MULTICRITERIA SPATIAL DECISION SUPPORT SYSTEMS

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SYNONYMS
Spatial multicriteria decision support systems

DEFINITION

A *spatial decision support system* (SDSS) is an interactive, computer-based system designed to support a user or a group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem [10]. It lies at the intersection of two major trends in the spatial sciences: *geographic information sciences* ~~(GIS)~~ and *spatial analysis* [10]. What really makes the difference between a SDSS and a traditional *decision support system* (DSS) is the particular nature of the geographic data considered in different spatial problems and the high level of complexity of these problems. An effective SDSS requires the addition of a range of specific techniques and functionalities, used especially to manage spatial data, to conventional DSS. According to [5], a SDSS should (i) provide mechanisms for the input of spatial data, (ii) allow representation of spatial relations and structures, (iii) include the analytical techniques of spatial analysis, and (iv) provide output in a variety of spatial forms, including maps. *Multicriteria spatial decision support systems* (MC-SDSS) can be viewed as part of the broader fields of SDSS. The specificity of MC-SDSS is that it supports *spatial multicriteria decision making*. Spatial multicriteria decision making refers to the use of *multicriteria analysis* (MCA) ~~to spatial decision problems.~~ MCA [7] is a family of operations research tools that have experienced very successful applications in different domains since the 1960. It has been coupled with geographical information systems (GIS) since the early 1990s for an enhanced decision making.

HISTORICAL BACKGROUND

The concept of SDSS has evolved in parallel with DSSs [12]. The first MC-SDSS ~~have been~~ developed during the late 1980s and early 1990s [10]. Early research on MC-SDSS is especially devoted to the physical integration of the GIS and MCA. These first tools ~~luck~~ interactively and flexibility since GIS and MCA softwares ~~are~~ coupled indirectly, through an intermediate system. Later research concerns the development of MC-SDSS supporting collaborative and participative multicriteria spatial decision making [9]. Web-based MC-SDSS is an active research topic which will be ~~consolidated~~ in the future [2].

SCIENTIFIC FUNDAMENTALS

1 General structure of SDSS/MC-SDSS

A typical SDSS contains three generic components [10] (see Figure 1): a database management system and geographical database, a model-based management system and model base, and a dialogue generation system. The data management subsystem performs all data-related tasks; that is, it stores, maintains, and retrieves data from the database, extracts data from various sources, and so on. ~~it~~ provides access to data as well as all of the control programs necessary to get those data in the form appropriate for a particular decision making problem. The model subsystem contains the library of models and routines to maintain them. It keeps track of all possible models that might be run during the analysis, as well as controls for running the models. The model base

management system component provides links between different models so that the output of one model can be the input into another model. The dialogue subsystem contains mechanisms whereby data and information are input to the system and output from the system. These three components constitute the software portion of ~~the an~~ SDSS. A fourth important component of any decision support system is the user which may be simple users, technical specialists, decision makers and so on.
MC-SDSS can be viewed as a part of a broader field of SDSS. Accordingly, the general structure of a MC-SDSS is the same that the one of a SDSS. However, the model-based management system is enhanced to support multicriteria spatial modelling and the model base is enriched with different multicriteria analysis techniques.

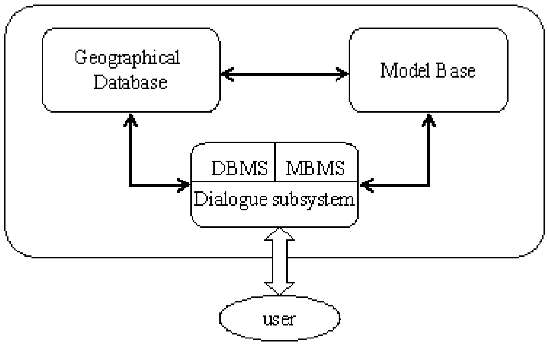


Figure 1: General structure of SDSS [10]

2 GIS and multicriteria analysis integration modes

The conceptual idea on which most of GIS-based multicriteria analysis ~~rely~~ is to use the GIS capabilities to prepare an adequate platform for using multicriteria methods [3] (see Figure 2). The GIS-based multicriteria analysis starts with the problem identification, where the capabilities of the GIS are used to define the set of feasible alternatives and the set of criteria. Then, the *overlay* procedures are used in order to reduce an initially rich set of alternatives into a small number of alternatives which are easily evaluated by using a multicriteria method. Finally, the drawing and presenting capabilities of the GIS are used to present results.

