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Spatial Decision Support Systems: A coming of age

by

Peter B. Keenan

UCD Business School, University College Dublin
Belfield, Dublin 4, Ireland
e-mail: Peter.Keenan@ucd.ie

Abstract: Decision Support Systems (DDS) have developed to exploit Information Technology (IT) to assist decision-makers in a wide variety of fields. The need to use spatial data in many of these diverse fields has led to increasing interest in the development of Spatial Decision Support Systems (SDSS) based around the Geographic Information System (GIS) technology. The paper examines the relationship between SDSS and GIS and suggests that SDSS is poised for further development owing to improvement in technology and the greater availability of spatial data.

Keywords: Spatial Decision Support Systems, Geographic Information Systems.

1. Introduction

Information Technology (IT) is increasingly ubiquitous in our society, and some of the most powerful applications of IT are in the area of decision-making. From the initial introduction of Decision Support Systems (DSS) some 30 years ago, these systems have evolved to incorporate many developments in IT, such as graphic user interfaces and the Internet. One growing area of IT application is the handling of spatial data, where data with a geographic component is stored, processed and displayed on computer systems. Computer support for spatial applications is provided by systems based on a Geographic (or Geographical) Information System (GIS). There are a variety of definitions of GIS (Maguire, 1991), these generally identify a GIS as a computer system that facilitates the display and storage of geographically or spatially related data and which allows the integration of this data with non-spatial (attribute) data.

As almost every activity has a geographic component, GIS has become important in a wide range of fields, from local government (O'Looney, 2000) and business (Pick, 2005), to transport (Miller & Shaw, 2001) and the environment (Halls, 2001). The need for decision support by specialist decision-makers in these diverse fields has led to increasing interest in the development of Spatial Decision Support Systems (SDSS) based on GIS technology.

The Information Systems (IS) field largely originated in the application of computer technology in business and administrative government applications. Data processing techniques were initially pioneered by government agencies such as the US Census Bureau. Business use of IT started in the 1950s in payroll, billing and invoice processing applications. These early initiatives exploited the "computer" as its name suggested, they were computationally intensive applications driven by the sheer processing speed of the new technology. These early applications allowed tasks to be completed faster, more accurately and more cheaply than ever before. Despite the high relative cost of computing at this time, significant cost reductions could be achieved by this automation of the clerical processes required for the day-to-day operation of business. As the speed of devices increased and the costs decreased, users' interest moved beyond the completion of calculations to the generation of reports. Consequently, the focus moved from computation to information provision. This led to computer technology becoming known as IT and to computer use providing the basis for the field of IS.

Initial reporting applications focused on the faster generation of information that had previously been difficult to obtain. The data available in organizations was initially used to produce regular reports in the form of a Management Information System (MIS). While these reports provided large amounts of information to managers, only professional programmers could modify the reports generated. Because of the difficulty of modifying these early systems, managers found them inflexible. As the limitations of this approach became obvious (Ackoff, 1967), managers wanted more specific information sources that were flexible enough to provide the manager with the precise information required. This desire led to the development of report generator applications, which offered greater convenience and flexibility in the generation of reports.

The introduction of database management systems and improved user interfaces in the 1970s facilitated the introduction of DSS. These systems constitute a flexible user-friendly interface linked to problem databases and specific models. As the name suggests, DSSs aim to support, rather than replace, the decision-maker (Gorry & Scott-Morton, 1971). By the early 1980s there were many books and papers published in the DSS field (Sprague, 1980; Alter, 1980; Bonczek, Holsapple, & Whinston, 1981) and DSS had become a recognised part of IS. DSS largely evolved out of the business data processing tradition and usually dealt with the financial and operating data associated with business use. However, DSS users were likely to be specialists, rather than the general managers that made most use of MIS.

