# Integrating Multicriteria Analysis and Geographic Information Systems: a survey and classification of the literature

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Over the last few years, there has been a revolution in the availability of information and in the development and application of tools for its management. As a consequence, decision-making nowadays underpins on an ever increasing amount of data and there is thus a need to allocate the Decision Makers attention efficiently.
This need is real, above all, in the context of sustainability assessments which are based on a multidimensional concept, including socio- economic, ecologic, technical and ethical perspectives.
Within this context, a very important role is played by the so called Multicriteria- Spatial Decision Support Systems (MC-SDSS; Malczewski, 1999), which, being based on Geographic Information Systems (GIS) and Multicriteria Decision Analysis (MCDA) coupling, represent a very efficient tool to implement a multi- inter disciplinary, participative and transparent approach.
Conventional MCDA techniques have largely been non-spatial, using average or total impacts that are deemed appropriate for the entire area under consideration. This assumption is however rather unrealistic because in many cases evaluation criteria vary across space.
Many decision-making problems are thus based on spatial (geographical) information, thus giving rise to the so called location decisions which represent now a major part of operations research and management science.
There is now a well established body of literature on GIS-MCDA integration and the techniques and the applications concerning GIS-based multicriteria decision analysis have been recently discussed in a very interesting study developed by J. Malczewski (2006). From 2000 the number of studies has been increasing worldwide and several applications can be found in different fields. Starting from the study developed by Malczewski, the present paper expands the survey and classification of the literature concerning MCDA and GIS integration by considering the period 2007-2011. The paper thus provides a review on recent efforts and developments in the MC-SDSS field, highlighting which methodological approaches are more commonly used with reference to the MCDA components (Multi-objective Decision Analysis *versus* Multi-attribute Decision Analysis), the GIS components (raster *versus* vector data models), the aggregation rule used, the decision process approach (value focused thinking *versus* alternative focused thinking), the extent of the GIS and MCDA integration and the type of application domain and decision problem.
The main objective of the present contribution is thus to survey and classify the most recently published GIS-MCDA articles. The search for relevant publications has been performed using the SCOPUS web based scientific database; it was limited to articles published in refereed journals and it was done using a Boolean search based on a combination of keywords.
The electronic search indicated that 365 articles appeared in refereed journals between 1990 and 2011, showing a growing trend in GIS based MCDA applications in recent years. The paper thus provides taxonomy of the articles published between 2007 and 2011 by identifying trends and developments in GIS-MCDA.
The results of the performed classification highlights that MC-SDSS are commonly applied to land suitability analysis in the context of urban and regional planning and are usually based on a loose coupling approach and on a value focused thinking framework.

Keywords: Multiple Criteria Decision Analysis, Geographic Information Systems, Multicriteria-Spatial Decision Support Systems.

## 1. Introduction

Research concerning how to manage and proper evaluate complex systems now dominates the scientific agenda and decision- making can be considered as one of the most important challenges that analysts and experts encounter to solve complex problems.

A particular living matter refers to the debate concerning how to face the complexity challenge in the field of sustainability assessments of territorial transformation projects which, together with spatial plans, are subject to evaluation and whose consequences must be considered and managed. In this context, different and conflicting objectives have to be taken into account, referring to social, cultural and symbolic interferences, that can be addressed through quality assessment, use values and imprecise temporal horizons (Roscelli, 2005). This leads to consider urban and territorial transformation processes as “weak” or unstructured problems since they are characterized by multiple actors, many and often conflicting values and views, a wealth of possible outcomes and high uncertainty (Prigogine, 1997; Simon, 1960).

In recent decades, different methods and algorithms have been presented to support decision-making. In this respect, one of the most widely used orientations for measuring the sustainability of a system is the ‘criteria and indicators approach’ (Pasqualini *et al*., 2011). A key question is how to aggregate the various indicators used to determine the multidimensional value of courses of action into a single index that measures the sustainability of the transformation as a whole.

In order to analyze decision problems in this field and to cope with the abovementioned complexity, the need to integrate spatial data with algorithmic techniques has been recognized and gave rise to a research stream in the context of Decision Support Systems (DSS) related to the so-called Spatial Decision Support Systems (SDSS). As mentioned by Maniezzo *et al*. (1998), these systems are concerned with how to integrate spatially referenced information in a decision-making environment in order to positively affect the performance of Decision Makers, showing how spatially integrated DSS can be used to bridge the gap between policy makers and complex computerized models. Within these tools, a fundamental role is played by the so called Multicriteria- Spatial Decision Support Systems (MC-SDSS; Malczewski, 1999), which combines Geographic Information Systems (GIS) and Multicriteria Analysis (MCA) in order to provide a collection of methods and tools for transforming and integrating geographic data (map criteria) and Decision Maker’s preferences and uncertainties (value judgments) to obtain information for decision-making and an overall assessment of the decision alternatives.

MC-SDSS thus integrate the sustainability dimensions while offering a systematic approach able to prove the importance of “where” in addition to “what” and “how much”.

