaching disaster. The system makes use of various types of GIS information, including several modes of visualisation (e.g. Google Earth).

Various similar applications have also been developed by large vendors, including ESRI (Amdahl 2001), Bentley (www.bentley.com) and Integraph (www.intergraph.com). Most of these, however, rely on specially prepared datasets and models.

#### 13.3.2.2 Demand-Based Systems

Very typical examples of demand-based systems are the command and control systems developed mostly at local and regional levels. These applications concentrate on the communication and sharing of information between different units; they are able to access distributed information and share dynamic data. The tools are available to all the users involved in a particular incident and are not domain-oriented (e.g. not only for police).

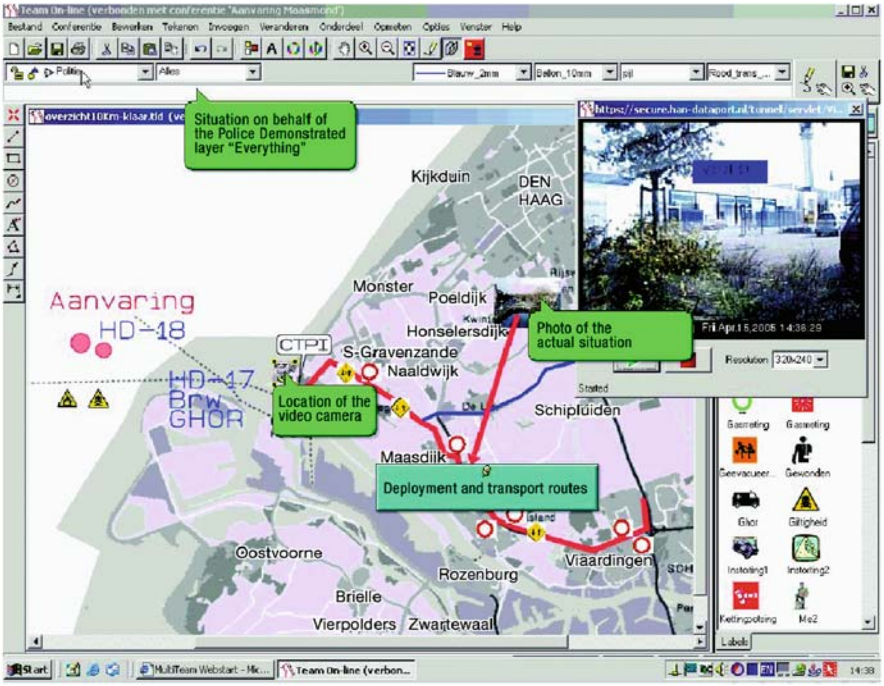
CCS (http://www.gdi4dm.nl) and MultiTeam (http://www.multiteam.info) are two systems for coordination and cooperation in the event of an emergency in the Netherlands. In both systems the different responding agencies (fire service, paramedics, police, municipal authorities and other special units) can log in to the system and exchange information about their location and the tasks that they are performing. They can show the location of their mobile units on a map (using special symbols) or mark important areas, such as those not accessible to the public. Each user of the system can select from a number of maps. Some maps can be accessed by other institutions via certain web services. The two systems differ slightly in their functionality and access to the information. While MultiTeam, shown in Fig. 13.8, has a quite large local database with information, the concept of CCS (Diehl and van der Heide 2005), shown in Fig. 13.7, is to provide access to distributed information stored at the individual organisations. In both systems, however, the spatial functionality is limited and extended spatial analyses are not available yet. The only available operation is map overlay for interpretation by visual inspection. Simulations (as discussed in flood risk management, above) are not available. Compatible communication systems are being developed to improve communication when flooding is imminent.

A remarkable work has been completed within the Open Geospatial Consortium (OGC) Open Web Services (OWS) Phase 4 test bed. Two major demonstrations have been presented, 36 interoperability program reports have been written, and 59 components have been developed in this test bed. One of the demonstrations is devoted to various aspect of emergency response: integrating data from GIS and CAD applications (in a 3D viewer), monitoring dangerous gas dispersion and integrating data from various sources – all based on OGC web services such as WFS (web feature services), WCS (web coverage services), SOS (sensor observation service) (Döllner and Hagedorn 2008; Lapierre and Cote 2008).

### *13.3.3 The Human Perspective*

Geo-information is now used in all phases of disaster management in various forms, from paper maps to digital models equipped with elaborated simulation and analysis tools. Many of these systems are still only understandable to the specialists and it

Fig. 13.7 CCS showing predicted plumes



Situation on behalf of the Police Demonstrated layer "Everything"

Photo of the actual situation

Location of the video camera

Deployment and transport routes

Fig. 13.8 MultiTeam interface

should be noted that many professionals involved in risk and disaster management are not familiar with GIS technology, and may even have difficulty in reading maps. Several authors (Kevany 2005; Neuvel and Zlatanova 2006; Brecht 2006) have discussed the various challenges in using GIS technology during disasters. Observations and tests have revealed many interesting issues.

In recent years the range of end users has become wider, but actual use of geo-information continues to be restricted primarily to those using Geo-ICT in their day-to-day work. Reports from recent emergencies indicate Geo-ICT use for a wide range of activities, from those managing and combating the emergency and involved in search and rescue operations to support operations in transportation, medical care, evacuation and shelter, security and recovery.

The technical skills of those involved in emergency management are slowly improving, although the majority still lack Geo-ICT knowledge. Most operations that involve the use of geo-information continue to be performed by geo-experts, who generate products for emergency personnel. In many cases hard copy maps are still the primary geo-products used in emergency response. Those using them tend to possess only general map-reading skills and little special emergency training is available (Kevany 2005).

Various organisations have recognised this problem and have formally or informally identified people to provide staffing for emergency response on an ‘all-times’ basis. An example is the GISCorps (http://www.giscorps.org), which was founded in 2003 in the USA to provide a formal mechanism for arranging volunteer information support where disasters overwhelm the capabilities of the local GIS organisations. At the end of 2007 GISCorps had over 1,100 enlisted volunteers spread across 47 countries in five continents. These volunteers include natives of 57 countries and the US volunteers come from all 50 states. GIScorps has implemented 20 missions around the world and clocked up over 5,100 volunteer working hours.

Geo-ICT usage is not identified as a specific emergency response function in most emergency response units. Consequently, most Geo-ICT experts working in disaster management are advisors and very few become emergency managers and decision makers. Little has been done to develop emergency geo-information leadership through training programmes or other mechanisms. As discussed in the literature (e.g. Brecht 2006), strong leadership is critical in emergencies. Lacking emergency training and having little opportunity to gain experience, Geo-ICT experts are therefore generally at a disadvantage compared with emergency managers and responders. The alternative – training managers to become experts in understanding and operating with geo-information – is also hardly applied.

Emergency managers are trained to save lives and protect property and infrastructure. The tools of the geospatial professionals are never the first things people think of when a disaster actually strikes. People on the field react according to their experience, training and instincts. In a crisis situation, people are reluctant to take the risk of relying on technology if they are not familiar with it. Recent studies have shown that only after employing a technology in their daily work do people feel confident enough to use it in emergency situations.

A general tendency towards increased interest in Geo-ICT can be observed. A large user investigation performed in early 2007 among fire fighters, police, ambulance and local authority staff in a province in the Netherlands (Snoeren 2007) has clearly revealed a desire for better systems that can provide a good overview of progress with combating disasters. Exhaustive information (from a large numbers of updated maps with locations of responders and in situ sensor data), better hardware (fast servers and communication channels) and improved graphic user interfaces are some of the issues mentioned.

## 13.4 Further Application of Geo-ITC in Disaster Management

Utilisation of geo-information in risk and disaster management is rapidly increasing, but a large number of developments in geotechnology can be envisaged. Some emerging areas are listed below.

### *13.4.1 Spatial Data Infrastructures, Semantics, Ontology*

A spatial data infrastructure (SDI) is intended to create an environment that will enable users to access and share spatial data in an easy and secure way (van Lonen 2006). Practically, it ensures that users save resources, time and effort because it provides access to data via standardised services and protocols. Generally, an SDI is defined as consisting of spatial data, standards, networks and policies. All components play a critical role in establishing an SDI for disaster management, but the technical aspects (spatial data, networks and standards) are especially critical. In this respect two international initiatives are of significant importance: the EU INSPIRE Directive (establishing an Infrastructure for Spatial Information in the European Community) for harmonisation of geo-information, and the European GMES initiative (Global Monitoring for Environment and Security) to bring data information and providers together with users. The European Commission has funded numerous large projects, for example for defining services (ORCHESTRA), developing data models (WIN), monitoring and processing of sensor networks (OSIRIS) and cooperation between different systems (OASIS). Various similar initiatives have been initiated at the national level (e.g. in the Netherlands: www.gdi4dm.nl, http://www.geonovum.nl/ontwikkeling-imoov.html) which pay much attention to client-server architectures that use standardised services. There is growing awareness that the information needed for risk and disaster management should be available for access at the source (which ensures that the information is up to date and reliable) and not managed centrally using replicated information from the original hosts.

Successfully integrating and analysing various types of data and providing appropriate information to the end users requires not only standards, but also a strong formalism to deal with the most difficult problem: the semantics of data. The spatial data used in disaster management are usually collected and managed within specific domains (land register, topography, utilities, water, soil, etc.) using specific representations and notations. These need to be understood by the users in the response sector, in risk management and in land use planning. Moreover, these users have different terminology and use specific language to denote features from the real world. It is expected that formal semantics and ontology will greatly help in providing the right information to the right people (Xu and Zlatanova 2007).

### *13.4.2 Management of Dynamic Data*

A variety of systems (GIS, CAD, Architecture, Engineering and Construction (AEC) software DBMS and combinations of these) can be employed for managing operational (in situ) data. One of the most critical aspects of a system for emergency response is time. Fast and efficient storage of fresh data into databases, quick search of data, flexible maintenance of time sequences and robustness of the approaches used are among the most important aspects to be addressed. All these processes have to be near real time. The in situ data used in emergency response are usually sensor data delivered by stationary gauges for monitoring particular phenomena (river level, gas dispersion, volcanic activity, etc.) or sensors (cameras, laser scanners, radar), mounded on mobile, aerial or satellite platforms, or information about moving objects (such as ambulances and police cars, fire engines and people) (Zhang, et al., 2002).

The second problematic issue is the third dimension. 3D geospatial information has always been a challenge due to the variety of data models, resolutions and details, and representation methods (boundary representations, voxel, constructive solid geometry, CSG). Since the 9/11 disaster in New York, interest in 3D models (of buildings, underground systems) for emergency responses has grown, but there is still no commercial system that can be used easily to manage and analyse 3D data. Obtaining 3D models of indoor environments is a challenging issue, especially when they have to be created in real time. Indoor spaces can be measured (using laser scanning or images) and reconstructed (by 3D modelling software) but this process usually requires much manual intervention (to resolve complex topologies that commonly occur). A promising approach is simplification of 3D design CAD models of buildings represented in the IFC (Industrial Foundation Classes) construction standard (Isikdag 2006). This approach allows a high level of automation, but there is a risk that the building has been modified during the construction.

### *13.4.3 Spatial Analysis*

Many tasks in disaster management require the affected area to be delineated with respect to area of impact. In GIS technology, this operation is known as the buffer operation. Suppose response units are looking for a water supply near a burning building. The first step in this operation can be to create a buffer object from a feature (such as a building on fire). Sources of water within the buffer object can then be identified using an overlay operation. In 2D, the buffer object is a polygon, while in 3D the buffer object is a 3D solid object. The 3D searching operation should be able to resolve complex geometric computational problems involved in defining topological relationships (inclusion relationships) between the 3D buffer object and well-formed 3D objects representing a microscale urban area (such as spatial units in a building) (Lee and Zlatanova 2008).

Another challenging operation that needs to be performed is a shortest path analysis in 3D space. Several evacuation algorithms have already been reported in the literature (e.g. van Zuilekom and Zuidgeest 2008). Most of the evacuation algorithms are 2D and cover outdoor spaces (the road networks). Scott (1994) implemented a shortest path algorithm for an unindexed three-dimensional voxel space using a cumulative distance cost approach. This approach produces a set of voxels, such that each voxel contains an attribute about the cost of travelling to that voxel from a specified start point, if there is uniform friction of movement throughout the representation. A 3D shortest path algorithm moves through the 'cost volume' along the steepest cost slope from target to origin using a 3 × 3 × 3 search kernel (Raper 2000). Boundary representation approaches are discussed in Kirkby, et al., (1997), Kwam and Lee (2005). Zhu, et al., (2008) implemented a modified version of the 'Dijkstra' shortest path algorithm in a 3D GIS, in which the gradient over a 2.5D surface was added into the computation. However, much research is still required to address the diversity of problems in evacuation from large buildings (Fig. 13.9).

