# [GS-02-025] Spatial Decision Support

## Abstract

It has been estimated that 80% of all datasets include geographic references. Since these data often factor into preparing important decisions, we can assume that a significant proportion of all decisions have a geospatial aspect to them. Therefore, spatial decision support is an intrinsic component of societal decision-making. It is thus necessary for current and aspiring analysts, and for decision-makers and other stakeholders, to understand the fundamental concepts, techniques, and challenges of spatial decision support. This GIS&T topic explores the unique nature and basic concepts of spatial decision support, discusses the relationship between Spatial Decision Support Systems (SDSS) and Geographic Information Systems (GIS), and briefly introduces Multi-Criteria Decision Analysis (MCDA) as a decision support technique. The impact of Web-based and mobile information technology, ever-increasing accessibility of geospatial data, and participatory approaches to decision-making are touched upon and additional resources for further reading provided.

## Author & citation

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## Explanation



1. **The Importance of Spatial Decision Support**

Spatial decision support is grounded in rational choice theory (e.g. Tversky & Kahnemann, 1986). It assumes that humans make important decisions on the basis of evidence and a structured process. Simon (1977) suggested that rational decision-making consists of three general phases: intelligence, design, and choice. Although the phases can be completed iteratively, intelligence is conducted early in a decision-making process and serves to determine whether a decision has to be made at all, and what its parameters are. The design phase includes collecting data and developing alternative solutions, while the actual decision is made in the choice phase. Jankowski and Nyerges (2001) present a macro-micro decision strategy, in which the micro activities gathering, organizing, selecting, and reviewing are repeated in each of the macro phases intelligence, design, and choice.

Since a large proportion of data owned and managed by government and business organizations – by many accounts on the order of 80% of all data – include geographic references, spatial decision-making is wide-spread and thus, spatial decision support an important field of study. Malczewski's (2006) literature review gives an idea of the many domains, in which spatial decision support can be applied. Among the most common domains are environment and ecology, transportation, urban and regional planning, waste management, hydrology and water resources, agriculture, and forestry. Each of these was represented by between 8% and 17% of all surveyed publications, for a combined total of over 70%. An updated literature review by Malczewski and Rinner (2015) confirms the same fields of application with the addition of natural hazard management.

## 2. **Basic Concepts of Spatial Decision Support**

To understand spatial decision support, we need to define its underlying concepts, starting with the distinction of the term "decision" from related concepts such as evaluation and modeling. A decision is the selection of a specific course of action from among a set of decision alternatives or options. Different forms of evaluation or assessment may be part of decision-making and decision support, but they can also occur independently for the purpose of understanding a situation, yet without immediately taking an action. Finally, modeling may be used in preparing and making decisions, but it has broader applications.

There are many ways to classify types of decisions. For example, Nyerges and Jankowski (2009) distinguish decision situations within planning, improvement programming, and implementation in government operations. The importance, or scope, of a decision will determine whether computer-based decision support is needed. For example, an individual's one-time decision about which restaurant to go to does not require formal spatial decision support. By contrast, many government and business decisions are so complex that they should not be made without a formalized, computer-assisted process. Among those decisions, we can further distinguish decisions of operational, tactical, and strategic scope. The higher the scope in this order, the more likely that decision support is needed. In addition, decision-making becomes more likely to be iterative or nested among multiple spatial and domain-specific levels.

Decision problems can also be characterized along a continuum from structured to unstructured. For structured decision problems, all parameters are accurately known and the solution (decision) can be computed. For unstructured problems, there is not enough information available to formalize the decision-making process. It is thus the semi-structured decision problems that call for the application of spatial decision support methods and tools. Another distinction to be made when surveying a decision situation is whether the decision-maker is an individual or a group. Groups with heterogeneous objectives and values require different spatial decision support than individuals or homogenous groups (Armstrong 1994, Jankowski & Nyerges 2001). Here, spatial decision support involves concepts of collaboration and participation.