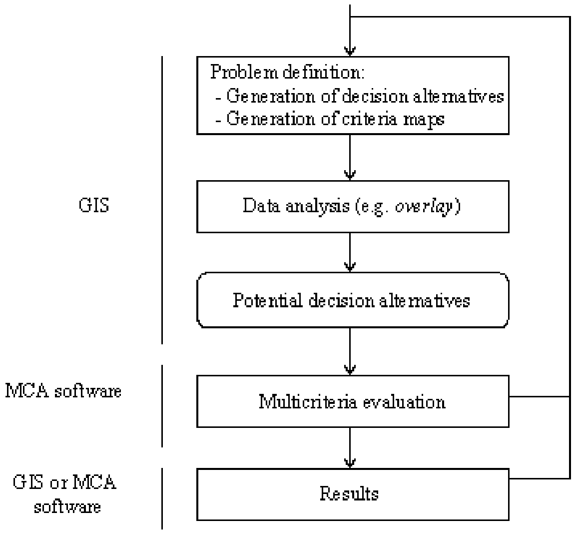


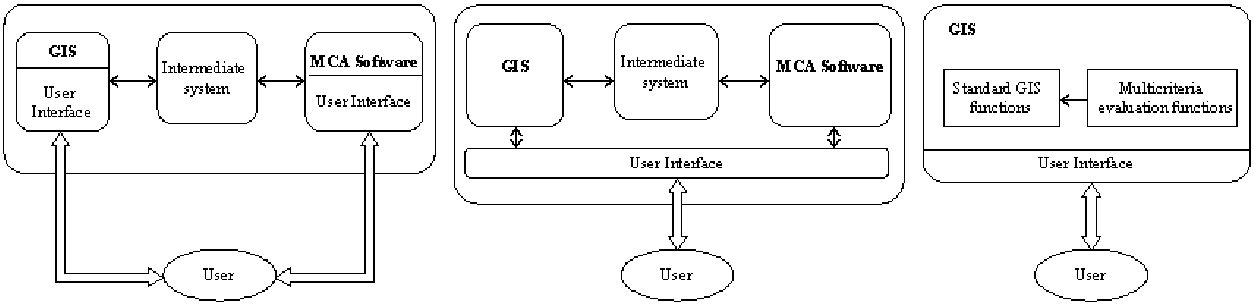
Figure 2: Conceptual schema for GIS and multicriteria analysis integration

Physically, there are four possible modes to integrate GIS and multicriteria analysis tools [**?**][13][10][3]: (i) no integration, (ii) loose integration, (iii) tight integration, and (iv) full integration. The first mode corresponds to the situation dominating until late ~~1980 where~~ the GIS and multicriteria analysis are used independently to deal with spatial problems. The three next modes correspond to increasing levels of complexity and efficiency.

Loose integration mode. The integration of GIS software and a stand-alone multicriteria analysis software is made possible by the use of an intermediate system. The intermediate system permits ~~to reformulate~~ and ~~restructure~~ the data obtained from the overlapping analysis ~~which is~~ performed through the GIS ~~into~~ a form that is convenient to the multicriteria analysis software. The other parameters required for the analysis are introduced directly via the multicriteria analysis software interface. The results of the analysis—totally made in the multicriteria analysis software—may be visualized by using the presentation capabilities of the multicriteria analysis package, or feedback to the GIS part, via the intermediate system, for display and, eventually, for further manipulation. ~~It should be noted that each~~ part has its own database and its own interface, ~~which limited~~ the user-friendliness of the system.

Tight integration mode. In this mode, a particular multicriteria analysis method is directly added to the GIS software. The multicriteria analysis method constitutes an integrated but autonomous part with its own database. The use of the interface of the GIS part alone increases the interactivity of the system. This mode is the first step towards a complete GIS-multicriteria analysis integrated system. Yet, with the autonomy of the multicriteria analysis method, the interactivity remains a problem.

Full integration mode. The third mode yields itself to a complete GIS-multicriteria analysis integrated system that has a unique interface and a unique database. Here, the multicriteria analysis method is activated directly from the GIS interface as any GIS basic function. The GIS database is extended so as to support both the geographical and descriptive data, on the one hand, and the parameters required for the multicriteria evaluation techniques, on the other hand. The common graphical interface enhances the user-friendless of global system.