### *13.4.4 Visualisation Environments*

One of the first possibilities to be considered is the human interaction with the system. New tools have to be constructed to ensure intuitive interfaces and easy-to-use visual environments. Virtual reality environments, such as Google Earth, Visual Earth, Second Life, and even more elaborate environments like CAVE (Cave Automatic Virtual Environment) or augmented reality systems still have to be explored. In this respect, a very interesting tool is the touch table, shown in Fig. 13.10. Users around the table interact with the system directly with their hands, avoiding the use of input devices such as a mouse or keyboard. The information displayed on the table is tangible for the users, allowing them to retrieve information by direct contact with the table (Scotta, et al., 2008). The system permits multiple users to work together and in parallel when gathered around the table. This multi-user quality introduces an original and unusual aspect to the system, since the current hardware and software is still based on single user input and as a consequence users are not aware of the advantages that can be derived from a multi-input tool. Such devices can be particularly beneficial in command and control centres, where decision makers analyse incidents and discuss response actions.

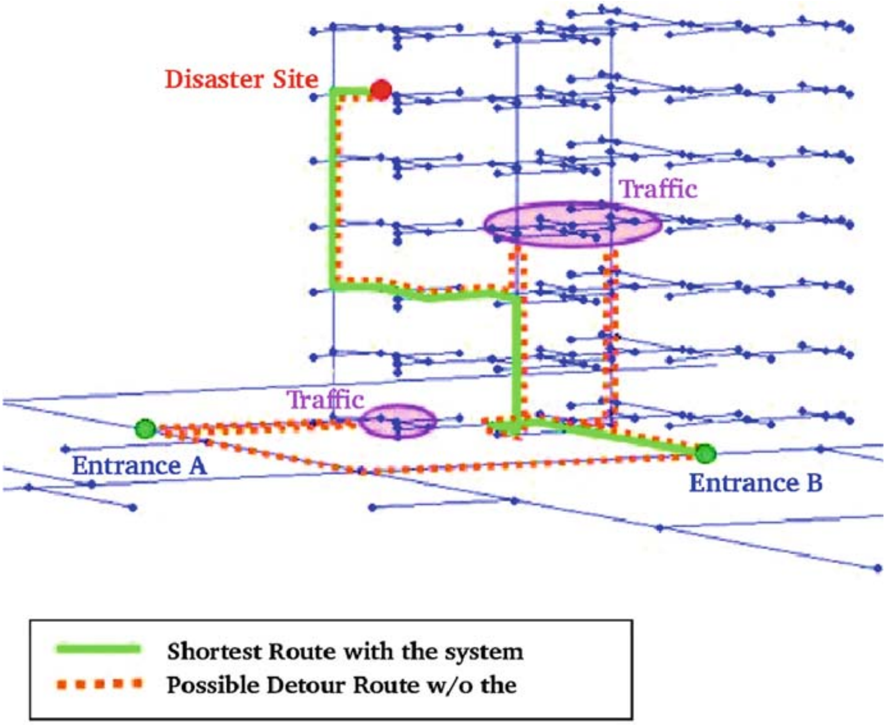


Fig. 13.9 Navigation routes in a building (Source: Kwan and Lee 2005)

Fig. 13.10 Touch table at Geodan B.V, The Netherlands

## 13.5 Discussion

In this chapter we have introduced the disaster cycle and its associated terminology and discussed the importance of location and Geo-ICT in disaster management. This shows how an increase in awareness has led to critical needs for Geo-ICT advances to overcome many of the present pitfalls in disaster management. These include risk maps of both the natural and technological risks and the importance of timely information delivery for effective emergency response. Present and future developments were pointed out in the areas of SDI, dynamic data, spatial analysis and visualisation environments.

The complexity of Geo-ICT systems and models used in risk and disaster management depends on the stage in the disaster management cycle. Maps are largely used as background information for location awareness and decision making, but the functionality of offer is varied. While the risk prevention phase can benefit from elaborate modelling and simulation tools, applications in the response phase are limited to relatively simple communication modules. Apparently, the time restriction and human perception are some of the major bottlenecks for working with complex models and of leaving decisions to be taken by 'machines'. Greater awareness of and trust in Geo-ICT is needed. This can be achieved by more training, but also by developing systems and tools that can be used in daily routine work.

It is increasingly important to allow the sharing and exchange of information within the entire disaster management cycle, from risk prevention and mitigations to response and recovery. As mentioned earlier, risk management has been mostly performed by land use planners who increasingly recognise the need to study disasters so that they can improve the quality of planning decisions, and particularly to arrange for preventative evacuation in the likelihood of a disaster. Armed with the knowledge that some areas are more vulnerable to a disaster than others, including the availability and capacity of escape routes, local and regional authorities could adapt spatial policies and development plans accordingly. The emergency sector is also seriously considering the implications of risk criteria and vulnerable objects used by land use planners. The systems that are used in land use planning contain information on hazardous sites and the location of vulnerable objects that can be extremely useful for emergency services. As this review has shown, hazard modelling systems are evolving to real-time demand-based systems to be used in emergency response. In this respect, building an SDI for disaster management can greatly contribute to connecting different systems and sources of spatial information. The use of web services and obtaining information via internet will play a critical role in the near future. Downloading, copying and storing information on local servers will be reduced drastically. The number of web services in use is growing and many new systems rely on client-server architectures using web services.

Risk and disaster management can be seen as an emerging science in which spatial information plays a significant role. Again, a distinction must be made between risk management and disaster management. While risk management could be referred to as an *explicitly spatial* discipline, disaster management is even more *implicitly spatially-oriented*. In the event of an emergency, the use of spatial information (except location) is not normally seen as the first priority. However, as the technology develops and new tools allow for a better use of spatial information, crisis management will evolve into a typically spatial discipline. The increasing availability of GIS analytical functions such as buffers, within-area, field-of-view, shortest distance and best distance (avoiding blockages and dangerous areas) and the capacity to dynamically monitor and forecast hazards or trajectories of moving vehicles and people during crisis response will help to make disaster management a fully spatially-oriented discipline. In addition, more advanced analytical tools should be developed to move from static to dynamic representations of spatial information. The aim should be to create spatial risk databases in which risk zones can be identified, queried in different manners and supported by reliability and certainty labels for task prioritisation.

Clearly, awareness of the importance of spatial information in both risk management and disaster management is growing. Two general tendencies can be distinguished here. Firstly, an increasing number of different types of spatial data are being used to perform tasks within risk and disaster management. Second, a general understanding is building up about sharing information between the two domains. This tendency is especially strong for spatial information and it is even difficult to determine when spatial information was first used in risk or disaster management. Both natural and man-caused hazards have been studied and modelled as real world phenomena and modelling has always been based on some kind of spatial information. However, practice in recent years has revealed the need for the integration of multiple spatial datasets in order to perform more complex analyses. Progress in Geo-ICT has been contributing to this process by making management, use, analysis and visualisation of various spatial-temporal data possible with easily adaptable and user-friendly interfaces.

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# Chapter 14
# Geo-ICT in Transportation Science

**Maria Teresa Borzacchiello, Irene Casas, Biagio Ciuffo, and Peter Nijkamp**

## 14.1 Introduction

'The function of transportation is to move people or objects between spatially separated locations, with the purpose of meeting demand for goods, services and activities' (Hall 1995). This broad definition highlights the linkage between transportation science and spatial approaches. Transportation science is devoted to explaining the phenomena leading to the movement of people and objects from place to place, by both developing and exploiting theoretical and application tools (Hall 2003).

Transportation systems have always exploited the most recent advances in various fields of technology to improve performance (Golledge and Stimson 1997). Technological advances have affected transport and progressively shortened effective distances (travel times), as we can see from Fig. 14.1, which shows how distances on the planet have shrunk from the 14th century until the present day as vehicle speeds have risen and, in the last few decades, the speed of information transfer has increased as.

At the same time, technological developments over the centuries have enhanced the quality of cartographic representation, right up to the development of geographical information systems (GIS). Since, given that the main objective of GIS is to store, retrieve and facilitate the analysis of spatial data (Goodchild and Janelle 2004), they have a seamless relation with space and location and have become one of the most powerful tools to support transportation studies and applications. The relevance of GIS, or Geo-ICT, to transportation is indeed quite natural, given that transportation itself is linked to spatial organisation and the development of networks in space and time, just like geography itself (Haggett 1965). Capitalising on this relationship, academics and practitioners have focused their attention on research and other work that makes use of GIS in transportation applications.

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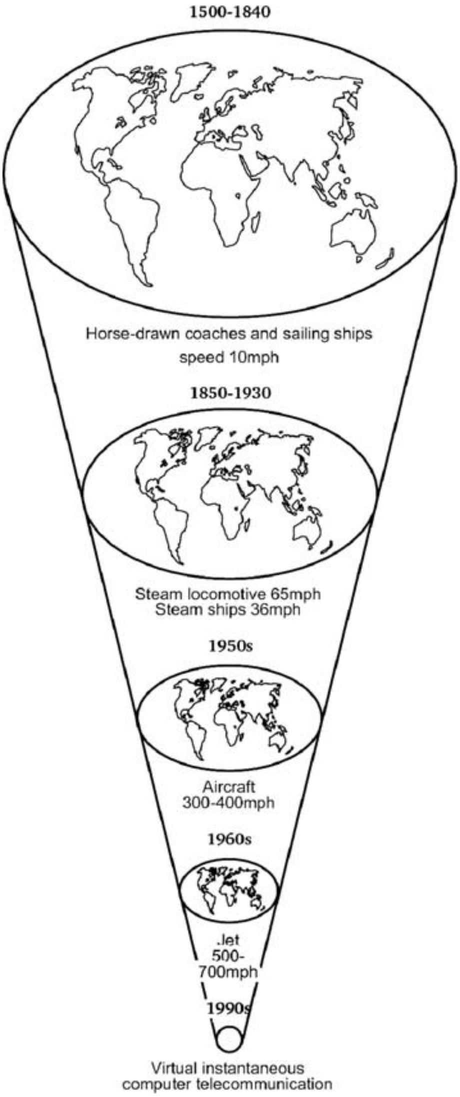

**Fig. 14.1** The role of technology in shrinking world distances (Golledge and Stimson 1997)

‘Geo-ICT and Transport’ has been of importance in the academic world since the early 1990s (Miller 1991; Kamal et al. 1994). However, besides some early contributions, which aimed at explaining the role of GIS in transportation planning (Sutton 1996), no significant studies were conducted until 2000, when a relevant attempt was made to collect and organise studies on GIS and transport previously published in *Transportation Research* C. An edited book was published as a result on ‘GIS in Transportation Research’ to identify various perspectives on the use of such techniques in transport applications. Since 2000, many studies and applications have been published on the topic. Whereas in the first research studies GIS were considered to be merely a technique to support applications, in the course of time they have been used to define the core methodology of the applications.

Today GIS are indispensable in transportation science applications (Spring 2004). In fact, sometimes public authorities with an interest in transportation are formally required to build a GIS framework to handle and manage transportation data and projects. For example, for the past 22 years the American Association of State Highways and Transportation Officials and the US Departments of Transportation (DoTs) have organised an annual GIS-T symposium to give practical support to government and industry organisations interested in the use of GIS for transportation purposes. This shows that the spatial approach is naturally integrated within transportation science, in contrast to other disciplines where there is a need to identify the particular role of 'geographically oriented subdisciplines' in a distinct way. Indeed, transportation scientists have been key players in the application of GIS (Goodchild 2000; Thill 2000).

GIS have influenced a variety of aspects of transportation science. Goodchild (1998) recognised that the discrete entity model and the network model are the most interesting GIS data models for transportation purposes and has identified the paradigms leading to their extensive use in transportation modelling. These are: digital map production, inventory and data management, integration of data, spatial analysis and dynamic modelling. He then differentiated three stages in the evolution of GIS-T: the map view (mainly concerning network visualisation and interoperability issues); the navigational view (connected with network modelling and algorithm resolution); and the behavioural view (linked to the use of the network by people and vehicles, which implies the dynamic modelling of transportation phenomena) (Goodchild 2000).