Modern business applications continue to exploit the rapidly increasing computational power of the computer. However, business applications also derive increasing benefits from the ability of IT to store and organise data (databases), distribute the information derived (networking), and present that information in an interactive format (interfaces). The trend towards flexibility and convenience meant that early MIS applications evolved into interactive systems such as Executive Information Systems (EIS), which provide executive management with an overview of business activity within the organisation and of competitive forces on the outside. The focus in EIS is on flexible reporting, which can meet the needs of particular groups of users. In general, EIS does not contain the specialist modelling capabilities of DSS, although some hybrid systems have evolved.

2. Geographic Information Systems

GIS is an area of IT application with a significantly different history from other types of IS (Coppock & Rhind, 1991). Computers began to be used in the late 1950s in North America for the automation of geographic calculations. The calculations required in quantitative geography, such as the calculation of the area of a region with irregular boundaries, were much more complex than in other forms of data processing. Consequently, early developments in GIS exploited the computational ability of the technology (Nagy & Wagle, 1979).

The first large scale project to use a GIS type system was the Canadian Land Inventory (CLI) project in the mid 1960s. This project was a multilayer land-use/planning map that sought to perform a detailed analysis to determine the areas in use or available for such activities as forestry, agriculture, or recreation. The large size of Canada meant that an area of about one million square miles (2.6 million Km^2 was involved. In such a large project, the computational ability of the computer made an important contribution to productivity, in a similar way to the use of data processing in other fields.

Later in the 1960s, there were various projects, notably in Britain, to use computer technology for automated mapping. Initially the attraction of automated mapping lay in the productivity improvements that IT made possible. Computers made easier the storage and editing of maps, in a similar way to word-processing allowing the easier manipulation of text. When these basic functions had been computerised, further gains became evident from the greater flexibility provided by IT. As technology improved, complex maps could be represented on computer screen as well as through output devices, such as plotters.

This period prior to 1970 saw the introduction of many of the basic concepts in GIS, although their widespread implementation awaited further developments in computer technology. The development of sophisticated GIS applications required the introduction of computer systems that had the necessary speed and storage capacity to process queries on the larger quantities of data involved. In the early years of GIS use, the power required could only be provided by expensive mainframe computers, which could not be easily used in a flexible way by end users. While personal computers became useful for many applications in the 1980s, GIS only became feasible on this platform a decade later.

3. Spatial Decision Support Systems

The volumes of data involved with typical DSS applications were relatively small compared with those found in the geographic domain. As computer systems became more powerful, some DSS type applications evolved that used basic map display or incorporated some spatial information. A good example is the Geodata Analysis and Display System (GADS) (Grace, 1977), which was used for routing applications. Nevertheless, the technology it used had limited graphics and inadequate processing power to exploit the full potential of spatial applications.

While these developments in DSS were taking place in the IS community in the 1970s, a largely separate trend of development took place in GIS. Spatial applications had placed heavy demands on the technology, and this slowed the progression from data processing to decision support applications. Nevertheless, improving performance from inexpensive computers has influenced spatial systems in a similar way to the development of other forms of computer processing (Table 1). This included interest in spatial what-if analysis and modelling applications. The idea of a SDSS evolved in the mid 1980s (Armstrong, Densham, & Rushton, 1986), and by the end of the decade SDSS was included in an authoritative review of the GIS field (Densham, 1991). This trend was evident in the launch of a research initiative on SDSS in 1990 by the US National Center for Geographic Information and Analysis (Goodchild & Densham, 1993).

Table 1. Progression of business and geographic IT

IT application	**IS application**	**Spatial application**
Calculation	Data processing	Quantitative geography
General fixed format reporting	Management Information System	Automated mapping
Specialised analysis	DSS	SDSS
General flexible reporting and analysis	EIS	Interactive GIS

Consequently, by the early 1990s SDSS had achieved a recognised place in the GIS community and was identified by Muller (1993) as a growth area in the application of GIS technology. The delay in the recognition of the importance of SDSS, compared to other DSS domains, is a reflection of the greater demands of spatial processing on IT. Nevertheless, despite these developments SDSS does not occupy a central place in the GIS field. An introductory GIS textbook aimed at the geographic disciplines might not mention SDSS at all (Schuurman, 2004), while a recent comprehensive GIS text deals with SDSS in a page or two (Longley, Goodchild, Maguire, & Rhind, 2005). This reflects a feeling among many in the geographic disciplines that SDSS applications involve a diversity of techniques, from different fields, largely outside the geography domain. For instance, Longley, Goodchild et al. (2005) suggest that SDSS is a view of GIS of interest to management scientists and operations researchers.