(*a*) (*b*) (*c*)

Figure 3: GIS and multicriteria loose (*a*), tight (*b*) and full (*c*) integration modes [10][3]

3 GIS and multicriteria analysis interaction directions

~~We may~~ distinguish five directions of interaction [13][11]: (i) no interaction, (ii) one-direction interaction with the GIS as the main software (iii) one-direction interaction with multicriteria tool as the main software, (iv) bi-directional interaction, and (v) dynamic interaction. One-direction interaction provides a mechanism for importing/exporting information via a single flow that originates either in the GIS or multicriteria software. This type of interaction can be based on GIS or multicriteria as the principle software. In the bi-directional interaction approach the flow of data/information can originate and end in the GIS and multicriteria modules. Dynamic integration allows for a flexible moving of information back and forth between the GIS and multicriteria modules according to the user's needs.

4 Design of a MC-SDSS

Different frameworks for designing MC-SDSS have been proposed in the literature [9][10][3]. ~~A part~~ differences in GIS capabilities and multicriteria techniques, most of these frameworks contain the major components introduced earlier. In the rest of this section, ~~we present an~~ revised version of the framework proposed in [3]. This framework is conceived of in such a way that it supports GIS-MCA integration and is also open to incorporate any other OR/MS tool into the GIS (see Figure 4).