More recently, Thill (2000) highlights the requirements of GIS in transportation applications and the core transportation research themes which employ GIS for research, planning, and management (referred to collectively as GIS-T). Like Goodchild, he provides a classification, but gives more attention to the use of GIS for handling large amounts of transport data rather than to the other aspects. According to Thill, GIS-T need:

- a data management system (whose aim is to facilitate the maintenance and the integration of the inventories of transportation infrastructures held by public authorities);
- data interoperability (to allow transportation data sharing among several agencies, each with its own database);
- real-time GIS-T (for real time georeferenced data storage, retrieval, processing and analysis);
- large datasets (which involve the optimisation of algorithms and analytical tools, and the discovery of innovative system designs);
- distributed computing (to allow the spread of GIS-T data over users and community by means of web services).

Identifying the main fields of transport in which GIS could contribute, and how it could make this contribution, presented a serious challenge at the beginning of this decade. However, the rapid technology advances in computing and increasing interest from public academic authorities have fuelled rapid improvements to GIS in recent years, and they have become systemic throughout the scientific world.

In 2006, Shaw and Rodrigue reviewed Goodchild and Thill's classifications. They considered that GIS-T studies can be classified into three groups: data representations, analysis and modelling, and applications. A review of the literature on Geo-ICT and transport leads to this classification, which is also very similar to the three frameworks suggested for this book. In this paper, we decided to adopt the geodatabase, geomapping and geomodelling frameworks as a classification, with the goal of allowing comparisons with other sciences. This classification will not lead us far from previous authoritative research and will make the discussion understandable to other disciplines.

This chapter examines the specific significance and role of location in transportation science in Section 14.2, while in the third section explains the use of Geo-ICT (GIS tools, spatial data and location-based services) within the three frameworks mentioned above, identifying, in Section 14.3.4, their mutual relationships. The comprehensive phenomenon of the integration of Geo-ICT in transportation science and the obstacles encountered are analysed in Section 14.4 and future directions are discussed in the last section, emphasising the challenges faced by Geo-ICT.

## 14.2 Location in Transportation Research

Starting from the definition of transportation science in the previous section and considering all the newer studies carried out in this field, we can assume that the concept of 'location' has a very wide meaning and at the same time is intrinsic to transportation itself. Each application in transportation science is carried out with reference to a particular spatial context, and therefore to a particular location (Taylor et al. 2000). For instance, the reason why people travel in the first place is the presence of different kinds of activities in different places. Therefore, information about the location of activities and the location of people interested in them is essential for studying travel demand and designing optimal transport systems (Cascetta 2001). Information about infrastructure locations is also important for designing efficient freight and public transport services.

Recently, scientists have been making considerable efforts at finding efficient ways of sending real-time information to transport users, not only about the location of accidents, road congestion and various kind of emergencies (natural and human hazards such as fires, landslides, terrorist attacks and so on), but also about transit position and vehicle tracking. Among the possible examples, we can distinguish between static and dynamic location (Noronha and Goodchild 2000). The first is related to the georeferencing of objects fixed in space, such as accidents, activities and infrastructures, while the second is related to objects changing their position in time, such as vehicles, passengers and goods. This dichotomy reflects the evolution of transportation science, which is increasingly adopting a dynamic problem-solving approach instead of the traditional static one.

It is important to note that in transportation science the term ‘location’ not only refers to the position of passengers and goods, which is an input for transportation studies, but it is also often considered to be a design output when it is understood as relating to the optimal location of facilities (Chan 2005). In order to deal with these location-based issues, transportation scientists first adopted graph theory. Graph theory can be used to explore the properties of sets of topologically related lines and points characterised by specific weights, and therefore to model and analyse transportation networks.

With the appearance of GIS, transportation scientists were attracted by the possibility of assigning a location meaning to network entities (nodes representing actual places or intersections and lines representing roads), an option which was limited in graph theory. For this reason, among the models provided within GIS, the network model is the one most used to represent topologically connected linear entities (Thill 2000). However, researchers have not limited GIS use to the traditional tools. Over time they have adapted and developed new tools for their own purposes to enable the representation of nonplanar models and multiple lanes (Fall et al. 1996), the analysis of turns and intersections (Miller and Shaw 2001), the linkage between two or more transportation modes and hence networks (Southworth and Peterson 2000), dynamic segmentation for the multiple representation of attributes of the same entity (Sutton and Wyman 2000; Choi and Jang 2000) and integration with transportation models (You and Kim 2000; Berglund 2001). Because researchers need to model reality more closely they have improved and enhanced the network model available in GIS. Technological advances in the field of computer science have also made this possible.

Since every element in the transportation system has a physical meaning and special characteristics if localised in a particular context or position, another important aspect of location approaches in science is the collection of data. The main transportation applications deal with the collection of several kinds of different location-based data on aspects such as physical facilities characteristics, road traffic, activity location, travel demand volume in a specific area and vehicle tracking. The data collection method used depends on the nature of the data to be collected. For physical information, the most common methods are in situ surveys, cartographic analysis and remotely sensed data; for travel demand, more or less complex sampling surveys (Cascetta 2001) are used; for activity location it is possible to make use of national datasets (e.g. the Census in the UK, Istat in Italy and so on); and for real-time traffic information, GPS and wireless tools are becoming indispensable.

Modelling and analysis of the transportation system necessarily involves the use of information from other fields, such as land use, environment and demography. This complexity unavoidably leads to the collection of large amounts of data. The datasets need to be stored, integrated, analysed, elaborated and made available. It comes as no surprise, therefore, that transportation science uses the power of GIS to improve transportation data management and dissemination through the extensive use of a georeferenced database approach and web-based mapping. Even in this field, however, transportation scientists do not limit their efforts to the use and application of commonly provided GIS tools, but try to adjust the technology to their own needs, confirming again that GIS-T is not a particular GIS application, but rather a GIS development enriched by a transportation information system (TIS) (Thill 2000). We now explore these aspects in detail using three analytical frameworks mentioned in the Introduction: geodatabase, geomapping and geomodelling.

## 14.3 Geo-ICT in Transportation Research

### *14.3.1 Geodatabase Framework in Transportation Research*

Transportation scientists have undoubtedly taken advantage of the possibilities for handling and managing large quantities of data with Geo-ICT systems within their geodatabase framework. The most important sign of this is the widespread use of geodatabases in every transportation application. Transportation researchers use geodatabases for different purposes: solving data interoperability issues; performing query optimisation; resolving map matching issues; using these databases as a basis for transportation models and for creating data repository to build decision support systems; integrating GPS data; and sharing data by means of web tools. Given the diversity in applications, scientists can exploit transportation data by storing such data in georeferenced databases. Applications of geodatabases in transport include query definition for the optimal resolution of multiple path algorithms and other kinds of network problems, and the creation of efficient spatial query resolution engines specifically designed for transportation models (Mainguenaud 2000; Huang et al. 2000).

The first implementation of a network model was based on a relational database, which could easily be adapted to the abstraction of a network represented by a graph. This model, usually referred to as the ‘arc-node model’, was used not only to model the network but also allowed topological relations to be created (Thill 2000; Shaw and Rodrigue 2006). It was then expanded to handle linear referencing, thus facilitating the modelling of point events within the network. However, the arc-node model was limited in its capabilities, restricting the uses to which it could be put. As database technology advanced and the need grew for network models to conform more closely to reality (i.e. multimodal networks), an object oriented model was proposed. This kind of model focuses on network features which make interaction between the elements possible. It is a more intuitive model for transport scientists since it is centred on objects and introduces a degree of flexibility that the previous model did not offer.

The first attempts to create geodatabases for transport (Claramunt et al. 2000; Dueker and Butler 2000) lacked common definitions of the transportation elements and of interoperability between traditional GIS and transportation-related models. However, as the models became more sophisticated and widely used, new integration frameworks were proposed. These new frameworks considered geodatabases and their relational structure as suitable for storing spatial data and maintaining a shared digital world model. Examples can be found in the literature that exploit the acquired experience in the Geo-ICT field (several data models have been developed: see Jang and Kim 2007 for an overview), the advances in computing and software development, the importance given to these issues by the appearance of international standards (ISO) and the newly created exchange languages (UML, XML, GML) and formats (shapefiles, coverages) (Darter et al. 2007; Jang and Kim 2007; Scarponcini 2007). The main purpose of these contributions is to propose new frameworks to overcome the problem of data sharing and interoperability.

Data sharing is one of the primary issues when using geodatabases for transport. For example, transport planners need to integrate different data sources into one system for retrieval, processing and forecasting, and so they must have a fully integrated GIS database (for an example, see Thong and Wong 1997). As the EU INSPIRE directive states, interoperability means, 'the possibility for spatial data sets to be combined, and for services to interact, without repetitive manual intervention, in such a way that the result is coherent and the added value of the data sets and services is enhanced'.

One of the most common transportation applications using GIS in which the interoperability issue is visible is spatial matching between two or more different networks obtained from various data sources or from GPS surveys. While initially such a problem involved time and energy resources due to the necessity for manual manipulation (Xiong 2000; White et al. 2000), several improvements have since been introduced that make use of the capabilities of GIS and of ITS, as described by Quddus et al. (2007). The map matching issue is very important whenever the integration between GIS representation and GPS devices is considered (Taylor et al. 2000; Mintsis et al. 2004; Byon et al. 2007). In these cases, GIS often provides a database management platform for the integration, display and analysis of data collected from GPS.

Geodatabases have been used to integrate GIS and transportation modelling for particular purposes, such as travel time forecasting (You and Kim 2000), congestion management (Quiroga 2000), traffic entity estimating for different road categories (Blume et al. 2005) and to build spatial decision support systems (SDSS), mainly to help public agencies to make efficient transportation planning decisions. Frank et al. (2000) led an interesting application related to hazardous material truck routing. They compared studies which implemented a solution within a GIS and those using a GIS embedded in an SDSS. They identified the advantages of the latter, which included support for the analysts. Adaptability to a wide range of problems, visualisation and interaction, and plan-generation orientation are the special features of the SDSS developed by Arentze and Timmermans (2000), who present a review of SDSS approaches and a framework to support transportation planning and location decisions.

More recent experiences, mainly led by the US Department of Transportation (DoT), deal with the implementation of spatial information system infrastructures that provide planners with the right and most up-to-date information for efficient decision making (Hall et al. 2005; Bejleri et al. 2006). In this respect, GIS – and geodatabases in particular – are used to integrate data collected from diverse sources, to organise data in exchange and standard formats, to analyse data and to create information which can be stored in the geodatabase itself and shared with public agencies and other stakeholders.

Similar efforts, some as yet only at an early stage, are also being made by the European Community. The European Transport Information System (ETIS) aims to 'identify and accommodate all required policy-driven information related to ETIS in a repository, to be kept up-to-date and controlled by experts and to be accessed through an Internet-based software tool' (Ballis 2006). GIS technology is used in ETIS for its capability to store georeferenced information in georeferenced data banks and to visualise and represent geographical information, even by means of an internet-independent application. The ETIS framework is a starting point for other contributions, such as Tsamboulas and Mikroudis (2006), whose aim is to build a comprehensive independent program (TRANS-POL) that is able to mediate between the needs of transportation planners and transportation models. Essential for this endeavour are the Geo-ICT peculiarities of data integration, spatial query, representation and visualisation.

As anticipated, one of the current research challenges regarding Geo-ICT, and in particular the geodatabase framework, is the data sharing issue. This can be achieved through the use of interoperable data formats and languages, but only when data can be shared across independent web-based applications. Several studies deal with this problem and most of the contributions which make use of geodatabases consider the internet as the final platform for distributing data between actors (see for example Peng and Huang 2000; Ziliaskopoulos and Waller 2000; Welch et al. 2007). A requirement for the development of such internet-based systems is the dissemination of interactive location-based and route-finding web services (such as Google Earth and Google Maps). Full advantage can only be taken of a geodatabase when it is paired with a visualisation tool.

### *14.3.2 Geomapping Framework in Transportation Research*

Transportation applications require visualisation and mapping capabilities not only to display results, but also to analyse and generate an overview of the problems. In this respect, transportation science has exploited the advances in geographical representation in Geo-ICT systems. Transportation applications have relied on GIS to explore new visualisation and mapping possibilities, raising questions regarding issues of map accuracy, map matching, location mapping and advances in 2D and 3D visualisation.

Many attempts have been made to use digital maps to better represent transportation network features and identify the precise location of their attributes through the dynamic segmentation features in commercial GIS packages. Norohna and Goodchild (2000), for example, relate the location expression problem to the interoperability issue and develop methods to compare maps and overcome map accuracy problems when data is derived from different sources. Sutton and Wyman

(2000) compare dynamic segmentation based on the linear referencing approach with dynamic location, which stores geometry as a single object in a database field.

