1. INTRODUCTION

Decision Support Systems (DSS) are recognised as being an important category of the information systems (IS) research, for example surveys of IS research have shown DSS to be an important theme (Teng and Galletta 1990). In almost three decades since the publication of early work in the field (Gorry and Scott-Morton 1971), the DSS field has built up a considerable body of academic research and practical applications. While there is some disagreement as whether this work has provided a cumulative research tradition (Eom, Lee et al. 1993) there is nevertheless a recognisable DSS field. This is reflected in publications and conferences associated with DSS. While there are many definitions of a DSS, there is general agreement that these systems focus on specific decisions and on supporting rather than replacing the user's decision-making processes. Definitions of DSS also emphasise the need to support semi-structured and unstructured decisions. There is a consensus in the generally accepted definitions of DSS that identifies interface, database and model components, as being required to support decisions. These components must be integrated into a comprehensive system; a collection of discrete software tools may assist in decision making, but do not constitute a DSS. As technology changes, the potential for decision support increases and the effective employment of new technologies allows the DSS field advance.

The traditional DSS field largely evolved from business data processing and general purpose management information systems (MIS), which were used to process relatively straightforward numeric and text data. Such systems produce many different types of standard report by processing data using relatively simple models, which were pre-programmed into the system and not easily controlled by the user. DSS was seen as providing a system more focused on one specific problem area where the user had greater control over the operation of the system. The DSS user was expected to have sufficient expertise, in their own domain, to interact effectively with the DSS. Historically the greatest complexity in such systems usually lay in the problem specific models; the typical skilled user would be expected to be familiar with these. Many of the systems described as being DSS were in fact management science models with relatively simplistic database and
interface components. Systems developed in the past, given the limitations of the available technology, were economical in the degree of the decision support provided. Many of the indirect influences on decision making were not supported by the computerised system. Such systems concentrated on the direct information needs of the decision maker, but lacked the capacity to represent fully the broader information needed to represent fully the context in which decisions were made. The restricted range of decision criteria modelled by such systems posed problems for their acceptance, as users were unwilling to accommodate the gaps in the decision support provided by the DSS.

Alter (1980) proposed an influential taxonomy for DSS which describes a number of systems which differ in the relative importance of the database and solver components. This approach recognises that different uses have different decision needs, with consequent differences in the requirements of a system designed to support their decision making. The modelling component of DSS, the solver, directly exploits the powerful computational ability of the computer. This computational ability may be utilised for the calculation of values that directly affect the decision. In many examples of model driven DSS, this computational ability greatly extends the capabilities of the decision maker. However, the quantitative data generated by the solver may also be indirectly used to facilitate decision making. This information may be used to provide the decision maker with information that can then be integrated with other non quantitative information to help the system user reach a better quality decision. The database component of the DSS provides data for use by the modelling components of the system. In a fully integrated DSS, the solver routines will be closely linked to the database, allowing their operation without unnecessary user intervention. The database component plays an important role in allowing the user a direct opportunity to explore the data relevant to the problem. For those systems falling into the data driven DSS category identified by Alter (1980), this is the most important contribution of the system to decision making. The interface component has a role to play in allowing control of the database and the modelling components of the system. However, it also provides a representation of the problem, allowing the user easily assimilate the information contained in the database and more easily to understand the output of the quantitative procedures.

In order to provide comprehensive decision support, a DSS must fully integrate these components and allow the user easily direct their use towards a specific decision making situation. For a given decision there will be essential data of direct interest to the decision maker and transformations of this data that are directly relevant to the decision making process. However, other elements in the DSS will provide indirect support, providing data that is indirectly used to calculate variables of interest. The absence of such tangentially relevant information may not prevent an adequate decision being made, but its presence will improve the quality of the decision. In a sophisticated DSS, there exists database information, modelling transformations and interface representations that make a partial contribution to the decision making process. It is desirable that these be included in a DSS, although a useful system could exist without them. For instance, in a production planning DSS the variables of direct interest to the decision maker might be the quantities produced and the costs of production. A variety of interim calculations would be needed to derive these final values. A production planner might not be very interested in the detail of these interim calculations, but a management accountant might value detailed access to this information. Information about the pattern of production, provided by the DSS, would be of interest to the production planner and might be used to improve the quality of the decision. In a problem solving situation, specific variables are manipulated within a more general context, a comprehensive DSS should allow this environmental context inform all of the components of the DSS. Data on the context should be contained in the database, it should be processed where appropriate by the models and it should be represented in the user interface to the extent required by the user. Different users of a given class of DSS will favour different problem representations and will perceive differently the degree to which information is directly or indirectly relevant.
2. USING GIS FOR DECISION SUPPORT