SDSS have yet to achieve prominence within the DSS research community. Initial reference to SDSS in the mainstream DSS field began in the mid 1990s when initial research in this area began to appear (Wilson, 1994). One of the first GIS related papers in an IS related publication illustrated the effectiveness of SDSS technology (Crossland, Wynne, & Perkins, 1995). While there have been occasional papers in the IS literature dealing with spatial systems, these have been relatively uncommon. This reflects the limited penetration of SDSS in the business and government sectors that are the usual concern of papers in IS. A recent book provides a comprehensive review of the GIS field from an IS and business perspective (Pick, 2005). One chapter in this book reviews the literature on GIS as a tool for business and gives an overview of the literature on the use of GIS for decision-making (Huerta, Navarrete, & Ryan, 2005). Another chapter in the same book reviews SDSS applications in business (Jarupathirun & Zahedi, 2005). This chapter outlines the main results of empirical studies on decision-making using GIS:

- Map users make faster decisions than those using tables
- For a geographic task that does not require examining spatial relationships, using maps is less accurate but provides faster decisions than using tables
- Performance deteriorates as problem size increases, data aggregation is reduced, and data dispersion is increased
- GIS maps perform better than paper maps because GIS tools reduce the load on the human cognitive information process
- Experts are more accurate than novices when using GIS technology to perform geographical tasks
- Education and training are important for the successful implementation of GIS,

4. Characteristics of SDSS

While an increasing number of GIS-based applications are described as SDSS, there is no agreement on what exactly a SDSS constitutes. In part, this reflects some degree of divergence in the definition of DSS in the DSS research community. However, as SDSS bridges two research communities, problems in definition also arise from the separation of GIS research from other DSS related research. Many fields, including the GIS community, have adopted the term DSS with little reference to the DSS field generally. Many widely accepted definitions of DSS identify the need for a combination of database, interface and model components directed at a specific problem (Sprague, 1980). The DSS literature also emphasises the specific nature of DSS applications, which are directed at a specific set of decision-makers rather than a larger set of general users. However, the specific nature of DSS applications means that users of one group of DSS see themselves as having little in common with other forms of DSS and this makes it difficult to achieve a common definition. Consequently, there is ongoing debate about the proper definition of DSS, with continuing ambiguity in the use of this term by academics and especially practitioners. Surveys have shown that many systems described as being DSS generally do not fully meet the definition, while other systems meet the definition of DSS without being described as such (Eom, Lee, Kim, & Somarajan, 1998). In a similar way, the term SDSS is frequently used to describe DSS applications with a simple mapping component, where little or no GIS technology is used. Conversely, other GIS applications could be characterised as SDSS, although the system builders do not describe them as such.

In assessing the role of GIS in decision support, it is useful to look at the exact capabilities of these systems. Modern GIS software comprises a spatial database for the storage of spatially indexed data. It contains a visual interface for the display of this data in the form of maps and this interface can be used to initiate spatial database operations. Consequently, the GIS interface serves as both report generator and a conduit for specifying user information requirements. This dual role complicates the design of GIS interfaces and makes these systems relatively complex to use. Consequently, GIS applications can especially benefit from better designed human-computer interfaces which meet their specific needs (Hearnshaw & Medyckyj-Scott, 1993).

The GIS user has a variety of spatial operations at his or her disposal, such as the ability to identify locations near to each other, locations inside larger regions, and regions that overlap. Modern GIS software provides a series of powerful general commands that allow a vast range of analysis in the hands of a trained user. Nevertheless, however extensive the range of commands found in GIS software, off-the-shelf software is necessarily general in nature. This contrasts with the specific focus that is inherent in the concept of a DSS.