A wide range of transportation applications and studies take advantage of the user-friendly environment provided by GIS software and of new possibilities from a visualisation point of view (Frank et al. 2000; Welch et al. 2007; Choi and Kim 1996; Moudon et al. 2005). GIS allows flexible interfaces to be created for visualising urban traffic data, where map symbols and computer animations are distinguished as possible means to represent dynamic traffic phenomena (Claramunt et al. 2000). More recent advances allow GIS to be used to represent transport data in more than two dimensions, in particular when studying travel behaviour (Kwan 2000; Kwan and Lee 2005; Pack et al. 2005 and 2007). There is also considerable interest in mapping newer elements associated with networks, such as risk and vulnerability (Church and Cova 2000; Kwan and Jiyeong 2005). With the development of the internet and web-related services like Mapquest and Google Maps for planning and route-finding, GIS has acquired a new role. Mapping services, some more sophisticated than others, are all over the internet and are setting a standard for transport planners and agencies to follow (Tang and Waters 2005).

### *14.3.3 Geomodelling Framework in Transportation Research*

From the above it is clear that geomodelling is the Geo-ICT application of choice for modelling the transportation system and has been used widely in the field. The commercially available GIS systems that are geared towards transport (e.g. *TransCAD* and the network extension of *ArcGIS*) provide different transport modelling processes as standard features. For example, *ArcGIS* has intrinsic functions for solving the travelling salesman problem (TSP), site selection, service areas, origin–destination matrix calculation and other spatial functions that can be linked with the network. In addition to the functions offered by *ArcGIS*, *TransCA*D offers transport planning functions such as user equilibrium and system optimal.

The extensive body of literature we have scanned shows that GIS has been used as a framework to support different modelling aspects in transport applications. Travel behaviour is one of the areas where GIS has been used for modelling demand for public transport modes (Choi and Jang 2000) and for private modes (Choi and Kim 1996). GIS has been used to model travel choice (Byon et al. 2007; McGowen and McNally 2007; Bricka and Bhat 2006; Ogle et al. 2005; Tsui and Shalaby 2006), destination choice (Chow et al. 2005), location choice (Nicholas et al. 2004; Shelton et al. 2004), mobility (Schlossberg 2006) and accessibility (Hodge 1997; Miller and Wu 2000; Casas 2003). It has been used for travel time forecasting (You and Kim 2000) and risk and evacuation models (Church and Cova 2000; Alexander and Waters 2000; Horner and Downs 2007). In terms of transport infrastructure, GIS has been used for road safety (Ozbay and Mukherjee 2000; Wang et al. 2007; Li and Zhang 2007), site selection (Nyerges et al. 1997) and investment and maintenance (Tsai et al. 2004; Ozbay et al. 2007). Intelligent transport systems have benefited from the use of GIS (Quiroga et al. 2006), for example, for data modelling and representation (Arampatzis et al. 2004), and traffic management (Ozbay and Mukherjee 2000; Zhou et al. 2006). Transport services focusing on other than passenger transit, such as freight, have also made use of GIS (Southworth and Peterson 2000; Frank et al. 2000). Lastly, research in transport policy has adopted GIS as a tool in areas dealing with pollution (Bachman et al. 2000; Armstrong and Khan 2004; Brown and Affum 2002), land use (Arentze and Timmermans 2000; Vicente and Martìn 2006), public participation (Prevost 2006) and sustainable mobility (Celsor and Millard-Ball 2007; Nijkamp et al. 2007; Cheng et al. 2007). As mentioned above, most of these examples use Geo-ICT to support transportation modelling and a wide range of transportation applications.

An original research direction, closely tied with the geodatabase framework discussed above, is the attempt to find the best data model to represent and model transportation elements. Besides proposing a custom enterprise GIS-T data model, Dueker and Butler (2000) provide an assessment of the data models used in GIS-T, highlighting the advantages and limitations of each of them according to the following standards: the Geographic Data Files model (GDF), an international standard used to model road network data for navigation purposes (ISO 14825 2002); the NCHRP 20-27, that is defined as a generic data model for linear referencing systems (Vonderhoe et al. 1998); and the Topologically Integrated Geographic Encoding and Referencing system (TIGER), developed by US Census Bureau (U.S. Census Bureau 2008). Jang and Kim (2007) outline the state of the art in transportation data models, including the Multi-Dimensional Location Referencing System (MDLRS) model (Adams et al. 2001), UNETRANS, the ESRI ArcGIS Transportation Data Model (Curtin et al. 2003) and TransXML (NHCRP 2007). They explain that GIS-T and GDF data models employ a common relational model, while MDLRS and UNETRANS are object-oriented models. However, neither of them has a 'semantically coherent framework', which would be useful to avoid transportation information being dependent on a specific platform. For this reason, they propose a different conceptual framework to develop a data model based on the ISO 19100 series of standards for geographical information. Research is ongoing with a view to developing and applying a proper data model that 'fits' the transportation systems.

The research being conducted to underpin the development of commercial transportation modelling software based on GIS technologies is more consolidated. You and Kim (2000) provide a review of the integration of transportation (travel time forecasting) models with GIS, distinguishing between models that incorporate GIS, those connected with GIS and those embedded within GIS software. Sutton (1996) provides an early and interesting classification of the ways transportation models can be linked with GIS technology and lists the pros and cons of each of them. The classification includes: 'hard coding', which allows linking by means of a correspondence between tables in the GIS database and those of the transport network; 'warm linkage', when the choice is to build the transportation network within the GIS platform (examples are *TransCAD*, which despite what Sutton says in his review has been further developed and has a very wide diffusion); and 'hot linkage', which involves data sharing by means of standard formats between the transport model and the GIS platform.

Within just one decade, substantial progress has been made, and what seemed 'off-putting' about GIS to some researchers (Sutton 1996) has been rapidly overcome. Following one of the paradigms of Goodchild (1998), dynamic modelling is the future challenge facing the use of GIS in transportation research. Since the work of Claramunt et al. (2000), who propose a 'very dynamic' GIS that integrates static urban data with dynamic traffic flows to monitor urban traffic, other contributions have explored the potential of GIS for performing temporal-based analysis for studying land use and transportation interactions and other transportation applications (Shaw and Xin 2003; Demirel 2004; Yu 2007; Ahmed and Miller 2007).

### *14.3.4 Framework Summary*

From the previous sections it is possible to specify the main characteristics and obstacles identified by researchers in the three frameworks. The references cited are only a small proportion of the vast literature on the use of Geo-ICT in transport. They provide a fruitful starting point before delving deeper into each particular field of study.

Briefly summarising, the geodatabase and geomodelling frameworks require interoperability and data model definition that go beyond model integration, while issues commonly raised within the geomapping framework are map accuracy, map matching and dynamic and multidimensional visualisation.

The three key frameworks for the use of Geo-ICT in transportation science are mutually interrelated. This is evidenced by the growing development of spatial decision support systems (SDSS) for transportation planning purposes in the international literature and in practice. Geodatabases are the core of SDSS, due to their capability to store, integrate, manipulate and retrieve large amounts of data from diverse sources and agencies. The geodatabase is commonly embedded in a comprehensive information framework which includes transportation modelling and macroscopic indicators as the outcome – typically represented in more or less advanced maps. Every step involves a logical procedure able to support transportation planning decisions.

This overview shows that each of the three frameworks has its own importance within transportation science. It is important to highlight that the main impulse for the use of Geo-ICT in the field has been its enormous power to organise and store data in a geodatabase framework. The relative popularity of this aspect of Geo-ICT systems could be explained by the need to handle data from intensive data collection procedures and surveys that are used to provide input to transportation models and analyses. Currently, the need to better represent, visualise and enhance the transportation models that have already been developed, with special attention to location and geographic reference, contributes to the extended use of the other frameworks as well. This shows that Geo-ICT in transportation science has the ability to integrate the three frameworks into one tool, which is an advantage and an improvement on what was available in the past (when the three frameworks were separate and different tools were required for databases, mapping, and modelling).

Future research will most likely continue to exploit and encourage the integration of the three frameworks to support transportation system analysis and modelling and to achieve an overall understanding of the dynamics that rule the system. Geo-ICT in transportation science is actually GIS-T, and, according to Fletcher (2000), GIS-T are 'interconnected systems of hardware, software, data, people, organisations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth that are used for, influenced by, or affected by transportation activity'. This definition is supported by existing technologies, but calls for cooperation between different actors – research institutes, public administrations, private agencies and the general public as well – in order to create proper infrastructures able to support not only land use and transportation planning, but also people's everyday life (receiving and providing location-based real-time information on transportation networks and facilities). This is probably the main challenge – more organisational than technological – to be addressed in the future.

## 14.4 Integration and Diffusion of Geo-ICT in Transportation Science

As explained in the introduction, Geo-ICT technologies are intimately connected with transportation science. The integration, or rather the diffusion of Geo-ICT within transportation science, is a bottom-up rather than a top-down process. Initially Geo-ICT was used by researchers in their applications; with the development and continued use of the tools, awareness of their importance in the field gained recognition and Geo-ICT has become a required tool.

The field of transport saw an increase in the use of GIS tools in the 1990s, although even in the 1980s some GIS software (e.g. the ESRI software *ArcGIS*) contained modules able to model networks, even if they were quite complicated to use. Although municipalities and utility companies were using this software as early as the 1980s, it was only in the mid 1990s that the first appraisals were carried out of the role of GIS in transportation planning and of ways to spread this technology among researchers and stakeholders (Sutton 1996). Sutton argues that Geo-ICT was introduced into transportation via its use in a wide range of applications. The aim was to use the 'tremendous potential' of GIS for organising and displaying information, but above all for managing transportation network data. This raised special issues like dynamic segmentation. The study also recognises that early practitioners started to investigate the use of GIS in transportation and to form small research communities, which then led in the US to the organisation of expert panels dedicated to exploring GIS-T issues and of special academic courses and conferences about GIS-T.

The recognition by public agencies, and therefore by national and international norms, of the importance and the need to collect, integrate and update transportation data can be identified as a driving force for the diffusion of Geo-ICT in transport. This tendency, can be seen in the US, where by now the final stage of the integration model seems to have been achieved, and, although somewhat lagging behind in time, in Europe, where the need for large-scale databases is recognised in the public sector (the EU INSPIRE Directive (2007/2/EC)).

From an academic perspective, developments in the US (Sutton 1996; Thill 2000) were not followed in Europe, or at least have not been so widely documented. For example, in Italy the use of Geo-ICT in advanced transportation engineering education is not being exploited to its full potential. It is used as an ancillary technology to speed up and facilitate processes that can be carried out without the use of GIS. But this trend is only apparent, because transportation engineers are well aware that without GIS software, modelling or simple visualisation would be very hard and too expensive.

## 14.5 Summary and Perspectives

The GIS technology capable of implementing and manipulating networks has been available for at least two decades. Initially, however, intensive training and knowledge of the software was required. GIS was an exclusive tool of geographers, while other disciplines were kept in the dark regarding its potential benefits for them. In terms of the software, the technology had not reached a level of maturity and there were problems of storage and processing speeds, which for transport applications were very important. In spite of these shortcomings, as the technology evolved and GIS gained widespread recognition, the benefits of using it in the transport field became apparent. With its increased use, demand for more specific transport functions emerged, forcing GIS developers to improve their network models and incorporate transport-related functions into their systems. This is a trend that continues today. Users demand more functionality from GIS and the software companies are willing to oblige. The existence of a tool that is so useful for modelling and implementing transport applications has attracted increasing interest and groups of users other than transport planners and researchers. GIS is now used by transport researchers across a number of different disciplines.

In this view, the main challenges recognisable from the literature reviewed are:

(a) Database information platforms;
(b) Real-time GIS;
(c) 3D data management.

### *14.5.1 Database Information Platforms*

GIS has acquired an integrative role not only in transportation science but in other disciplines as well. It has become a development platform which allows the different components of a project to be combined into a single system. The three frameworks discussed in this paper – geodatabase, geovisualisation, and geomodelling – can all be part of the same application, with a seamless and efficient interaction (see Section 14.3.4 above). This unique characteristic has made GIS a popular tool in the advancement of transportation science. As more organisations and researchers use GIS, the technology becomes a norm and its perceived usefulness and ease of use become more apparent.