Developments in other fields are relevant to the growth of DSS. One such influence is the considerable growth in the importance of geographic information systems (GIS). GIS has its origins in the fragmented use of computer technology in the 1960s for automated cartography and address matching software. The original GIS applications were of interest to geographers and those in related disciplines. While this represents quite a different constituency to that of the typical users of information systems in that period, both groups had a need to process large amounts of comparatively routine data. However, geographic data is much more complex than the routine accounting data typically found in early information systems applications. Therefore, the development of comprehensive GIS software required improvements in graphics and database techniques. By the 1980s a number of different forms of commercial GIS software became available generally based on the use of UNIX workstations. At the end of the 1980s, PC based GIS software become available; reflecting the increase in PC performance to levels previously associated with workstations.

Many areas of DSS application are concerned with geographic data, including one influential early example of a DSS, the GADS system (Grace 1977). The display of maps has been a feature of DSS and researchers have noted that computer technology can greatly facilitate the use of mapping data (Ives 1982). However, the technical limitations imposed on early systems meant a restricted use of spatial information which falls far short of the potential of modern GIS. There has been limited impact by mainstream GIS techniques on DSS research. GIS techniques are beginning to have an impact on DSS applications. Surveys of DSS applications (Eom, Lee et al. 1993; Eom, Lee et al. 1998) identified marketing and routing as important areas of DSS application. These fields are also recognised as areas of GIS application (Maguire 1991). In the area of routing Bodin, identified in the survey by Eom, Lee and Kim (1993) as an important author in routing DSS, has argued for incorporation of GIS in routing (Bodin and Levy 1994). Keenan (1998a) has argued for the use of SDSS for routing problems. Demographic data is widely available in a suitable format for use in GIS software. This has lead to the development of a number of specialised GIS products, for example the marketing GIS products from Tactician Corp., or the TransCad GIS that is aimed at routing and transportation applications.

Within the GIS field there is increasing interest in the use of GIS software to provide decision support. This is reflected in the increasing appearance of papers referring to spatial decision support systems (SDSS) at GIS conferences. While an increasing number of GIS based applications are described as being DSS, these descriptions suffer from a lack of agreement on what exactly a DSS actually constitutes. As Maguire (1991) points out, some authors have argued that a GIS is a DSS. In some cases, GIS applications are described as being DSS without reference to the DSS literature. Many GIS based systems are described as being DSS on the basis that the GIS assisted in the collection or organisation of data used by the decision-maker. This may be a reflection of the trend identified by Keen (1986) for the use of any computer system, by people who make decisions, to be defined as a DSS. However, other authors justify GIS being regarded as DSS in terms of the definition of DSS. Mennecke (1997) sees SDSS as being an easy to use subset of GIS, which incorporates facilities for manipulating and analysing spatial data. These differences of definition reflect the differing needs of decision-makers that use spatial information. For many of the current SDSS applications, the main information requirement of the decision-makers is for relatively structured spatial information. This group may indeed find that standard GIS software provides for their decision-making needs.

The DSS literature incorporates many definitions of DSS (Mallach 1994 pages 5-7). Many widely accepted definitions of DSS identify the need for a combination of database, interface and model components directed at a specific problem. In terms of these definitions a GIS would not be regarded as a DSS as it lacks support for the use of problem specific models. However, the view of GIS as a DSS is not entirely without support in the existing definitions of DSS. Alter (1980) proposed an influential framework for DSS which includes data driven DSS that do not have a
substantial model component. Standard GIS software could be regarded as an analysis information system in Alter's framework, the critical component of such a system being the database component. Common to all definitions of DSS is a sense that these systems must support a particular type of decision. This characteristic distinguishes DSS from general purpose management information systems (MIS). While GIS applications may contain the information relevant to a decision, they are usually general purpose systems, not focused on a particular decision. For some decisions, where the standard features of a GIS provide the information essential to the decision maker, a GIS may indeed be a DSS. However, for the wider user community of potential SDSS users, a GIS can be regarded as the starting point for building a DSS.