The simplest perspective on the definition of SDSS is that a GIS is implicitly a DSS, as a GIS can be used to support decision-making. This type of informal definition is also used in other fields; Keen (1986) identified a trend for the use of any computer system, by people who make decisions, to be defined as a DSS. Many GIS-based systems are described as DSS on the basis that the GIS assisted in the collection or organisation of data used by the decision-maker. In this context GIS may be have contributed to these decisions, but it is questionable if it can be viewed as a system for supporting decisions. The view of GIS as a DSS typically derives from the perspective of the limited set of users in geography and related fields. For this group, spatial analysis is the focus of their interest; the standard functions of GIS provide the bulk of the information for their decision-making needs. As GIS now embodies a wide range of spatial data and techniques to manipulate that data, users of GIS need significant training to make effective use of the techniques.

A more academic approach is to examine the role of GIS in terms of the definition of DSS. From this perspective, it is possible to argue that a GIS already meets the requirement of being a DSS, as GIS contains an interface, a database and some spatial modelling components. The view of GIS as a DSS has some support in the well-established definitions of DSS. One recognised category of DSS are data-driven systems (Power, 2002), in which the model component is less important; GIS might be regarded as a data-driven DSS. Mennecke (1997) sees SDSS as an easy-to-use subset of GIS, which incorporates facilities for manipulating and analysing spatial data. The view that SDSS is a subset of GIS reflects the need for decision-makers to focus on their specific problem, and their lack of interest in GIS features outside this domain. This view suggests that the techniques needed for SDSS are already within the GIS domain and that a subset of these techniques can be applied to a particular problem. As the features of a standard GIS are directed at the needs of its traditional users, this group is most likely to subscribe to the view of SDSS as being merely a subset of the larger GIS field.

An important limitation of this perspective, of GIS as a DSS, is that the ultimate potential for SDSS use greatly exceeds this set of traditional users. The wide range of techniques from operations research, accounting, marketing, etc., needed for this broader set of users is unlikely ever to be included in standard GIS software. Nor are users in this broader community ever likely to have extensive training in spatial techniques. In general, this broader set of SDSS users are not interested in a detailed understanding of the full range of spatial techniques in modern GIS software, they are concerned only with the understanding required for their own exact needs.

The view of SDSS as a subset of DSS is commonly held among traditional GIS users. However, others within this community perceive the opposite relationship, that GIS (and spatial techniques) are just one component of a DSS. In a relatively early paper, Honea (1990) argues for a focus on decisions rather than technology and emphasises that GIS should be seen as just one component of a DSS.

Some authors in the GIS field have looked to the classic definitions of DSS (Keen & Scott-Morton, 1978; Sprague, 1980) and found that GIS lacks the modelling component needed to be accepted as a DSS (Armstrong & Densham, 1990). From this viewpoint, SDSS requires the addition of modelling techniques not found in basic GIS software. This position sees SDSS, not as a subset of GIS, but as a superset formed by the intersection of GIS and other techniques. This point of view seems to this author to be the most flexible one, where GIS is regarded as a form of DSS generator (Sprague, 1980) to which models can be added to made a specific DSS (Keenan, 1996). A SDSS therefore contains specific decision models, which use the general spatial capabilities of the GIS (Table 2).