Conceptual challenges in spatial decision support include documenting, reviewing, and monitoring the outcome of decisions taken. The documentation of the decision-making process is akin to creating metadata, yet very little research and practical implementation has been completed in this area. Although a review phase is sometimes included in formal decision processes, review of a decision and monitoring of its outcomes is often an after-thought not covered by the resources initially allocated to the decision process. This inhibits the evaluation of the effectiveness of a decision and future improvement of the process.

3. **What is Special about Spatial Decision Support**

Fundamentally, Geographic Information Systems (GIS) help answer two types of questions. One asks what attribute or feature type is found at a given location, and the other asks where a given attribute or type of feature can be found. Although other authors have identified 3-5 different types of spatial decision problems, they can all be reduced to two distinct types of problems, and their combination. In analogy to the what- and where-questions for GIS, allocation problems are concerned with deciding what to place at a given location, and location problems examine where to place a given item. For example, assigning residential postcodes to food banks represents an allocation problem of creating service areas, while finding a site for a new food bank is a location problem of optimizing travel distances and other relevant factors. The combination of the two types is known as location-allocation problems. For example, locating a new food bank in the above example will also require (re-)allocating client populations. Navigation is a particular type of spatial decision problem that offers well-developed online and mobile support tools and appears as a distinct type of decision problem related to network analysis in GIS. However, determining a route can be viewed as an iterative location problem solved for each route segment.

The influence of geographic location on both main types of decision problems requires specialized assistance provided by spatial decision support. The degree to which specialized decision support is needed depends on which elements of the decision problem are explicitly spatial. For example, decision alternatives typically are locations and therefore spatially explicit. However, decision criteria and decision models are often aspatial. They can therefore be found in regular, non-spatial databases and model bases. Paradoxically, research into extending the spatiality of decision support methods and tools is still in its infancy (e.g., Ligmann-Zielinska and Jankowski, 2014).

4. **GIS and Spatial Decision Support Systems**

Spatial Decision Support Systems (SDSS) aid in making decisions in geospatial applications. There is no standard definition in the literature, but with Malczewski (1999), we will call SDSS “an interactive computer based system designed to support a user or group of users in achieving a higher effectiveness of decision-making while solving a semi-structured spatial decision problem.”

Different authors also disagree on the number and type of components that make up an SDSS. The following three components are included in most SDSS frameworks (e.g., Armstrong et al, 1986, Malczewski, 1999):

- **Database management system -** spatial and non-spatial data collection, storage, and retrieval
- **Dialog component -** user interface, visualization, report generator
- **Modeling toolkit -** spatial models, spatio-temporal models, decision models

Other components referenced by some authors include analysis functionality, expert or knowledge-based system, and the stakeholders/users themselves. Some authors separate the user interface and reporting functions into two components. It is surprising that only few authors explicitly list analytical functionality as an SDSS component; however, it can be argued that GIS analysis operations are spatial models and thus included in the modeling toolkit.

Sugumaran & DeGroote (2011) distinguish problem-specific SDSS, domain-level SDSS, and generic SDSS. Problem-specific SDSS are designed and implemented for one specific decision problem and are usually not suitable for application to other problems. Domain-level SDSS can be used to address multiple problems within an application domain. However, Sugumaran & DeGroote (2011) also note that there are many domains, including environmental applications, for which a domain-level SDSS has yet to be developed. Most SDSS are implemented on the basis of GIS software and therefore, the generic SDSS category, or SDSS generator, essentially consists of GIS software such as ArcGIS and Idrisi. This suggests that an SDSS must be viewed as designed for one specific application, or multiple similar applications within a domain, not as a generic software package.

With the development of Web mapping and online GIS, spatial decision support has been extended to network-based implementations. In a multi-tier system architecture, parts of the SDSS system components – most commonly the user interface – are moved to the client side, while the remainder of the system resides on one or more server computers. An early example was an online connection for the Multi-Criteria Evaluation functions of Idrisi GIS (Rinner, 2003). Today, GIS software vendors offer numerous Web-based tools and services such as Esri's ArcGIS Online, which can be turned into online SDSSs.