### *14.5.2 Real-Time GIS*

Real-time applications aim to reveal the (transportation) system conditions at all times so that they can to deliver the most up-to-date information to users (to influence their decisions) and to the system itself (to orientate its behaviour). Currently, the main problem of real-time GIS is not in the technological field, which has undergone rapid growth, but rather in new modelling efforts which are required to better understand how to use these advanced tools properly. Indeed, the rapid growth in technology in recent years has opened the doors to applications that were inconceivable just a few years ago and were therefore not included in any modelling approach. Examples in the transportation field are in-vehicle information systems (IVIS) and the advanced driver assistance system (ADAS), which exploit all kind of devices useful for obtaining location-based information (already available), but whose impact on the transportation system is not yet clear and still under investigation.

### *14.5.3 3D Data Management*

In recent years, researchers in very specific fields of transportation science have appreciated the potential of Geo-ICT for data management. For example, specific applications such as microscopic traffic simulation packages and driving simulation systems are now providing GIS importing and exporting tools, which in earlier versions were not considered at all (TSS 2006; Oktal 2006). Moreover, the involvement of these new GIS users is driving the expansion of the capability of information systems to manage and use 3D data. In fact, they require a more detailed representation of the transportation supply model for better evaluations of single-vehicle behaviour. For this reason, the GIS capability to store, organise and retrieve data on Z values is becoming indispensable. At the same time, 3D mapping will surely have an influence on enhancing navigation systems for ordinary drivers and making road databases more accurate (TeleAtlas 2007).

Geo-ICT in transportation continues to grow in terms of the number of users and is an important factor in driving the advancement of transportation science. The three frameworks discussed are evidence that transportation is an area where these technologies are readily applicable and can provide advantages in data storage, visualisation, and processing/modelling. GIS as a tool is flexible enough to allow researchers to propose improvements in these areas via programming (i.e. code development). However, as this requires a level of expertise that is not easy to attain, those who do have the knowledge and know-how to advance the field should share it with others. This can be achieved via the internet by creating a shareware site, following the example of other open source code projects that already exist in different areas. This will also allow a wider use of the tool and increase the number of users.

The science behind GIS, on the other hand, allows us to raise fundamental questions about the technology, within the three frameworks discussed in this paper, with the aim of contributing to the advancement of science and technology. In particular, GIS technology has shown that it can be a flagship of transportation science and, in time, will transform the discipline and become one of the forces driving its development.

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# Chapter 15
# Geographical Information Systems and Geography Teaching

**Joop van der Schee and Henk J. Scholten**

## 15.1 Introduction

Different documents published by the International Commission on Geographical Education of the International Geographical Union (IGU) show that in many countries the position of geography as a subject in secondary education is not a strong one. In his overview of curriculum issues in school geography, Naish (2004, p. 55) writes: “The most fundamental issue is that of establishing a secure place for the subject in the curriculum, across the school age range.” Although the IGU’s International Charter on Geographical Education (Haubrich, 1992) says that it is essential that all students follow a continuous programme of geographical studies throughout their years of formal schooling, geography has lost a part of its territory in the school curricula of many countries. Geography has an uncertain place not only in the upper levels of secondary education, but also in primary education (Rawling, 2004, p. 168). The question is how geography can be put on the map again. Are digital maps and geographical information systems (GIS) the solution?

The growing popularisation of spatial tools also feeds the growing interest in spatial methods and in skills for informed spatial reasoning (Janelle and Goodchild, 2009, Chapter 2 of this book). The use of maps in printed and visual media, the spread of geographical positioning systems and vehicle navigation systems, and easy access to map and satellite imagery via geobrowsers like Google Earth and Virtual Earth all point to a growing need for spatial perspective. Recent international publications in the field of geography in education, such as the report “Learning to Think Spatially” compiled by the US National Research Council (2006), state that GIS is an important tool for promoting spatial literacy. The strength of GIS lies in their capacity to integrate many types of data with a known spatial component, visualising and processing them quickly and efficiently and combining other information bearers, such as pictures, with map images.

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This chapter focuses on the use of Geo-ICT in education, particularly secondary education. In the near future, GIS could contribute significantly to the social relevance of geography teaching. Initial experiences in higher education (Donert and Charzynski, 2005) and in secondary education (Audet and Ludwig, 2000; English and Feaster, 2003) are promising. The use of Geo-ICT can prepare young people for using it in their daily lives. However, the introduction of a new subject will not automatically be successful. In this chapter we examine the position of GIS in secondary education in different countries and try to identify the necessary preconditions for implementing Geo-ICT in geography teaching, specifically focusing on the crucial role of teacher training and research.

## 15.2 GIS in Education

In view of the increasing use of GIS in society, it is logical for schools to train students in the use of GIS. Universities and higher vocational training schools offer GIS courses partly to satisfy the growing demand for geo-information scientists, but also from the conviction that this subject is part of a certain branch of science. The VU University Amsterdam has had a chair of Spatial Information Science since January 1990 and Geo-ICT training is being provided. It is therefore one of the first universities to take a structural approach to determining how this education can be provided in the best possible way and has established a successful international partnership of 17 universities in the field of GIS distance learning, known as UNIGIS (www.unigis.org). Scholten and Molendijk (2005) mention the hurdles that have been overcome in recent years in the quest to introduce this new branch of education into universities. Although most universities have positioned this new subject within the field of geography studies, other disciplines also realise its potential and are investing in Geo-ICT, an example being the Faculty of Economics and Business Administration at the VU University Amsterdam. Besides UNIGIS, another important GIS university study in the Netherlands is the Geographical Information Management and Applications (GIMA) MSc programme offered by TU Delft, Wageningen University, Utrecht University and the International Institute for Geo-Information Science and Earth Observation (ITC Enschede). GIMA and UNIGIS both use distance-learning systems to prepare students for modern society, in which GIS and related technologies are widely used in a variety of organisations and within a diversity of working processes.

Interest in GIS is also slowly growing in secondary education. The developments in this field in different countries show many similarities as well as differences.

### *15.2.1 North America*

In North America and Canada, the importance of introducing GIS into geography teaching was recognised as early as the 1990s. The pioneers in the United States include Nellis (1994) and Sui (1995). Several people describe the significance of GIS for education in very similar terms. For example, Stoltman and De Chano (2003, pp. 115–137) say: "The capability of GIS to incorporate numerous data sets as mapped layers and to display these quickly and efficiently may help students to visualise relationships between and among spatial phenomena." In 2006, the US National Research Council published *Learning to Think Spatially, GIS as a Support System in the K-12 Curriculum*. This book underlines the strengths of the existing GIS software for American secondary education, including the fact that GIS is consistent with the ideals of problem-solving learning and working with authentic situations, and that it can be used for both subject-specific and subject-exceeding (or interdisciplinary) education. Some important recommendations relate to the simplification and adaptation of professional GIS packages for educational ends, and to the training of teachers in GIS use.

The firm ESRI in particular has made considerable investments in the US and elsewhere in the world to introduce GIS into education. These include the publication of the book *Mapping Our World* (Malone, et al., 2002), which sets out a step-by-step approach to managing GIS software, and books on successful GIS projects in American schools (Audet and Ludwig, 2000; English and Feaster, 2003). Three arguments have been put forward for promoting GIS in the US (Bednarz and Van der Schee, 2006):

1. the *workplace rationale*: GIS as an essential tool for knowledge workers in the 21st century;
2. the *educative rationale*: GIS in support of learning and teaching processes in geography;
3. the *place-based rationale*: GIS as the ideal resource to study geographical problems on different scales.

Despite these arguments, implementation in the US has proceeded less smoothly than expected. Kerski (2003) reported that in 2000 less than 8% of the 20,000 high schools in the US had GIS software, only half of the teachers who had purchased a GIS software package had actually used it and hardly 20% had used it in more than one class in more than one course. Some important constraints on GIS use were the complexity of the software, the teachers' lack of time to organise classes with GIS and the lack of technical support.

### 15.2.2 United Kingdom

In the United Kingdom, GIS was introduced in secondary education in the 1990s and is considered of the utmost importance for geography teaching (Wiegand, 2001). Unwin (1992) and Rhind (1993) are some of the people spearheading this development. In an article in the *Secondary Geography Handbook* of the Geographical Association in the United Kingdom, Jeans (2006) underscores the crucial role GIS now plays in modern society and the important role geography teachers can play in introducing students to the power and relevance of GIS. In that same book, Morgan (2006) points out that the capability of the more powerful GIS packages to show animations, for example of three-dimensional landscapes, helps students to think about planning decisions that could be taken in a certain area. In different publications of the Geographical Association, which include the magazine for English geography teachers called *Teaching Geography*, teachers are enthusiastic about the possibilities and use of GIS in the classroom (Davidson, 1996; Watts, 2005). But research tells a different tale. Results of a survey performed by the Ordnance Survey in 2004, which was answered by 250 schools, showed that most respondents did realise the usefulness of GIS for (geography) teaching, though only 7% actually used it (Lawrence, 2004). Freeman (2003) also says that the use of GIS in English geography teaching is limited, despite the popularity of GIS at the public and private sector levels. And looking beyond his own country, in 2004 Wiegand said in his keynote address in the education symposium of the International Geographical Union congress that "The prevailing 'cartographic culture' in schools in both the USA, the United Kingdom and other parts of Europe remains robustly pre-GIS."

### *15.2.3 Germany*

During the 1990s in Germany, too, several individuals, editors and institutions took initiatives to integrate GIS into education. In February 2004, the magazine *Praxis Geographie* was dedicated entirely to GIS in geography teaching. It describes a series of examples of successful GIS projects at different school levels, though it also clearly points to some bottlenecks. Krause (2004) describes the use of GIS in a primary school as part of a project called *Digitaler Kinderstadtteilplan*, in which primary school children mapped their play areas in the school surroundings. They added a description and assessment of the play areas to their digital map. The result was a picture of the neighbourhood from the children's perspective. The final result was placed on the school's website, with the parallel objective of showing new students the neighbourhood. Krause says that the project was an encouragement and a success that led to a better understanding of maps among the children, though there was a lack of software that is adequate for the primary school level. Schleicher and Schrettenbrunner (2004) also affirm that GIS use at school is an encouraging and informative element, especially if the students can collect and process their own data. They describe an interdisciplinary project in which primary school children in Heidelberg mapped and analysed the quality of trees in the areas surrounding the school. In this extensive project, the students practised many skills and developed new knowledge on biology and geography. Falk and Nöthen (2004) report on a comparable project for secondary school students who were equipped with decibel meters to study noise pollution at different places in Berlin. They mapped, processed and presented the data with the aid of GIS. Despite the authors' generally positive opinion on this project, they also mentioned some areas for special attention, emphasising technical problems with the computer and the large amount of time this project required. GIS is slowly gaining ground in German education (Falk and Nöthen, 2005). It is a slow process because of the complex software, the limited availability of teaching materials and the fact that most teachers are not trained to use GIS in education (Cremer et al., 2004).

### 15.2.4 The Netherlands

As in some other European countries, incorporating the use of GIS in geography teaching in the Netherlands has been a difficult process for various reasons, such as the unavailability of data. In North America, this is easier than in most European countries. In Canada, the Ministry of Natural Resources, the agency responsible for generating topographical data and aerial photos, decided in April 2007 to make available the gigantic amounts of maps, data, aerial and satellite photos of the entire Canadian territory free of cost. In the Netherlands, separate negotiations are still required on each data file for educational ends. After a cry of distress by two geography teachers in the magazine *VI Matrix* (Korevaar and Koenders, 2003), the Dutch Land Registry Office, the VU and Geodan decided to break the impasse and develop a GIS portal for education called EduGIS (www.edugis.nl). The Land Registry Office, Statistics Netherlands and some ministries provided data. This first initiative was set within the framework of a partnership established in the Netherlands to facilitate the exchange of geo-information among different government parties, called the National Clearinghouse on Geo-Information (Bregt et al., 2005). It soon became clear that the creation of a portal is only one of the preconditions for getting GIS education off the ground. Thanks to a major subsidy from different ministries in the Netherlands, it was possible to continue with the second phase of the EduGIS project, which is now one of the projects of the Space for Geo-Information programme. This programme receives government funding until the end of 2008. Through the internet, editors, teachers and students can access EduGIS free of cost to obtain information on GIS and GPS, different digital maps of the Netherlands, course modules using these digital maps and course modules that use Google Earth.