For the purposes of this paper, we define a DSS as a specific system designed for a specialist user familiar with the decision and the modelling aspects of the specific problem. Barbosa and Hirko (1980) suggested that DSS required: a convenient interface, support for a spectrum of control of the system, flexibility

Table 2. Relationship between GIS, DSS and SDSS

GIS	**DSS**	**SDSS**
Concerned with spatial data	Can be in any problem domain	In problem domain with spatial component
General purpose tool	Specialised software	Specialised software
Sophisticated interface (typically)	Sophisticated interface (typically)	Sophisticated interface (typically)
Spatial Database	Database	Database with spatial component
General spatial data handling models	Specific decision models	Specific decision models making use of general spatial data models

in the use of automated and manual operations and that it should provide feedback on the operation of the decision-making procedures. Consequently, a DSS is not a "black box", instead it provides a system that can be effectively manipulated by the user for a specific decision-making process that is well understood by that user. This has important implications for SDSS design, as SDSS users come from different backgrounds with different requirements. Those from a geography background have a good knowledge of the data and models underlying the GIS and are generally concerned with activities that predominately use these types of models. Such users will expect to be able to exert effective control over the specialised spatial models in the GIS. This type of user is most likely to see a GIS, perhaps with some customised macros, as constituting a SDSS.

Where spatial information is only one component of a more complex decision-making process, the users may have less interest in the purely geographic issues in the system. For this class of decision-makers, the aim of the system builder must be to cater for the problem representation of the user, the logical view of the problem, rather than provide a system too closely related to the physical characteristics of the data. Different users should have problem specific system representations and operations, in similar way to the concept of subschemas providing a distinctive presentation of a database to a user. A specialised user will only be interested in the ability of the GIS to support their decision and the full range of spatial operations associated with GIS need not be made available. Different users of a given type of information may be accustomed to quite different presentation formats for that information. The need to accommodate this diversity of user requirement places important demands on the design of the components of the SDSS, not only the interface, but also the database and modelling components (Grimshaw, Mott, & Roberts, 1997). Flexibility is a key requirement of the GIS software used to build specific system of this type, as interaction with other software is needed to extend the GIS for the specific problem.

In this view of SDSS, the GIS is an important component of the system, but further specialised models and systems are added to build a system that is focussed on the specific needs of a specialised decision-maker. Consequently, a successful SDSS must be based on GIS software that gives system builders the flexibility to accommodate user preferences and facilitates the form of interaction with which users are most comfortable. The result will be a system that allows the user to interact with models that represent the decision; these models may make indirect use of spatial operations (Table 3). Users must work with the level of detail appropriate to their decision; the user need not be familiar with processing issues that lie below the decision-making level. A spatially trained user of GIS may know nothing of the computer science techniques of indexing, sorting, and searching that underpin the system. The GIS user assumes that computer scientists have devised appropriate techniques to ensure that algorithms are numerically stable and that calculations will provide the correct answer. In a similar way, a user of a specialised SDSS may not be concerned with the full complexity of geographic information science techniques. The SDSS user assumes that the SDSS builder has implemented the models using appropriate spatial handling techniques. This means that the SDSS builder plays a critical role in understanding of both the specific needs of the decision-maker and the strengths and limitations of GIS.

4.1. Building SDSS

Several categories of GIS software exist. Traditionally, at the top end large powerful packages were used which were capable of dealing with large amounts of data, for example the ESRI ArcInfo software. This powerful software is typically employed for building large datasets. This type of GIS traditionally required specialised workstations and was not always easy to use for decision-making purposes. Modern versions of this type of software are more flexible and can be more easily integrated with other applications. Below this level there are a number of user-friendly desktop software applications, for instance ESRI Arcview (ESRI) or Mapinfo (Mapinfo), which are more often associated with decision-making applications. As desktop machines increased in performance, such machines have acquired the capacity to deal with large amounts of data. Consequently, each new version of desktop GIS software has introduced additional features and improved interface design, making these applications accessible to an increasing set of users. Those users who find GIS software directly applicable to their decision-making needs will typically use only a few of the many additional features on offer, reflecting the viewpoint of SDSS as a subset of GIS. Mapping software, for example Microsoft Mappoint (*http://www.mappoint.com*), is less sophisticated than desktop GIS software. However, this software provides increasing functionality and may develop further to a level that makes it suitable for building SDSS.