3. BUILDING SDSS FROM GIS

SDSS can therefore be seen as an important subset of DSS, incorporating GIS techniques with other modelling approaches, whose potential for rapid growth has been facilitated by technical developments. The availability of appropriate inexpensive technology for manipulating spatial data enables the creation of SDSS applications. The benefits of using GIS based systems for decision making are increasingly recognised. In a review of GIS, Muller (1993) identified SDSS as a growth area in the application of GIS technology. However, the value of SDSS is not determined by its innovative use of technology. Instead, the contribution of these applications will be determined by how well they support the need for a spatial component in decision making. Because of the variety of decision-making situations where spatial information is of importance, clearly SDSS will be an increasingly important subset of DSS in the future. It is useful to examine the relationship of GIS software to such systems. Densham (1991) discusses the development of DSS in the context of the framework proposed by Sprague (1980)(Figure 1). In Sprague's framework, a DSS may be built from tools, individual software components that can be combined to form a DSS. These would include programming languages, programming libraries and small specialised applications. At a higher level in Sprague's framework are DSS generators, from which a specific DSS can be quickly built. Generators may be built from lower level tools. Sprague envisioned that different specific DSS applications would require different combinations of the generator and tools. Sprague used GADS (Grace 1977), which can be regarded as a form of GIS, as an example of a DSS generator.

In building DSS, specific generators have been designed for certain classes of problem. In other situations general-purpose software such as spreadsheets or DBMS packages have been regarded as generators. In modern DBMS and spreadsheet software, the use of macro and programming languages facilitates the creation of specific applications. Various generators have strengths and weaknesses in terms of their provision of the essential components of a DSS: an interface, a database, and models. In the case of a spreadsheet, modelling is the basic function of the software; various interface features such as graphs are provided, but the database organisation is simplistic. DBMS software, such as Access or Paradox, has good database support, provision for interface design using forms, report and charts, but almost no modelling support. In this case, the modelling support has to be added to the specific DSS built from such a system.

In Sprague’s framework, the SDSS builder may make use of tools, which provide some, lower level data processing. In software design these might include operations such as sorting or searching which are important algorithms in their own right but which are not of direct interest to the decision maker. The decision regarding the appropriate mix of DSS tools and the use of a generator is an important component of the process of building a DSS. However, the design of a DSS is likely to be strongly influenced by the availability of DSS generators for that class of problem. The DSS solutions actually constructed are strongly influenced by the perceived availability of suitable generators. Consequently, the effective application of DSS technology can benefit from additional generator software becoming available. Awareness of the potential of the use of GIS based systems as DSS generators will lead to problems, currently being solved in other ways, being approached by using a SDSS.
GIS can be distinguished from other forms of information system by the distinctive data stored and processed by such systems. Geographic data comprises three fundamental spatial structures, points, arcs and polygons. Each of these can have conventional non spatial or attribute data associated with it. The characteristic nature of SDSS is determined by components that store and allow manipulation of these forms of spatial data. Many problems of interest to decision makers use spatial data. For SDSS techniques to be of interest, real world problems need only have a spatial component in one aspect of the decision making. While important elements of the decision process may use only non-spatial (attribute) data in the SDSS, the spatial operations may have an important role to play. For example, the data set to be used for the non spatially based modelling process may be identified by spatial operations. For example, spatial analysis may determine the number of potential customers for a new retail outlet; this could provide data for use in a financial model. The decision maker is concerned with financial data; the spatial component of the system provides a model of the real world context in which the financial planning is taking place. Conversely, the outcome of a non-spatial model may identify spatial operations that need to be performed. For instance, a vehicle routing algorithm may produce truck routes; spatial techniques could then identify the areas affected by noise resulting from the increased traffic. Vehicle routing, a well-established area of DSS research, is a good example of the potential for SDSS. Routing problems routinely employ data on points and arcs and SDSS would facilitate an extension of these problems to more advanced ones which also consider polygon data (Keenan 1997). Users of systems such as routing DSS, unlike more traditional GIS users, have no direct interest in the basic spatial processing techniques. This type of user is focused on the information needs of the routing process and requires that the system facilitate the provision of this information, by automating much of the spatial processing required.