Before the start of EduGIS, in 2003, a written survey was held among 200 geography teachers working at secondary, pre-university and pre-vocational education schools from all over the Netherlands to make an inventory of the situation regarding some aspects of GIS in geography teaching. The survey results show that of the 73 respondents, only 12% have occasionally used GIS in geography courses (Korevaar and Van der Schee, 2004). Of the respondents, 81% want more GIS in geography courses and as many as 40% of the respondents want GIS to be a compulsory part of geography teaching. Eighty-seven per cent (87%) of the respondents said they would follow a GIS in-service training if provided.

In brief, the results of this survey show that in 2003 GIS was still in its infancy. It is clear that many geography teachers understand the importance of GIS and are prepared to attend in-service training. It is remarkable that these results do not come from a group of young teachers: half of the respondents were 50 to 60 years old and had been teaching for more than 15 years.

A more recent study among geography teachers at secondary, pre-university and pre-vocational education schools with 82 respondents (Pleizier, 2007) reveals new developments, although not all obstacles have been overcome. Half of the respondents know EduGIS and half intend to use EduGIS (again) in the coming school year. Of the respondents, 40% use Google Earth in their courses and two out of every three teachers say they will do so (again) next school year. More than half of the respondents say that GIS should be given a clear place in the examination programme. However, at the same time 75% of the teachers say they are unable to prepare a good lesson with Geo-ICT.

There are very few results from studies of students. A small-scale study on EduGIS in two secondary schools shows that 75% of the students believe EduGIS is useful and interesting, although the students do have several comments on the technical performance of the software (Pleizier, et al., 2006). Some of the important stumbling blocks for the teachers are time, accessibility of the datasets and technical and didactic skills for working with Geo-ICT in the classroom. Within the framework of the EduGIS project, GIS courses for starters as well as advanced courses have started, but more time and effort will be required to train all teachers than is available in the current EduGIS programme. Considering that the current EduGIS programme finishes at the end of 2008 and that teachers have asked for more support, the issue now is what is needed for ensuring the sustainable implementation of Geo-ICT in education.

## 15.3 Continued Implementation of GIS in Education

Introducing innovations into education is not an easy task. Stringfield (2002), who studied 20 multiannual, large-scale educational reforms over a 15-year period, concludes that changes in education cost much more time and energy than many policymakers and education managers realise. Following Spady and Mitchell (1979) and Murray and Porter (1996), Bednarz and Van der Schee (2006) distinguish four conditions for the successful introduction of GIS in education:

1. *Authority*: Enthusiastic experts show what GIS can bring to education. In the Netherlands, the VU University Amsterdam is trying, with others, to set the trend in primary, secondary and higher education through lectures and publications. The Royal Dutch Geographical Society is active through its Geoweek, when Geo-ICT companies open their doors to education and geo-information scientists lead activities with students or give lessons at schools.
2. *Power*: GIS must be anchored in the curriculum. Further definition of requirements regarding GIS in the curriculum is a necessary condition for training students in GIS. Besides including GIS in the curriculum, it is important to develop test assignments. A good start for a test matrix are the rubrics devised by

Bednarz (2000). In these rubrics, she describes what can be expected of the students in terms of "Problem Based Learning GIS". A third aspect has to do with the role of book editors, who must integrate GIS into their methods. Different major editors of geography methods for secondary education contacted EduGIS at the beginning of 2008 to work on this together. This is a big step in the right direction.

3. *Manageability*: GIS must be easy to introduce into educational practice. GIS software suitable for educational purposes is being developed in Germany, the United States and other countries. These fall into two broad groups: educational variants of professional desktop GIS packages, such as ArcVoyager and Diercke GIS, and special web GIS packages for education, such as EduGIS, SchulGIS and Tahoma Virtual Atlas (O'Dea, 2002). Every GIS package for education offers different capabilities for viewing, analysing and processing data, which in turn means that every GIS package offers different possibilities for triggering young people's geographical thinking and awareness. In Germany, Cremer et al. (2004) underscore the importance of the "manageability" of GIS packages such as SchulGIS and Diercke GIS. In the United States, SAGUARO (Science and GIS: Unleashing Analysis and Research Opportunities) is an example of a GIS project that tries to adapt technical matters in such a way that they do not distract students too much from the subject matter. In the end, the idea is not to learn about GIS but to work with GIS (Sui, 1995, pp. 578–591). "Making GIS use transparent to the student shifts the focus to learning science and geography concepts and spatial problem-solving and moves GIS education from more technical training to more stimulating education" (Hall and Walker, 2005). Often too much emphasis is placed on learning the GIS technique and too little on content-related aspects of the subject. The central objective is to learn with GIS, although it is inevitable that this will have be combined with some explanation of how a GIS software package works (the use of open source applications is becoming an increasingly realistic option). The subject matter to be taught with the aid of GIS should be organised in such a way that important functions for geographical reasoning are covered, such as queries and the drawing of areas in the form of buffers. The underlying technical steps must be automated as much as possible. Another indispensable element is that it must be possible for the students to visualise and process relations between different features of areas and between areas on different spatial scales – from their own environment to a worldwide scale – without the need for a good knowledge of statistics. To meet all these requirements, the development work and development research must go hand in hand.
4. *Consistency*: the first three conditions must be met in a manner which is fully compatible with other education variables, such as teacher characteristics.

There are many initiatives on the introduction of GIS into secondary education, but they are still in the take-off phase. Although there are barriers to using GIS in education, these can be overcome. It goes without saying that GIS is part of the education of the future. The question is not whether GIS should be used in education, but how. In higher education, we see that GIS is becoming increasingly integrated into courses as students become more proficient in its use. Expectations are that this trend will also occur in secondary education.

One of the essential elements of learning with GIS, the necessary geographical knowledge, has not yet been widely considered. In the end, the central constraint for teaching with GIS is not the hardware or the software, but the geographical knowledge of the students – and sometimes also of the teachers (Kerski, 2003). The use of maps, digital or paper requires considerable expert knowledge of geography. Without this know-how, GIS will remain stuck on a superficial level, whereas geography can hardly be called a superficial subject. Drawing on Hoekveld (1969) and Van der Vaart (2001), we can distinguish between three key competences in geography education:

1. students acquire a geographical world view;
2. students acquire knowledge and understanding of spatial topics;
3. students learn to manage the geographical approach.

These competences can be summarised as spatial or geographical awareness, says Van der Vaart (2001), a concept that is "a combination of a way of thinking and a certain basis of knowledge". Geographical awareness can be compared to historical awareness, which can be conceived as "a combination of a way of thinking and historical basic knowledge". Geographical awareness is the focus of geography and something which GIS can contribute to. It has to do with an active map image of one's own living environment and the living world, awareness of the regional variation and regional shifts in the world, and an active knowledge of important relations in the world (climate zones, trade relations, etc.) as well as knowledge of a few specific spatial issues such as water management, climate change, sustainable development and spatial organisation. Geography is a complex and many-sided subject. Harvey (2005, pp. 211–255) says that despite this complexity, four structural components can be distinguished in geography: "(a) cartographic identifications, (b) the measure of space-time, (c) place/region/territory, and (d) environmental qualities and the dialectical dynamics of socio-environmental change". In the description of geographical awareness above, these structural components are considered through working with maps, orientation in time and space, attention to regional changes and attention to the relationship between society and nature.

In a modern technological society, geographical awareness is important in that it contributes to citizenship education. GIS is a powerful tool for bringing about this awareness by stimulating spatial literacy. The question in this regard is which GIS components we must distinguish to facilitate an analysis of the way in which these components can be incorporated into education in the best possible way. In line with the structure of this book, we start from:

- a geodatabase framework, location as a specific component in the databases;
- a geomap framework, visualisation and map-making;
- a geomodel framework, location as a key variable in the explanatory models.

The first two components do not require any long explanations. In recent years, in the EduGIS project in the Netherlands we have been able to develop the geodatabase framework and make this available also for education. The same can be said for the geomap framework. The visualisation of data and digital map-making now take place in a well-organised environment, with efficient tools, and we can be confident of continuing development. The linking of our own data and tools with the data and tools of Google and Virtual Earth in the EduGIS project has provided geography education with an enormous potential for developing spatial awareness. Nevertheless, it is clear that this potential cannot be taken for granted. We must also determine the technical and methodological obstacles to making optimum use of Geo-ICT for developing spatial awareness. We will start with a more in-depth analysis of the geomodel framework, drawing on Janelle and Goodchild (2009, see Chapter 2).

The Center for Spatially Integrated Social Science (CSISS) was founded in 1999 with support from the US National Science Foundation to develop research infrastructure in the social and behavioural sciences (Goodchild, et al., 2000). CSISS improved the accessibility of spatial analytic tools like GIS through web technologies, workshops and publication programmes. Faced with the question of how best to present the case for spatial analysis in the social sciences, CSISS developed an operational strategy and a model to advance spatial methods.

This model recognises the key role that space plays in human society and in the structuring of social processes. The CSISS strategy acknowledged that nearly every domain of the social and behavioural sciences could benefit from concepts of spatial thinking and from tools of spatial analysis. Hence, beginning with core themes in the literature of the social sciences and with evidence of applications in meeting societal needs, CSISS designed programmes to provide infrastructure to help scholars to add spatial context to the prevailing practices, applications and theories of their disciplines. (Janelle and Goodchild, Chapter 2 of this book).

Foundation concepts for spatial thinking are Location, Distance, Network, Neighbourhood and Region, Scale, Spatial Heterogeneity, Spatial Difference, Spatial Dependence and Objects and Fields.

Most of these concepts are also found in the work of famous geographers in education, such as Graves (1984). They are a good basis for developing students' thinking with GIS. In conjunction with the appropriate spatial tools, these concepts provide a basis for designing research, solving problems and structuring education programmes. Figure 15.1 shows a model based on the work of Janelle and Goodchild (2009). Tools and concepts can be used together to develop spatial literacy. If we accept that spatial literacy is indispensable in modern society, along with reading, writing and arithmetic, the question is how education can contribute to spatial literacy. As mentioned before, in the EduGIS programme we need to take steps to further develop the tools, concepts and infrastructure and then make them available. This will be quite a challenge in the next stage of the project, but very important for the successful introduction of this framework in education. After all, the teachers will have to play a crucial role in introducing the above-mentioned elements in the classroom.

**Figure 15.1.** An educational framework for spatial literacy

Critical themes in curriculum

+

Tools and concepts for spatial thinking

+

EduGIS infrastructure programmes

=

Advances in students' spatial literacy
and geographical awareness

## 15.4 Teacher Training

If we look closely at GIS in teacher training, we see that this component is practically absent in many countries. Schleicher and Lawrence (2005, pp. 84–88): "The German teacher-education system does not include GIS education as a basic competence for geography teachers." Neither do teachers in the United States receive sufficient training in the use of GIS in the classroom (Bednarz and Audet, 1999). Fitzpatrick (2001, pp. 85–87) complains about the limited ability of American teachers to use GIS in the classroom: "Mere visualisation is sufficient for most, a definable and achievable objective for teachers whose geography backgrounds are modest, and/or pedagogical vision is fixed." In the US, many commentators say that the teacher training programmes are the proper place to deal with the problem, not only to improving teachers' knowledge of GIS technology, but also their geographical awareness and expertise in the field of geography in education. "This lack of specialist geography teachers means that many teachers have limited pedagogical content knowledge, defined as knowledge about the best way to teach the subject matter. The result is that few teachers assigned to teach geography recognise the potential opportunities GIS offers to teach geography content and skills" (Bednarz and Van der Schee, 2006, pp. 191–205).

Teachers are the gatekeepers of educational changes and educational innovation. It is therefore important to devote time and attention to training teachers in new developments such as GIS (Wallace, 2004). This training must be part of teacher training and the continuing education of current teachers. It should be possible to make "learning to work with GIS in education" a standard element in all geography teacher training courses in the coming years.

Based on his research on GIS use in American high schools, Kerski (2001) concludes that the use of GIS by current teachers will improve significantly if teachers from the same school are trained together. Moreover, school-specific technical preconditions frequently form a stumbling block when introducing GIS into the classroom. Because of these two factors, it is advisable to organise GIS training for teachers in the form of "in company training" programmes at school instead of an individual course at a specialised institute. One way to do this is for regional GIS teams to provide courses for teachers in different schools. Besides continuing education, it is important to provide the teachers with ongoing support, possibly through web-based communities and regional meetings of teachers and academic geographers at colleges and universities.