Table 3. Specialised SDSS analysis based on generic GIS

GIS feature	**Generic GIS analysis**	**Specialised SDSS analysis**
Measurement	Distance between two points	Which is the nearest branch to a customer? How far are we from a water source for firefighting?
	Slope	What might be the rate of flow from a chemical spillage? What is the risk of landslide?
Buffer	Band along network feature	How many people are at risk from hazardous waste shipments on a main highway? What farms can conveniently supply fresh milk? What houses are at increased risk of burglary?
	Zone around polygon	Who lives in a region with increased risk of flooding near lake? Which areas do we need to patrol around a security facility?
Overlay	Point in Polygon	Which branch should service a customer? How many facilities do we have in an administrative area?
	Polygon overlay	What service regions can be rationalised of service regions after a corporate merger? Which property owners are affected by a new development?

Early applications of GIS were often concerned with building datasets and typically involved a limited set of potential users such as geographers or surveyors. When these digital spatial datasets had been compiled, they then became available to the much more diverse set of users who wanted to use such data. Consequently, GIS vendors began to recognise the importance of making their software flexible and customisable to the needs of this larger set of potential customers. From the late 1980s vendors added customisation facilities to their products; these used proprietary standards, in the absence of well-established standards at that time. As systems evolved, vendors began to emphasise the modularity of their products. A modular approach meant that different parts of the system could be used as required by the different groups of potential users. This has now led to the situation where many of the off-the-shelf products are simply one of many possible configurations of the underlying tools with which the software is built.

SDSS builders, either third parties or the users themselves, require the flexibility to provide customised configurations directed at supporting specific decisions. This requires that GIS vendors expose details of the system functionality by creating and documenting a set of Application Programming Interfaces (APIs). Where products are modular in nature, the API can allow the system builder interact with the various parts of the system. Modern software is typically built using the Object Oriented (OO) programming paradigm, and often developed using OO tools such as the Java or C++ programming languages. Frameworks such as The Object Management Group's (OMG) Common Object Request Broker Architecture (CORBA) form a basis for the technical standards for interchange between software using the OO approach. In addition to general developments in the software field, the Open Geospatial Consortium (OGC) (*http://www.opengeospatial.org*) aims to define a comprehensive set of open interface specifications to enable developers to write interoperable components to provide access to heterogeneous geodata and geoprocessing resources in a networked environment. As SDSS requires a combination of GIS and other software, these types of standardisation initiatives have an important role to play in facilitating SDSS development.

The GIS vendors are moving their products towards commonly recognised standards. For example ESRI, the largest GIS vendor, has discontinued its proprietary scripting language, Avenue, and has moved its products to a Visual Basic for Applications (VBA) based scripting language. All vendors provide products that support popular software interchange standards such as Object Linking and Embedding (OLE). Vendor software typically provides an API for integration with Java, C++ and Microsoft Net. Adherence to these industry standards has facilitated third party developers in producing a range of specialist add-ons for GIS products. For instance, add-ons for ESRI products include tools for mapping crime, for managing electricity grids, for planning new road developments and for dispatching fire engines.

Another technical development of interest is the extension of GIS techniques to the Internet. Internet standards have some limitations for use in spatial applications, but new software and plugins continue to be developed. A variety of current applications offer map display, but frequently fall short of providing comprehensive GIS functionality. Nevertheless, services such as Mapquest (*http://www.mapquest.com*) or GoogleMaps (*http://maps.google.com*) illustrate how mapping can be delivered in a usable way over the Internet. Google Maps offers an API that allows developers embed Google Maps in their own web pages. There is growing interest in the concept of online GIServices, which allow users access data sets from remote geodata repositories (Tao, 2001). SDSS applications typically involve the use of a large data set to produce a much smaller set of output, a scenario well suited to a client/server model (Coddington, Hawick, & James, 1999).