In DSS applications, the focus of the decision-maker is on the decision being made. The output from the DSS is of interest only to the extent that it facilitates decision making. The DSS user wants to make use of the DSS to explore aspects of the decision. This should not require the user to go through long sequences of commands, to enable data move between different modules of the system. It is central to the design of DSS that the modelling routines can automatically extract the
relevant data from the database component of the system. In a DSS, the user should only need to intervene in the system to direct the modelling process; not to conduct the basic operations needed for modelling. In a SDSS the models must be able to make use of the spatial database tools as appropriate. This requires that the SDSS be built with modelling tools that allow the model designer access to the database and interface components of the SDSS. In order to be used as a DSS generator, GIS software must allow easy automatic interchange of data between the GIS modules and modelling techniques operating on non-spatial elements of the data. This may entail a departure from traditional assumptions in GIS design of the user operating the system by direct manipulation of interface commands. If it is to be used as a SDSS generator, then GIS software must make data available in a format that is appropriate for modelling techniques drawn from other disciplines. This lack of integration hinders comprehensive use of GIS as a SDSS generator for a variety of problems that use geographic data.

As standard GIS software may lack the problem specific models needed for SDSS applications, its role can be seen as a software component, which may be used to build a SDSS. In assessing the suitability of GIS software for building SDSS, two major issues arise. Firstly, can GIS be effectively integrated with other software to build a complete system? GIS used in conjunction with other software may aid decision-making, but not constitute a DSS. A complete system providing full decision support requires that models and data can interact within the system. User intervention is needed to alter modelling parameters that affect the decision; such intervention should not be needed to link the modelling and data components of the system. The second issue is whether systems can be built more easily using GIS as a DSS generator rather than by using alternative approaches. The use of software that simplifies system development, enables a DSS system builder spend time designing features which directly support the decision being made, rather than having to spend a lot of time attempting to understand the tools or generators being used. Current trends in software development allow the integration of distinct software components and facilitate the use of modelling components with GIS software (Keenan 1998b). These features allow data to pass between the modelling, interface and data components of the GIS. More importantly, they also allow control over the operation of these elements.

An important group of SDSS users is those in the traditional areas of application of GIS, in disciplines such as geology, forestry, and land planning. In these fields GIS was initially used as a means of speeding up the processing of spatial data, for the completion of activities that contribute directly to productivity. In this context, the automated production of maps, in these disciplines, has a role similar to that of data processing in business. In these subject areas, there will be growth of decision-making applications in much the same way as data processing applications evolved into DSS in traditional business applications. An example of this type of application is the DSS for the assessment of geological risk by Mejia-Navarro (1995). This group is distinguished by a direct interest in the spatial operations provided by the SDSS and considerable background knowledge of the spatial techniques used. For this category of users, the spatial data and the spatial processing techniques are of direct interest rather than simply providing the context in which other variables are being manipulated.

The greater complexity of spatial information processing and its greater demands on information technology have lead to the ten to fifteen year time lag identified by Densham (1991). As information technology costs decline, inexpensive personal computers can now cope with the demands imposed by the manipulation of spatial data. The rapid increase in the 1980’s in the use of database managers, led by Dbase II, is being emulated by the increase in the use of spatial database tools at present. In the context of decision support we are now seeing the movement towards the widespread use of PC based GIS systems that reflects the move towards PC based DSS in the 1980’s.