## 15.5 Research

Following Goodlad, Van den Akker (1996) underlined the difference between ideals in education (the "intended curriculum"), average teaching practice (the "implemented curriculum") and student performance (the "attained curriculum"). Research on learning to think with GIS should focus on the curriculum as implemented by teachers in practice students because the professional competence of the teacher is an important factor (McKenney, et al., 2006). Nonetheless, analyses of practice are not enough. Theoretical development is also needed if more progress is to be made. Many discussions of GIS use in educational situations, in both professional and scientific publications in the field, are enthusiastic descriptions of experiences. Except for a limited number of evaluation studies on GIS use in education, like the ones mentioned above, research on the contribution of GIS to education is scarce. Hardly any experimental research has been conducted on teaching modes with GIS and the effectiveness of teaching with GIS. Baker and Bednarz (2003) consider the lack of research on the effectiveness of GIS use in education to be an important bottleneck. From a study in which they compared lessons with GIS to lessons with paper maps, Baker and White (2003) concluded that the students who participated in the GIS lessons performed significantly better in certain skills, such as data analysis. However, when reflecting upon their research, Baker and White concluded that many questions on the effectiveness of GIS use in education have not yet been answered and that "GIS technology can be an invaluable resource for extending student learning when a proper instructional framework is provided in the content area, along with data analysis and spatial reasoning concepts". The question is what this subject disciplinary framework should look like.

The Centre for Teacher Training, Assessment and Research (CETAR) of the VU University Amsterdam has recently started a study on effective GIS use in geography teaching. One important question is the degree to which GIS use in education contributes to the development of higher thinking skills in general and spatial literacy and geographical awareness in particular. Will students, once they have learned to work with GIS, look for regional variations more easily, more systematically and faster? Does their capacity to perform spatial analyses increase? Do they find it easier to relate spatial data? Do they have a better understanding of how regional diversity leads to different decisions? Such questions can be studied in a development research structure in conjunction with teachers. The effects of working with GIS can be measured through a combination of design and analysis assignments with digital maps, think-aloud assignments, surveys and interviews. Important pillars for this research are geographical knowledge, GIS and "learning to think" strategies.

Besides this research, three studies are needed with a view to the implementation of GIS in education:

- a study on the way in which the GIS applications currently used in education, like EduGIS and ArcVoyager, can be developed into a web based SchoolGIS;
- a study on the development of learning lines for geographical awareness, which includes GIS and fieldwork;
- a study on the way in which activities for learning to work with GIS can be integrated efficiently and effectively into teacher training programmes, because without GIS-wise teachers there will be no GIS-wise students.

## 15.6 GIS and the Future of Geography Teaching

We have seen that for GIS implementation in the Netherlands, a third phase must be defined for the EduGIS programme in which we can place the lessons learned in a model or framework, like the one introduced by Janelle and Goodchild (2009). Critical themes in the social and natural sciences can be analysed using modern tools and concepts for spatial thinking. Students in secondary and higher education should be trained systematically in this. In addition, the relation between learning with GIS, spatial literacy and geographical awareness should be explored further.

In the digital era the world is changing at a rapid pace, driven by modern information technology. This also offers new prospects for education. The computer's capacity to quickly and efficiently process data and respond flexibly to user input enables people to think about the organisation of their living environment at their own pace and in accordance with their own interests. In 1996, at the request of local the authorities, students of Chelsea High School, Massachusetts, USA carried out research into the places in town where hazardous materials were stored. The students first drew up an inventory of the locations where hazardous materials were stored through field research. Using the results, they compiled a risk map and then discussed what could happen in the event of chemical explosions, taking into account variables such as the location of residential areas and hospitals, weather conditions and the amount of traffic. The students coordinated this project with the fire brigade and the Local Emergency Planning Committee in Chelsea (Paul and Hamilton, 2000).

There are similar projects in other countries, sometimes even of an international nature, such as the EU Minerva project Geographical Information Systems Applications for Schools (GISAS). In this project seven schools from Belgium, France, Greece, Hungary, Italy, Latvia and Sweden worked together on water research in the school environment, using GPS and GIS software. The result was a web atlas which in several respects taught students to look beyond borders. Through the internet, the schools could view and ask questions about one another's products. The students learned new techniques in an interdisciplinary setting, in which geography served as a pioneer. Besides, by comparing their own product to that of their peers elsewhere in Europe they learned to see the importance of the regional setting when determining the quality of surface water (Johansson, 2006).

Nowadays more and more teachers are working with Google Earth and Virtual Earth images and interactive boards. Geography could acquire a better position in education if it becomes clear how, with the aid of modern technologies, it analyses the social issues of today and tomorrow. Topics such as urbanisation, land use, water, security and logistics can be visualised much better than before and in an interactive way using modern technology. As long as there are capable teachers to guide this process, such activities will enhance students' "learning to think" capacity. In spatial literate society, just looking at fascinating digital images of the world around us is not enough. With the aid of GIS tools and geographical concepts, spatial literacy can help us to analyse social issues and acquire geographical awareness.

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# Chapter 16
# Synthesis: Geospatial Technology and the Role of Location in Science

**Niels van Manen, Henk J. Scholten, John Stillwell and Rob van de Velde**

## 16.1 Introduction

We now arrive at the end of a special explorative journey. Over the last three years we have been considering the question of what role Geospatial Technology plays in science, given the importance of spatial location not only as the dimension underpinning the discipline of geography, but also because of its relevance and adoption across a range of different disciplines. As Norman M. Bradburn, Assistant Director for Social, Behavioral and Economic Sciences at the National Science Foundation stated in 2004: "We are at the dawn of a revolution in spatially oriented social science." Change in technology within location-based industries has been occurring very rapidly and applications of location-based technology have now become increasingly common in routine, everyday society.

Technological development has meant that people now expect to have immediate access to spatial information that is accurate and reliable. One of the most obvious examples of this is the route navigation technology installed in many vehicles, which uses artificial earth satellite systems, such as global positioning systems (GPS), to determine geographical position. The information about 'where you are' is itself valuable as an indicator of progress when travelling from one place to another, but significant value is added if the software also provides data from other sources that inform the driver of major roadworks or traffic jams in the vicinity, or which is able to compute the shortest route to the destination given certain potential obstacles, so that an expected time of arrival can be ascertained. Thus, through this routing function alone, Geo-ICT is supporting a multitude of decisions taken by vehicle drivers across the world. The value added is beyond doubt and in 2007 the route planner was included in the driving test in the Netherlands.

The original motivation for satellite navigation technology was for military applications, improving precision in the delivery of weapons to targets and thereby

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greatly increasing their lethality while reducing inadvertent (civilian) casualties from misdirected weapons. The transition of the Geospatial Technology from an innovative product to a consumer good has involved different phases and been assisted by other developments. At the end of the 1980s, for example, companies started to digitise road networks with the help of considerable government subsidies. At the beginning of the 1990s, the development of technical equipment gained momentum with the expensive and hard-to-assemble gyroscope being replaced by the GPS. Then, at the onset of the 21st century, companies like TomTom began to market the technology as a product for mass consumption to be found in supermarkets or in retail outlets on the high street.

At the moment, there appears to be a huge demand for products of this type. Those companies that worked on digitising the location data some years ago but never really made any profits have become successful businesses in recent years according to the 'content is king' rule (Tele Atlas, Navtech, CycloMedia). The investment in Geospatial Technology by Nokia shows that its use is not limited to route navigation. Soon, we can expect to have the facility to display maps on all telephones or cell phones and user locations will be identifiable. This leads to new information-related issues, including the ability to track where friends or relatives might be at any moment in time, as well as to find out the locations of points of interest, such as parking spaces, restaurants or shops.

The technology drive with regard to the registration of location data goes hand in hand with the increasing importance of visual information. We are experiencing an explosion of photographic and video materials generated by consumers. By georeferencing this information, which is now automatic in some of the new (2008) digital cameras through an inbuilt GPS, an incredible amount of spatially defined visual material is created that can be accessed through the internet. Thanks to the image-processing industry, satellite images and aerial photos have become available at levels of resolution that were almost unimaginable a decade ago. Using digital photogrammetry, it is possible to make accurately georeferenced panoramic and cycloramic images that are virtual representations of cities and regions on a desktop computer. At the same time, video systems in the form of surveillance cameras and webcam systems are now widely operational along roadsides and in city centres. Image processing methods and Geospatial Technology are therefore reinforcing one another in a variety of different applications at different spatial scales.

It is less easy to identify such clear stories of successful adoption and diffusion of Geospatial Technology in an academic setting. In many ways this should not come as a surprise. In the last half century, social historians and sociologists have demonstrated the complex, yet often slow, dynamic advancement of science, not as the result of brilliant individuals coming up with dramatically new interpretations, but communities of scholars gradually refining their understanding of particular phenomena facilitated by a shared set of assumptions, questions, modes of explanation and platforms of dissemination. Developing and sustaining such an infrastructure ('paradigm' or 'network') involve costly and time-consuming formulation and fine-tuning of theoretical and technological tools, and integrating new members into the community. Therefore, when faced with alternative perspectives (e.g. geographic analysis) and instruments (e.g. geospatial tools), scientists will either seek to incorporate these into their existing frameworks or ignore them altogether. In other words, whereas creativity and flexibility predominate within the framework, methods and tools that are deemed unsuitable will be treated with indifference or scepticism.

## 16.2 Geospatial Technology in Scientific Disciplines: A Synthesis

To establish the status of geographic approaches and Geospatial Technology adoption in science, it is perhaps less appropriate to identify best practice examples than it is to discern general patterns in scholars' attitudes and practices. Do we detect a growing appreciation for space and location among scientists? If so, to what extent is this increasing awareness driven by the introduction of Geo-ICT? If not, why not and by which means should spatial approaches and the use of Geospatial Technology be promoted in academic research and teaching?

### *16.2.1 Spatial Thinking and Geospatial Technology Adoption*

To start logically with the first of these questions, we conclude that all contributors, with the notable exception of Boonstra writing about Geo-ICT use in history, suggest a profound or, at the very least, growing awareness of space in their disciplines. And yet, the degree to which geographical perspectives have diffused within each particular field varies greatly from discipline to discipline. For example, whereas spatial economics is a small subfield in a largely non-geographical discipline, other fields are more 'naturally' inclined towards *where* questions: archaeology, earth science, planning and transportation studies, and, of course, human and physical geography. Outside these spatially-explicit disciplines (a professor in archaeology we spoke to while preparing this book defined his field of study as "the reconstruction of past human behaviour based on the location of their physical remains"), the prominence of geography is very much a matter of academic fashion.

Since the physical environment affects human behaviour in both past and present, there is no obvious reason why historians should be less interested in *where* than in *when*. Although the geographical dimension was for a long time a standard layer of analysis in academic history (particularly in the decades prior to and following the Second World War, under influence of the French Annales School), and although historians continue to study issues with obvious spatial dimensions, the locality of historical events has gradually moved out of sight during the last thirty years. At the same time, demography underwent a transformation in the opposite direction, evolving from a discipline strongly grounded in aspatial theory, concepts and methods to one in which the geographical dimension has gained increasing prominence.

How can we account for such obvious variations? As the case of demography illustrates, the introduction of Geo-ICT has mostly facilitated rather than instigated a ‘spatial turn’. Where scholars are showing a greater interest in the geographical dimension of their discipline, it is generally part of a wider shift towards quantitative methods and more applied lines of research. Such shifts often occur in direct response to developments *outside* academia. For example, subdisciplines of spatial demography and geodemographics emerged in the context of the development of statistical projections, driven by public sector and business demands for more accurate insights into population variations between and within regions. Similarly, the need for quantifiable and geographically precise solutions for traffic congestion in and around urban centres has given rise to an altogether new field of study: transportation science. It is in spatially-explicit, quantitative and application-oriented fields such as these that Geospatial Technology has also been most readily adopted. Although these structural factors may partly account for the general success of the technology in urban and regional planning, risk and disaster management and transport planning (that tick all the boxes), and for its general failure in history and economics (that tick none), they are certainly not ‘laws of nature’.

There are profound differences in the use of Geospatial Technology within disciplines between countries or institutions. A good example of this is the field of criminology. The Netherlands Institute for the Study of Criminality and Law Enforcement (NSCR, *Nederlands Studiecentrum Criminaliteit en Rechtshandhaving*), part of the University of Leiden, has a research team on Mobility and Distribution of Crime, but it does not use Geo-ICT for its spatial analysis. This contrasts sharply with the situation in the United States, where geographical suspect profiling using Geo-ICT is a standard part of criminal investigations (note that this is indeed about the application of scientific methods and Geo-ICT) and the police regularly ask criminologists for help. Besides national differences and contrasting approaches between universities, the variations within faculties can often be significant. Spatial analysis and spatial modelling are important sources of new understanding for researchers at the Department of Regional Economics at VU University. They share a building space with the econometricians, who view location as a factor in their model that must be ‘corrected for’.