The main rationale for integrating GIS and MCA is that they have unique capabilities that complement one another. On the one hand, GIS has great abilities for storing, managing, analyzing and visualizing geospatial data required for the decision-making process. On the other hand, MCA offers a rich collection of procedures, techniques and algorithms for structuring decision problems, and designing, evaluating and prioritizing decision alternatives (Malczewski, 1999) by combining factual information (e.g., soil type, slope, infrastructures) with value-based information (e.g., expert’s opinion, quality standards, participatory surveys) (Geneletti, 2010).

The integration of the two distinctive areas of research, GIS and MCDA, allows to close their respective gaps and to enhance the efficacy and the reliability of the decision-making process.

Hence, it is in the context of synergetic capabilities of GIS and MCDA that it becomes possible to see the benefits for advancing theoretical and applied research on MC-SDSS (Malczewski, 2006).

The most significant difference between spatial multi-criteria decision analysis and conventional multicriteria techniques is thus the explicit presence of a spatial component. The former as a matter of fact, requires data on the geographical locations of alternatives and/or geographical data on criterion values (Sharifi and Retsios, 2004), while the latter usually assumes spatial homogeneity within the study area.

Territorial transformation planning has obviously important spatial implications, as many of the alternative courses of action’s costs and benefits are distributed spatially. Indeed, it has been estimated that 80% of the data used in decision-making is spatial (Worral, 1991).

The visualization of available alternatives on a map, assisting the user to locate the spatial elements in their actual environment, and the possibility of automatic representation of alternatives in the criterion space, provides a value-added for the decision analysis and support processes in

territorial transformation problems where usually several options must be compared (Countinho-Rodrigues *et al*., 2011).
Over the last twenty years or so, there has been an exponential growth of theoretical and applied research concerning MC-SDSS (Malczewski, 2010).
The literature now contains a wealth of references to MC-SDSS developments and applications in a variety of domains; this is why the present study aims at exploring and summarizing the recent global trends in MC-SDSS research from multiple perspectives, trying to expand the previous survey made by Malczewski (2006) and to serve as a potential systematization for future researches.
The remainder of the paper is organized into 6 sections. The research objectives and the methods used for surveying the literature concerning MC-SDSS are discussed in the next section. Section 3 provides the theoretical background on which MC-SDSS models underpin. Subsequently, section 4 briefly illustrates the state of the art of MC-SDSS while section 5 presents the classification of the literature according to various perspectives. Finally, section 6 summarizes the conclusions that can be drawn from the study, putting in evidence opportunities for future developments.

## 2. Research objectives and literature survey methods

The purpose of the present analysis is to survey and classify MC-SDSS related articles focusing on those published in refereed journals between 2007 and 2011 (Ferretti, 2011b).
Mention has to be made to the fact that Malcewski (2006) presented an extensive survey of the GIS-MCDA literature published in the period 1990-2004 with a classification of the papers depending on the different elements involved in the problem.
The specific objective of the present study is to explore and systematize recent global trends concerning MC-SDSS applications with reference to the MCDA components (Multi-objective Decision Analysis *versus* Multi-attribute Decision Analysis), the GIS components (raster *versus* vector data models), the aggregation rule used, the decision process approach (value focused thinking *versus* alternative focused thinking), the extent of GIS and MCDA integration and the type of application domain and decision problem.
The search for relevant publications has been performed using the SCOPUS[1] scientific database, which is the largest abstract and citation database of peer-reviewed literature and quality web sources with smart tools to track, analyze and visualize research.
The search performed in this study was limited to articles published in refereed journals in the period between 1 January 1990 and 15 September 2011. It was done using a Boolean search containing the following combination of keywords: ((“Multicriteria” OR “Multicriteria analysis” OR “MCA” OR “Spatial Multicriteria Analysis” OR “Spatial Multicriteria Evaluation” OR “SMCE”) AND (“Spatial Decision Support Systems” OR “GIS” OR “Geographic Information Systems”)). The result of the search on the SCOPUS database provides the list of scientific papers containing the aforementioned combination of keywords either in the title, or in the abstract or in the keywords.
Among the 365 articles appeared in refereed journals between 1990 and 2011, the present study focuses the attention on those published between 2007 and 2011 (209) in order to put in evidence the most recent global trends of the research in the MC-SDSS field.
Papers identified in the search, but that were clearly irrelevant, were omitted from further consideration, leaving 196 articles that were reviewed thoroughly.

## 3. Multicriteria- Spatial Decision Support Systems: the theoretical background

Multicriteria- Spatial Decision Support Systems can be viewed as a part of the broader field of Spatial Decision Support Systems which have been extensively covered in the literature (e.g., Densham and Goodchild, 1989). The need for using such systems is derived from situations where