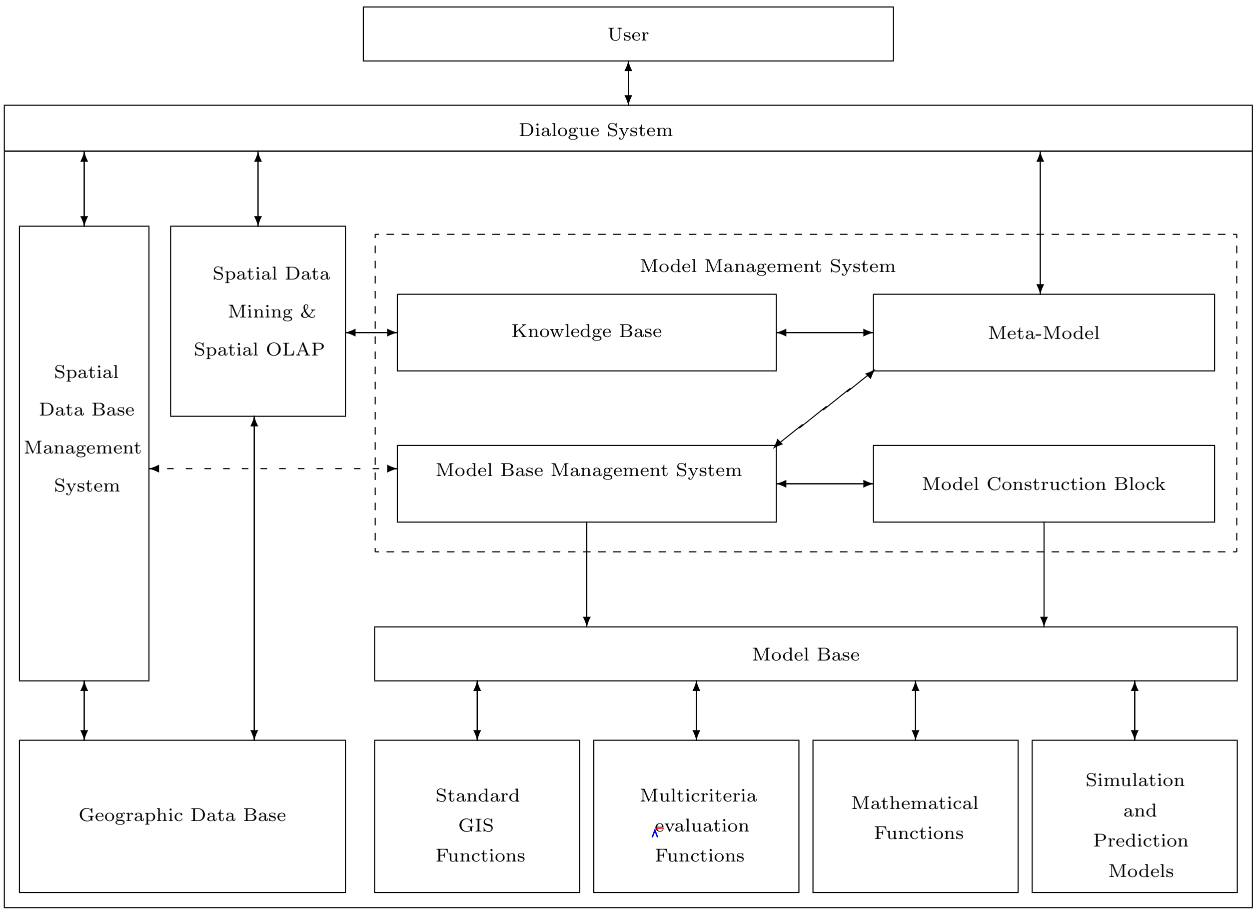


Figure 4: A design of a multicriteria SDSS

4.1 Spatial data base management system

The spatial ~~data base~~ management system is an extension of the conventional database base management system. It is used specially to manage spatial data.

4.2 Geographic database

The geographic data base is an extended GIS database. It constitutes the repository for both (i) the spatial and descriptive data, and (ii) the parameters required for the different OR/MS tools.

4.3 Model base

The model base is the repository of different analytical models and functions. ~~Among these functions, there are surely the basic GIS ones (e.g. statistical analysis, overlaying, spatial interaction analysis, network analysis, etc.).~~ The model base contains also other OR/MS models~~. Perhaps~~ the most important ones are ~~those of MCA. Nevertheless, the~~ system is ~~opened~~ to include any other OR/MS tool (e.g. mathematical models, simulation and prediction models, etc.), or any other ad hoc model developed by the model construction block.

4.4 Model management system

The role of this component is to manage the different analysis models and functions. The model management system ~~which~~ contains four elements: the meta-model, the model base management system, the model construction block and the knowledge base.

4.5 Meta-model

This element is normally an ~~Expert System~~ used by the decision maker to explore the model base. This exploration enables the decision maker to perform a "what-if" analysis and/or to apply different analytical functions. The meta-model uses a base of rules and a base of facts incorporated into the knowledge base. The notion of meta-model is of great importance in the sense that it makes the system open for the addition of any OR/MS analysis tool. This requires the addition of the characteristics of the analytical tool to the base of rules, and, of course, the addition of this model to the model base.

4.6 Knowledge base

~~Knowledge~~ base is the repository for different pieces of knowledge used by the meta-model to explore the model base. P~~ractically, the~~ knowledge base is divided into a base of facts and a base of rules. The base of facts contains the facts generated from the model base. It also contains other information concerning the uses of different models, the number and the problems to which each model is applied, etc. The base of rules contains different rules of decision which are obtained from different experts, or automatically derived~~,~~ by the system~~,~~ from past experiences. This base may~~, for instance, contains:~~ *If the problem under study is the concern of many parties having different objective functions* ~~*then the more appropriate tool is that of MCA*.~~

4.7 Model base management system

The role of the model base management system is to manage, execute and integrate different models that have been previously selected by the decision maker through the use of the ~~Meta-Model.~~

4.8 Model construction block

This component gives the user the possibility to develop different ad hoc analysis models for some specific problems. ~~The developed ad hoc model is directly added to the model base and its characteristics are introduced into the base of rules of the KB.~~

4.9 Spatial data mining and spatial on line analytical processing

Data mining and *on line analytical processing* (OLAP) have been used successfully to extract relevant knowledge from huge traditional databases. Recently, several authors have been interested in the extension of these tools in order to deal with huge and complex spatial databases. In particular, [6] underlines that *spatial data mining* is a very demanding field that refers to the extraction of implicit knowledge and spatial relationships which are not explicitly stored in geographical databases. The same author adds that *spatial OLAP* technology uses multidimensional views of aggregated, pre-packaged and structured spatial data to give quick access to information. Incorporating spatial data mining and spatial OLAP into the MC-SDSS will undoubtedly ameliorate ~~the quality of data and, consequently, add value to the decision-making process.~~

4.10 Dialogue system

The dialogue system represents the interface and ~~the equipments~~ used to ~~achieve~~ the dialogue between the user and the MC-SDSS. It permits the decision maker to enter ~~his/her~~ queries and to retrieve the results.

KEY APPLICATIONS

MC-SDSS have been used in a wide range of practical applications of spatial multicriteria decision making problems ~~including~~ nuclear waste disposal facility location, solid waste management, land-use planning, corridor location ~~problem~~, water resource management, ~~habite~~ site development, health care resource allocation, land suitability analysis. In the rest of this section ~~we provide~~ a brief description some SDSS.