Why do some scientists decide to embark on Geospatial Technology, while their colleagues opt for other methods to study similar questions? This was another of the questions that we asked the contributors to this volume to consider. Practically all of them gave a similar response, emphasising the impact of ‘champions’ – prominent scientists who, in their field of study, advocate spatial ways of thinking and use of Geo-ICT. Their contagious enthusiasm attracts a growing number of ‘converts’ (through research guidance: PhD students or research assistants). These individuals encourage colleagues to become ‘champions’ elsewhere (through publications and guest lectures).

### *16.2.2 The Use of Geospatial Technology*

A similar interaction between structural and personal factors can also be discerned in the ways in which the technology is used after adoption. The contributions to this book suggest that no single type of use (geomapping, geomodelling or geodatabase approach) is best suited to any particular discipline. Instead, the applicability of the different approaches depends on the stage of implementation. In many disciplines, Geo-ICT adoption has followed a similar trajectory: initially the systems are primarily used for explorative purposes – plotting data or outcomes on a map to see if otherwise invisible patterns appear (geomapping); once evidence of patterns has been identified, attention shifts from exploration to explanation and efforts focus on analysis (geomodelling); to present the resulting findings in an insightful way, particularly if research is aimed at decision support, increasing importance is attributed to visualisation (geomodelling and geomapping); and, finally, to enhance the validity of the analysis, datasets are extended in size and scope, turning Geo-ICT into a comprehensive research tool (geodatabase, geomodelling and geomapping).

This sequence does *not* apply equally to all fields of study. For example, the fact that some historians use Geo-ICT as a tool for exploration is no guarantee that they will eventually adopt it for other stages of their research, or that others will follow their example. This is partly due to methodological preferences (such as historians' general dislike of quantitative methods and disregard of geographic factors) but is also related to practical obstacles (unlike archaeological remains, where the site is a 'natural' part of the investigation, historical sources tend to be removed from their 'original' location and may contain geographic references, but ones that require careful interpretation in order to be transcribed to recognisable x-y data). Similar obstacles are also encountered in criminology and epidemiology, in which scholars rely on limited datasets (only reported cases of crime and disease are included) with poorly recorded location information.

But even disciplines that neatly follow the stages outlined above, such as spatial planning, do not always turn to Geo-ICT in predictable ways. Following decades of increasingly accurate projections of optimum land use, supported by increasingly sophisticated spatial models, planners have recently been forced to seek alternative methods. With a general shift in political culture away from a 'directive' government and towards more democratic forms of planning, the role of academic planners has shifted from 'decision support' to 'discussion support'. This has also dramatically altered their use of Geo-ICT from a positivist tool of geographic determinism towards a qualitative means to facilitate discussions between different stakeholders involved in the planning process. This 'participatory planning' (see Geertman and Stillwell 2009) has evolved alongside tremendous technological advancement: the development of 'tangi-tables' (tables that work like interactive computers, with touch screens), map tables and 3D virtual reality. Geospatial Technology has not only facilitated a shift in planning methods, but scholars' use of the systems has also stimulated their development in particular directions.

Such interplay between method and technology is typical for the latter stages of implementation. Initially, Geo-ICT is merely used as a tool to automate standard queries, seeking greater speed, accuracy and validity. Where generic software cannot perform conventional analysis, scholars develop their own applications. For example, as proprietary GIS do not contain specific demographic modelling methods, demographers themselves have developed software packages to model migration flows or project populations. Determined to keep the academic community on board, commercial software developers do what they can to incorporate such functionality. ESRI, for example, established an Atmospheric Special Interest Group that assisted in equipping ArcGIS 9.2 with data sharing (NetCDF or Network Common Data Form) and temporal analysis functions. Building on their experience with discipline-specific applications (in this case meteorologists working with atmospheric information systems), scholars make their expertise available to the wider research community, including non-academic users of the software. Moreover, as scientists familiarise themselves with generic systems, they discover attributes that stimulate them to approach their object of study in novel ways. This in turn makes them more attractive as policy-advisors (e.g. archaeologists offering advice on heritage management).

This combination of conventional and novel Geo-ICT use can be clearly discerned in Chunglin Kwa's paper on visual aids for the study and management of ecological systems. On the one hand, despite a shift from aerial photography to remote sensing, ecology is still dominated by the study of 'ecotopes' – the smallest land units in the natural environment, discovered through use of the older technology. As the images produced by remote sensing do not readily show these land units, ecologists have to carry out what Kwa refers to as 'digital enhancement' (colouring essential shapes and filtering out 'unnecessary' detail). On the other hand, the added value of remote sensing goes beyond superior storage capacity. Through animation, researchers can perform what Kwa terms 'reality checks'. For example, seeing changing patterns of algae concentrations allows the ecologist to determine the cause of a certain irregularity (e.g. unexpectedly low concentrations of algae in certain areas) and to decide whether it is a 'real' event or an artefact. Similarly, overlay functions allow criminologists not only to plot certain locations on a map (e.g. the victim's route leading up to the crime scene), but also to switch certain layers of information on and off (e.g. switch off or only show cycling paths), which can aid their understanding of the offender's escape routes.

### 16.2.3 Obstacles for Geospatial Technology Adoption

Besides a general aversion to modern technology (particularly evident among historians), two common misconceptions form the greatest obstacles for Geospatial Technology adoption: the idea that Geo-ICT implies geographical determinism, and the notion of maps as mere 'pretty pictures'. As the examples of participatory planning and ecologists' use of animations to evaluate mathematical findings indicate, such scepticism oversimplifies the potential and actual use of the systems. To focus on the former criticism, although this technology is indeed grounded in the assumption that all objects of study can be affixed to a 'real' location on the earth's surface (x-y coordinates), this does not necessarily result in mere reductionism. In accounting for geographical variation in housing prices, for example, spatial economists have considered the impact of both 'actual' proximity of open space as well as people's 'perceived interpretation' of openness. Although Geo-ICT has been primarily used for statistical analysis, numbers do not necessarily reflect ‘hard’ facts, but can also represent ‘softer’ values.

These examples are important because they suggest that Geo-ICT does not have to remain a symbol of positivism but can actually contribute to bridging the gap between quantitative and qualitative scholarship. This could have important implications for humanities subjects, such as history, that show little interest in geography but much interest in ‘soft’ approaches to space (e.g. the impact of trade and migration on people’s identity). Within history there are indeed more structural attempts to bring the two together, exemplified in joint conferences of socio-economic and cultural historians (Kocka 2003, Burke 2004). As the examples from economics and planning (see above) suggest, if these attempts succeed, this could make the work of historians more interesting to other scientists and non-academic partners alike.

### *16.2.4 The Added Value of Geospatial Technology*

This brings us to the first important value added contribution that follows from the adoption of spatial thinking and the introduction of Geo-ICT: its potential for encouraging the integration of different fields of study. Since the beginning of the 19th century there has been an ever-deepening specialisation within science. The traditional dichotomy between the natural sciences and life sciences has gradually faded and has been replaced by a seemingly uncountable number of disciplines and subdisciplines. This certainly has advantages – with scientists developing an unprecedented amount of expertise in a specific phenomenon – but there are also some drawbacks: the place of specific matters in the bigger picture is lost from sight.

In fact, researchers from different fields of study often focus on common topics: climate change, conflict management, illness and wellbeing, government and authority, demographic development, public participation, etc., but by developing their own technical jargon, this common interest base is lost. In this situation, an argument might be made that the geographical component (present in all these topics) offers the possibility of integrating data and exchanging information (by means of a common framework of ideas, such as spatial concepts).

The same argument also applies to relations between scientists and non-academic professionals. Here Geospatial Technology can have a similarly unifying impact. One good example is the use of a tangi-table, referred to before, around which the people involved in the development of a certain region literally sit. During the discussion, they can directly access the current state of the region (aerial photos), legal provisions (cadastral data on the delimitation of plots, zoning plans, etc.) and possible scenarios (dynamic visualisations). Though this type of geodata integration, modelling and visualisation is visible in some other disciplines as well (traffic and transportation, disaster management and physical geography), most fields of study still have a long way to go. How can the use of spatial methods and concepts be encouraged in these sciences?

### *16.2.5 Strategies for Further Dissemination*

To successfully apply Geo-ICT in research and education, enthusiasm alone is not enough. A first requirement is a digital environment for storing and processing spatial data. However, working with more advanced software requires skills that can only be acquired only through education and experience. The same goes for the use of spatial concepts and analysis methods (GIScience). Next, platforms are needed to exchange research experiences and results (publications, conferences, etc.). In other words, a technological and methodological ‘infrastructure’ is required. This type of infrastructure requires considerable amounts of time and money, as well persuasive powers, which is usually impossible for individual champions to bring about. Only when they join forces with fellow researchers and university administrators, and partners outside the academic community, will they generate sufficient support for investment in establishing centres of excellence.

An international example is the American Center for Spatially Integrated Social Science (CSISS) at the University of Santa Barbara, California. With a multi-million dollar investment from the National Science Foundation, the CSISS has tried to raise the use of spatial methods among social scientists in the US to a higher level through a range of education and research programmes. This included quantitative research on the number of publications with a spatial component (a tripling between 1990 and 2001), publication of two compilations with examples of best practices in the field of spatial analysis (2004) and modelling (2008), and participation by hundreds of young researchers and university teachers in week-long workshops, where they were trained in the use of GIS, cartographic visualisation and spatial statistics. Well known Geo-ICT scientists exchanged their newest methods and applications with colleagues in symposiums and a web portal was developed with links to relevant publications and software.

The actual impact of this initiative will become clear in the future, but the first signs are hopeful: by May 2009 about 40,000 documents had been downloaded from the web portal and the number of applications for workshops amply exceeded the number of available places (706 places and 1,789 applications). Nonetheless, the CSISS chose another format for the follow-up project: spatial@ucsb. Launched in 2007, it focuses on the further integration of spatial ways of thinking and technology within the university itself. This put it more in line with a second example: the Spatial Information Laboratory (SPINlab) at the VU University Amsterdam.

With funding from the Faculties of Economics and Earth Sciences, SPINlab has three main tasks: development and maintenance of spatial tools and data for employees of both faculties; support for existing education and research in the faculties; and the encouragement of innovating research and education university-wide. Within the framework of these tasks, the SPINlab is involved in archaeological fieldwork, it offers a module on health geography and it performs research on improvement of the logistics and security at the Academic Medical Centre (AMC, Amsterdam). It also acts as the academic partner in EduGIS - a state-funded web portal with GIS modules for Dutch secondary schools - and member of UNIGIS international - a network of 16 universities providing distance learning courses to Geo-ICT professionals around the world. As such, the SPINlab is not only a helpdesk for economics and earth sciences, but also a valuable bridge to other faculties and universities and to institutions outside academia.

A similar interplay between government funding, academic outreach and professional and public participation can be found in the UK. As part of a programme in 'eSocial Science', funded by the Economic and Social Research Council (ESRC), scientists at University College London have developed gride-enabled virtual environments within which users are able to link spatial data about cities to GIS software to create *Geographic Virtual Urban Environments* (GeoVUE). GeoVUE will provide decision support for a range of users, from academics and professionals involved in understanding cities to planners and urban designers who require detailed socioeconomic data in plan preparation. It will also offer geographical information to a more general public interested in problems and policies associated with the impact of change in cities. Another section of the programme is based at the University of Leeds, where the objective is to develop representation of the entire UK population as individuals and households, together with a package of *Modelling and Simulation for e-Social Science* (MoSeS) – tools which allow specific social research and policy issues to be addressed.

The recognition and stimulation of leadership – regardless of whether there is only one champion (as in the discipline of history) or a network of prominent scientists (as in spatial economics and spatial planning) – seems to be the decisive factor for the success or failure of Geo-ICT. But what do these leaders have to focus on specifically? First of all, there is a need for a vision: what is the value added of a geographical approach for the specific field of study, and how can this value added be shown in the best possible way? Then, backing must be found for the necessary investments (in time and money): without educational facilities, technological infrastructure and the data infrastructure, it is impossible to raise Geo-ICT use to a higher level. The potential gains are significant. Besides opening up new directions of research and encouraging scientists to contribute to technology development, Geospatial Technology can also held build bridges between academics and non-academic professionals and aid dissemination of scientific findings to a more general audience.

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