Similarly, the proliferation of location-enabled mobile computing devices, notably smartphones, may have an impact on spatial decision support. However, the mobile environment does not normally involve high-stakes decision-making. As discussed above, the limited scope of choosing a restaurant may not warrant the use of an SDSS, although any of today's mobile mapping services essentially supports that kind of decision with base maps, driving/walking directions, and information about points of interest, including user reviews.

The operational challenges with spatial decision support are numerous. They include the comprehensive definition of the decision problem, collection of all necessary data, design of suitable alternatives, representation of decision-maker preferences (subjectivity), model selection, and interpretation of results in making a final choice or recommendation. The spatial dependency of many elements in decision problems poses additional challenges to the analyst.

## 5. **Specific Spatial Decision Support Techniques**

The role of GIS software in generating SDSS (Keenan 1996, Sugumaran & DeGroote, 2011) is based on its data integration, geographic visualization, and spatial analysis capabilities. Armstrong et al. (1992) suggest that novel cartographic displays within an interactive modeling environment can support all phases of decision-making. Through combination of geovisualization with analytical tools, the growing field of geovisual analytics contributes to spatial decision support (Andrienko et al, 2007). While geovisualization can support different stages of decision-making, it is not specific to spatial decision support.

Similarly, spatial analysis functions and most spatial modeling tools provide critical information for spatial decision-making. For example, established GIS functions such as buffering and overlay can be used to design decision alternatives or develop decision criteria. Advanced modeling functions that were recently integrated in GIS software, such as agent-based models, cellular automata, or geospatial data mining can be used to create more complex input into the decision-making process, such as population or demand forecasting.

There is one group of tools that stand out, because they explicitly serve the decision support function of SDSS: multi-criteria decision analysis (MCDA) tools. While MCDA is a modeling approach, it is distinct from other models in that it is normative (Malczewski & Rinner, 2015). Spatial analysis and modeling are descriptive in that they attempt to replicate real-world structures or processes. In contrast, normative modeling with MCDA includes decision-maker values and takes the perspective of what "ought to be", rather than what "is" or "will be."

The most commonly used MCDA technique is weighted linear combination, also known as simple additive weighting or weighted average. In this approach, decision-maker(s) determine a limited set of alternatives (e.g. possible food bank locations), criteria (e.g. transit access, real estate cost, distance from existing food banks), and weights of importance. Each alternative is evaluated by a score which consists of the sum of weighted criterion values. The evaluation scores enable the analyst to rank the alternatives and recommend implementation of one or more of the top-ranked alternatives.

Unfortunately, different MCDA techniques will produce diverging results, making the choice of a technique and its parameters a difficult decision in itself (Ferretti & Montibeller, 2016, McHenry & Rinner, 2016). To overcome the gap between normative and descriptive models, some researchers have integrated geosimulation techniques such as agent-based modeling with MCDA (e.g., Bone et al, 2011; Arsanjani et al, 2013). Additional technical and design challenges include the benefit-cost ratio of complex SDSS software; ensuring usability through user-centered design; and effectively integrating models and Web services with the core SDSS platform.

## 6. **Summary and Conclusion**

GIS is an essential tool for spatial planning, prediction, modeling, research, and ultimately, decision support. Sugumaran & DeGroote (2011) observed that most of the SDSSs described in some 450 scholarly articles were one-time prototype applications with limited potential for re-use, as they represent problem-specific SDSS implementations. While most GIS software packages are missing explicit decision models, these can be added in their scripting and programming environments, or through manual linkages. Therefore, GIS is the primary platform for developing application- or domain-specific SDSS. It is important that GIS analysts and developers understand the fundamental concepts, opportunities, and limitations of spatial decision support as they broadly apply to Geographic Information Science and Technology.

The emergence of government open data catalogs broadens the application potential of SDSS. We can expect increasing demand for spatial decision support services in the context of smart cities, which will also provide enhanced IT platforms for spatial decision support, such as cloud-based data processing. Real-time data streams, new high-resolution aerial and remote sensing techniques, along with high-detail 3D modeling could result in a proliferation of spatial decision support in applications such as environmental monitoring or public safety, which could put our trust in surveillance regulations and algorithmic governance to the test.

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