The second group of decision-makers, for whom SDSS can make an important contribution, is in fields such as routing or location analysis. Although the spatial component of such decisions is clear, in the past DSS design has been driven predominantly by the management science models.
used. There model driven systems often had very limited database or interface components and the DSS provided little contextual information to the user. In the future these models will be incorporated into GIS based SDSS, providing superior interface and database components to work with the models (Keenan 1998b). The role of the superior GIS data handling facilities will be to provide a richer context for the use of the specific models and for display on the user interface. For this class of problems the variables of direct interest might be distance travelled, the number of vehicles used and the loads on each vehicle. Early routing DSS would only have stored data related to these directly relevant variables. However, the use of GIS technology allows the inclusion of other indirectly important information. For example the inclusion of elevation data would allow more realistic travel times be used in quantitative modelling of routes. The display of distinctive natural features such as rivers or mountains on the interface can make it much easier for the user to understand the representation of the routes generated. This synthesis of management science and GIS techniques will provide more effective decision-making. Keenan (1997) has argued that the use of GIS techniques can extend the range of decision support for vehicle routing problems, allowing consideration of path constraints that have not been comprehensively modelled in the past. This group of potential SDSS users has limited experience of using manual spatial techniques. Such users are not usually directly interested in the spatial processing techniques provided by the SDSS but only in the interaction of these techniques with the management science models. However, the secondary use of spatial data by the models and the display of spatial information on the interface can greatly enrich the decision making process. This group can benefit from the geographic context being fully reflected in the problem representations used.

The third group of decision-makers who will find SDSS important include those where the importance of both spatial data and modelling is somewhat neglected at present. In disciplines such as marketing, additional possibilities for analysis are provided by the availability of increasing amounts of spatially correlated information, for example demographic data (Mennecke 1997). Furthermore, the geographic convenience of product supply relative to customers' locations is an important tool of market driven competition. The availability of user friendly SDSS to manipulate this type of data will lead to additional decision possibilities being examined which are difficult to evaluate without the use of such technology (Grimshaw 1994). The group of potential SDSS users have little background in spatial processing and are not usually experienced users of DSS technology of any type. This category of users are not accustomed to the restrictions on model realism and the interface limitations that many users of management science based DSS have been willing to put up with in the past. Such users will therefore require systems that are straightforward to use and which do not require the user to accommodate artificial restrictions on the problem representation. Such users will benefit from the more realistic modelling and interface representations facilitated by the inclusion of additional contextual information provided by SDSS and other sophisticated technologies.

4. **MULTIPLE DECISION CONTEXTS FOR SDSS**

The increasing suitability of GIS software for use as the basis of a SDSS reflects these trends towards integration. However, it also reflects the greater awareness of the need to extend the use of spatial techniques to a wider range of applications. SDSS represents a form of ‘second order’ DSS where complex and mature technology acts as a basis for systems to support a general class of problems. This general technology is synthesised with more specialised elements, for example models, to form a problem specific DSS. This wider set of applications inevitably involves many potential users of the SDSS who are not drawn from the traditional geoscience disciplines. The extension of SDSS use to such a broader cross section of users offers great potential benefits but also raises a number of interesting issues. How should the design of a SDSS for a business user differ from a system designed for a geologist? Can users make good use of such systems, without substantial training in the use of spatial processing techniques? While some of these issues arise
only in the context of SDSS, the issues arising from the design of these more advanced systems are also of interest to DSS designers generally.

SDSS applications, on the other hand, contain relatively complex spatial database structures and powerful tools for manipulating the data stored in these structures. A common feature of all such systems is the use of spatial data, points, lines and polygons, but a wide variety of models may be applied to this basic data. GIS based DSS applications can make use of the spatial data processing provided by the GIS; these techniques would be supplemented by problem specific models for a given application. However, the wide range of areas of SDSS application implies the existence of a broad spectrum of potential users of SDSS. These users will not be interested in the full range of spatial processing techniques but only in those relevant to a given application. The trend in the future is likely to be for a growth in the use of SDSS by business users without formal training in disciplines such as geography or cartography (Mennecke 1997). This poses a challenge for SDSS builders to cater for this diverse user group using systems built on a similar basic spatial processing platform