In a review of Internet SDSS, Rinner (2003) found that many systems fell short of the definition of a DSS, but suggests that public participation SDSS are a potentially important category. Environmental and planning applications frequently require input from a range of sources and Internet-based systems provide a mechanism for doing this. For instance, publicly available systems delivered over the web could allow people model the implications of proposed developments (Sikder & Gangopadhyay, 2002). Future developments offer the possibility of a distributed SDSS that could connect with datasets held at distant locations on the Internet. In this scenario, multiple specific SDSS applications might use the Internet to share the geographic data that they have in common. In principle, all geographic data could be stored in a logically linked database, a geolibrary (Goodchild, 1998), although in practice the data might be physically distributed. Such data could be made available over the Internet for use by a wide range of users with the use of appropriate software standards and with an appropriate charging mechanism.

5. SDSS implementation

Many of the issues arising in SDSS implementation also arise with other categories of DSS. However, the distinct characteristics of SDSS also present several potential problems. The data required in spatial systems is typically a combination of general data on the geography of regions and specific data related to the area of decision-making. The general data is typically outsourced outside the organisation using it; this is less common in the general DSS field. Digital spatial data is now available for developed countries; its cost and pricing structure can have an important influence on the development of GIS applications, including SDSS (Tomlinson, 2003). Specific data must be collected for use in the system and properly integrated with the general data. For example, the spatial location of customers might be derived from their addresses (geocoding) or from direct data capture techniques such as a Global Positioning System (GPS) located on vehicles visiting these customers.

The correct handling of data is one example of the importance of the need for the DSS builder to understand the specific problem, while also having some spatial training. The user of the SDSS is operating at the decision level of problem, for example trying to improve customer service or make the logistics function more efficient. The end user of an SDSS is not directly concerned with spatial techniques. The DSS builder has to build a system that allows the user control over the decision process by interacting with the models or the customised version of the system; these in turn should take care of spatial data handling as much as possible. The DSS builder needs a skill set that includes understanding of the operation of GIS, together with an appreciation of the decision being made by the end user. This combination of skills is not always readily available. Courses in business, IS or DSS rarely include any significant amount of GIS. On the other hand, people trained in GIS are frequently happier to work on the technical level rather than deal with business issues (Longley et al., 2005).

The importance of the availability of spatial data to SDSS has implications for the growth of spatial decision-making. In sectors where spatial data has long been used, users will continue to see scope for further applications of this data; this will include applications that require extending GIS to give better decision support for specific problems. Consequently, systems will continue to emerge in traditional areas of GIS application such as forestry or planning (Chakroun & Benie, 2005).

Other areas where DSS applications are well established are accustomed to working with limited representations of spatial data. Network analysis applications such as routing or location analysis are a good example of this. Traditionally, DSS in these areas used mathematical models with representations of roads or power networks, in isolation from the surrounding geographical data. The combination of these techniques with GIS can provide a SDSS with a much richer representation of the problem (Keenan, 1998).

GIS is seen as having a growing importance in areas such as business that are outside the traditional spatial disciplines (Pick, 2005). Consequently, a much wider range of organisations include spatial references in their data. Many of these are in sectors that would be long established users of other forms of IT. In such organisations, awareness will increase of the possibility of building SDSS applications directed at specific decision requirements. One example is the insurance sector, where decision-makers have been accustomed to using statistical and actuarial models, but have not tended to use information on the location of their customers. As insurance risks are often strongly spatially correlated, this sector needs to make more use of spatial techniques in the future (Morton, 2002). As insurance risk is driven by natural events such as weather, for example storms (Li, Wang, & Wang, 2005), this is an obvious area of application of SDSS. Software vendors are aware of the market for GIS related risk management software and are moving to provide solutions for this market (Francica, 2003).

Other recent developments in business such as the growth of Electronic Commerce (E-Commerce) (Kalakota & Whinston, 1997) also provide opportunities for the use of spatial systems. Although the Internet is available throughout the world, the location of customers is of importance in the services offered in many E-Commerce applications. Many consumer E-Commerce applications offer goods that must be delivered to the customer. This mode of doing business requires a sophisticated delivery operation and SDSS techniques have an important role to play in the management of this function.