- OSDM (Open Spatial Decision Making) [1] is an Internet-based MC-SDSS designed to support the selection of suitable sites for radioactive waste disposal by the public in Great Britain. An important characteristic of OSDM is that it does not require prior knowledge of GIS or MCA.
- Spatial Groupe Choice (SGC) [9] is a GIS-based decision support system for collaborative spatial decision support making. The system has been used successfully for ~~habit~~ site selection in the Duwamish Waterway and area and for health care resource allocation.
- IDRISI/Decision Support is a built-in decision support module for performing multicriteria decision analysis. This system have been applied in different real~~-~~world applications. The case study described in [10] illustrates the use of the system for analyzing land suitable for a housing projet in Mexico.
- DOCLOC has been designed for aiding ~~for aiding~~ health practitioners in the selection of practices in the sate of Idaho [8]. One limitation to this system is the use of the loose coupling strategy.
- Collaborative Planning Support System (CPSS) [14] provides an example of a system employing multiobjective fuzzy decision analysis. It is a multicriteria collaborative spatial decision support system for sustainable water resource management.

FUTURE DIRECTIONS

Use full integration modes

The first limitation concerning MC-SDSS is relative to the integration mode adopted. In fact, most of the proposed works use loose or tight integration modes. One possible solution to permit ~~a~~ full integration is to identify a restricted set of *multicriteria evaluation functions* and ~~their incorporation in~~ the GIS [3]. These functions represent elementary operations required to implement the major part of multicriteria methods. This integration strategy avoids the necessity of programming the different multicriteria methods. In addition, it permits a full integration since the multicriteria evaluation functions are generic and can easily be incorporated in the available commercial GIS.

Incorporation of a large number multicriteria methods

It is well established that each multicriteria method has its advantages and disadvantages. This means that a given method may be useful in some problems but not in others. One intuitive solution to this problem is to incorporate as many ~~as possible~~ multicriteria methods in the MC-SDSS. However, this idea has several limitations: (i) the obtained system is not flexible enough, (ii) it requires a considerable effort for programming the different methods, and (iii) there is no way to develop “personalized” methods. The integration strategy proposed in the previous paragraph permits ~~to handle this limitation~~n. In fact, the multicriteria evaluation functions are defined in a generic way and can be used to implement different ~~existing~~ multicriteria methods or even to create *ad hoc* methods ~~adopted~~ to the problem under consideration.

Formal methodology to select the multicriteria method to apply

~~Disposing of a large number of multicriteria methods in the MC-SDSS permits to extend and renforce the analytical potentiality of the GI~~S. However, a new problem appears: how to choose the method to use in a given problem? There are generally three possible solutions to the multicriteria method selection problem: (i) the use of a classification tree (ii) the use of a multicriteria method, and (iii) the use of an ~~E~~xpert ~~S~~ystem or a decision support system. ~~We think~~ that the last solution is more appropriate ~~in a~~ perspective of GIS and multicriteria analysis integration. The development of a rule-based system needs (i) the characterization of the spatial decision problems, the multicriteria methods and the decision maker(s) (ii) the identification and quantification of knowledge about multicriteria methods, and (iii) the establish~~ing~~ of ~~a corresponding between~~ the elements enumerated in (i). The result is a collection of rules. These last ones are then used~~,~~ by the inference system~~,~~ as a basis for selecting the most appropriate method.

Choice of the standardization/weighting techniques

Among the problems that are not sufficiently treated in GIS-based multicriteria systems is the selection of the standardization and the weighting techniques. There are many different standardization/~~weithing~~ techniques that can be used in MC-SDSS. It is important to note that different standardization/weighting techniques may lead to different results. The development of a formal framework for aiding the decision maker during the selection of the standarization/weighting technique—similar to the one proposed for the selection of the multicriteria method—is a good initiative.

Developing multicriteria spatial modelling environnement

The use of multicriteria analysis in the GIS is complicated by the lack of an appropriate multicriteria spatial modelling environment. A possible solution is to develop a script-like programming language supporting the different multicriteria evaluation functions. DMA, *decision map algebra*, proposed in [4] and inspired from Tomlin's [15] map algebra seems to be a good start point.

Web-based multicriteria spatial decision making

Web-based MC-SDSS is a recent and active research topic [2]. This is particularity important since it permits ~~to share~~ geographical information and facilitates multicriteria collaborative spatial decision making.

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Spatial multicriteria decision making

Spatial Analysis

Spatial Data Warehousing and Decision Support

RECOMMENDED READING

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