This user diversity can largely be catered for if there is a clear focus on the specific problem, rather than on the technology used. For ease of system building a DSS generator may be used, such as a GIS, that has multiple functions. However, for any one problem or one user many of these facilities may not be need. Existing design frameworks such as the ROMC (the representations, operations, memory aids and controls) approach (Sprague and Carlson 1982) should be used to identify the system features of interest to the specific user. The general purpose features of the generator can then be customised by the system builder to provide the representations, operations, memory aids and controls appropriate to the problem. These may differ substantially from user to user. It is an important characteristic of successful information systems that they provide information in a format appropriate to the user. Different users of a given type of information may be accustomed to quite different presentation formats for the information. Distinctive nomenclature may be used in different disciplines. This poses a problem in the context of SDSS where the language used by geographers, which underlies documentation and interface design for GIS software, may be quite different than that used by potential users of SDSS. A successful system must provide system builders with the flexibility to accommodate user preferences. The DSS components can be configured to provide direct users access to information of interest, while other features of the DSS provide contextual information to enrich the decision making process. Contextual information can be found in the database, processed by spatial models and displayed in an appropriate representation on the interface (Table 1).

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<tr>
<th>Directly Relevant</th>
<th>Contextual Information</th>
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<tr>
<td>Solver</td>
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<td></td>
<td>Database</td>
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<td>Interface</td>
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If GIS software is seen as a DSS generator, rather than as an end in itself, different strategies for interface design might present themselves. 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 geographic data. Different users might have different system representations and operations, in similar way to the concept of subschemas providing a distinctive presentation of a database to a user. Not all the data in the system need be made directly available to every user. Even if limited access to information is provided, the full range of GIS operations need
not be made available. Simplified information representations, that might be appropriate for users who only indirectly employ that information, might be inadequate for other users directly interested in that data. Unlike earlier systems modern DSS can be much more complex, for example GIS based SDSS, this implies multiple features at a level of detail that goes beyond that needed by any one user.

A user based design will not impose unfamiliar control concepts on the user. For example, a typical operation in GIS might involve selecting a procedure from several levels of submenu. The spatial data to be used for this operation might be then identified by drawing a box on the screen with the mouse. This approach presents problems for the SDSS user who is not familiar with many of the operations provided by the GIS. A more user centric approach might allow the user draw the box on screen with the mouse and then a menu would appear offering only that subset of operations appropriate to that set of data.

Artificial intelligence (AI) techniques might be used to facilitate this interface simplification. Two existing interesting examples of DSS prototype which use AI techniques, Tolomeo (Angehrn and Lüthi 1990) and Alto (Potvin, Lapalme et al. 1994) can be regarded as a form of simplified GIS. Tolomeo allows the users describe the problem visually and the interface includes a map that includes the representation of visual features other than those that can be directly manipulated by the user. These features provide the geographic context within which the user specifies the problem in terms of the cities to be visited, etc. This type of intelligent DSS interface could usefully be incorporated in a fully fledged SDSS to increase its acceptance to a broader user community.

5. CONCLUSION

Given the advances in information technology, modern DSS can incorporate a more extensive directly and indirectly relevant information for a given class of decisions. The designers of these systems must aim to provide maximum user control over those aspects of the decision where the user has specific expertise, while providing the user with maximum support for areas where the user is less expert. This may require that DSS generator software, such as GIS, be designed with flexibility in mind so that different types of user can make use of the intelligence in the system for less critical parts of the decision.

We suggest, therefore, that much DSS development in the future will take place using relatively complex combination of DSS generators and tools. A substantial variation in the type of problem and user will exist within the general group of systems built from such generators. Spatial decision support systems are a good example of a class of sophisticated DSS. Such systems 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. Such users required full control over the spatial operations in the system in order to improve the quality of the decision. In the future, the use of SDSS will be extended to applications where the spatial information is only an interim stage or a subset of the information required for the decision. Such information provides the geographic context within which specific decisions are taken. Users dealing with this broader set of applications need to be given control over the important variables in the decision while other processing is performed without the need for extensive user interaction. With the development of such systems, new classes of decision and new types of user can be effectively supported.

6. REFERENCES