Mobile computing and telecommunications is an emerging area of IT application that is of increasing interest to business (Mennecke & Strader, 2003). GIS-based systems are widely used for operational activities by mobile and broadband wireless service providers for modelling service levels and locating signal masts (Scheibe, Carstensen Jr., Rakes, & Rees, 2006). Mobile services can be largely distinguished from fixed Internet services by the presence of a locational element (MacKintosh, Keen, & Heikkonen, 2001). Mobile services can be divided into mobile commerce and Location-Based Services (LBS) (Mitchell & Whitmore, 2003). LBS applications require the integration of wireless technology with GIS applications (Francica, 2005). A typical LBS application might be providing support for a mobile user to locate a facility of interest. For example, a traveller might want to find a nearby restaurant or bank. This type of application can be characterised as a mobile SDSS. The limitations of mobile technology mean that the user of a portable device cannot easily avail of the full functionality of GIS. However, the limitations of mobile devices do not prevent very specific decision support from being provided. A mobile SDSS might be based on models extracting the appropriate information from the GIS and presenting it to the user in a representation convenient for their specific purpose, which can be provided within the limitations of the devices used. These services are likely of to be of interest to a large number of people. Jarupathirun and Zahedi (2005) suggest that Internet and mobile spatial applications will be of interest to more people than workstation and desktop applications.

6. Future diresctions for SDSS

This author suggests, therefore, that SDSS development in the future will predominately use relatively complex combinations of GIS and other forms of DSS tools. SDSS will support a wide range of problems and users, with quite different systems being used in each situation. Spatial applications have largely been used in the past for problems where the manipulation of spatial data was the key or only information component of the decision to be taken. This type of decision required a system that provided users with full control over the spatial operations in the system. The group of users will continue to use these systems and will be able to exploit technology driven enhancements in the capability of GIS.

In the future, traditional SDSS applications will be extended to the large number of potential applications where the spatial information is only an interim stage or a subset of the information required for the decision. This will require the construction of systems where users can concentrate on the variables of interest to their decision, while other processing is performed without the need for extensive user interaction. These systems will incorporate research and techniques from fields quite separate from the traditional geography-based disciplines that initially used SDSS. This may lead to some fragmentation of the SDSS field, a trend long noted in the DSS field generally. Such a trend will increase the sense of separation between SDSS and the disciplines that pioneered the development of GIS. This reflects similar trends in other decision-making systems where systems draw from fields such as computer science or operations research. Decision-making applications exploit a synthesis of techniques, without necessarily representing a new breakthrough in the fundamental reference disciplines. Research work continues in developing new models for these reference disciplines; in the future these developments may be incorporated into decision-making systems. The separation of fundamental principles from applications, in this case the separation of Geographic Information Science from spatial applications, allows a focus on user-oriented systems. This will allow new classes of decision and new types of user to be effectively supported.

As the market grows, GIS software will become less expensive and easier to use and will continue to be used directly for decision-making by those in the traditional geo-spatial disciplines. Better integration of models and GIS will extend SDSS applications to a range of applications where DSS is already important, but where GIS has not played a full role in the past. Examples of this would include routing and location problems, which have a long tradition of the use of mathematical techniques. It has long been recognised that these techniques can be greatly enhanced when coupled with the spatial interface and database processing found in GIS software, but this integration still has some way to go. The increased availability of user-friendly SDSS will allow other less technical business disciplines such as marketing to start to exploit spatial modelling for the first time (Viswanathan, 2005). This will allow exploration of the spatial component of business relationships, which rarely takes place at present.

A number of potential directions can be identified when looking at the future prospects for SDSS development. Improvements in standard GIS software might increase the range of people who could easily use it directly for decision-making. Superior customisation features in GIS software might allow easier modification of GIS for specific decisions. Enhanced features for interaction with other software might allow GIS be readily extended to form a large variety of SDSS applications. Future developments are likely to encompass all of these trends, with different groups of users taking advantage of these changes.

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