[1] www.scopus.com

complex spatial problems are ill or semi-structured, and Decision Makers cannot define the problem or fully articulate their objectives (Ascough *et al*., 2002).
From the methodological point of view, a spatial decision support tool can be defined as an interactive computer system designed to assist the user, or group of users, to achieve high levels of effectiveness in the decision-making process, while solving the challenge represented by semi-structured spatial decision problems (Malczewski, 1999).
An MC-SDSS is thus a procedure to identify and compare solutions to a spatial decision problem, based on the combination of multiple factors that can be, at least partially, represented by maps (Malczewski, 2006). As previously indicated, the MC-SDSS framework is based on the integration of GIS capabilities and Multicriteria Analysis (MCA) techniques and takes advantage of both. GIS techniques have an important role in analyzing decision problems, in supporting storage and visualization of maps and spatial data, and providing functions for spatial analysis, while MCA provides a full range of methods for structuring decision problems and for designing, evaluating and prioritizing alternative decisions (Malczewski, 2006).
While GISs are often used to support decision-making in planning and land use, they are distinct from SDSS because they lack analytical modeling capabilities and do not support multiple decision-making strategies (Densham, 1991). Hendriks and Vriens (2000, p.86) explain this difference by stating that “GIS look at data, whereas SDSS look at problem situations”.
As a matter of fact, the capabilities of GIS for generating a set of alternative decisions are mainly based on the spatial relationship principles of connectivity, contiguity, proximity and the overlay methods. For instance, the overlay operations are often used for identifying suitable areas for new development, be it a new industrial facility, waste disposal site, school, hospital, etc. In this context, the functionality of GIS is essentially limited to overlaying deterministic digital map layers to define areas simultaneously satisfying a set of location criteria. However, when the selection involves conflicting preferences with respect to evaluation criteria, the overlay functions do not provide enough analytical support, because of limited capabilities for incorporating the Decision Makers' preferences into the GIS-based decision- making process (Malczewski, 2010). This is why GIS has been coupled with MCA, thus yielding to MC-SDSS.
The input for an MC-SDSS model is thus represented by a number of maps of an area (so-called criteria or effects), and a criteria tree that contains the way criteria are grouped, standardized and weighted. The output of an MC-SDSS model consists of one or more maps of the same area (the so-called composite index maps) that indicates the extent to which criteria are met or not in different areas, and thereby supports planning and/or decision-making (Rahman and Saha, 2008).
Spatial multi-criteria analysis therefore represents a significant step forward compared to conventional MCA techniques because of the explicit spatial component, which requires both data knowledge and representation of the criteria (criterion maps) and the geographical localization of the alternatives, in addition to the Decision Makers' preferences. In fact, conventional non-spatial MCA techniques typically use the average or the total impact of an alternative on the environmental system, considering them appropriate for the whole area under consideration. In other words, conventional approaches assume spatial homogeneity within the study area but this assumption is clearly unrealistic since the evaluation criteria, or rather the attributes that are used to measure them, vary spatially.
According to the model proposed by Simon (1960), the decision-making process can be divided into four main stages, named intelligence, design, choice and review (Fig. 1).
The framework shown in Figure 1 refers to the development of an MC-SDSS model and highlights how each phase of the decision-making process involves the methodological contribution of both GIS systems and multicriteria evaluation methods.

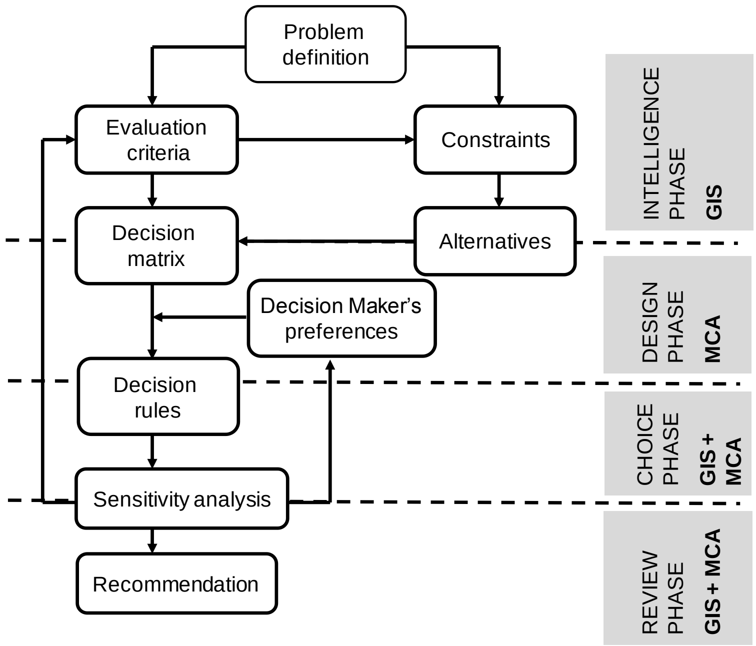


***Figure 1*** *– Spatial multicriteria analysis framework (Source: adapted from Malczewski, 1999 and Simon, 1960)*

The intelligence phase refers to the structuring of the problem, during which the system under consideration is defined and the objectives to pursue are explored. One or more criteria, or attributes, are then selected to describe the degree of achievement of each objective (Keeney, 1992).
The design phase involves data collection and processing, as well as the development of Multicriteria Analysis through the definition of the relationship between objectives, attributes and preferences of the Decision Maker (Malczewski, 1999).
As it is generally recognized, no MCDA technique is the "best" for all problems and the various methods often produce different results for the same problem (e.g., Figueira *et al*., 2005a; Hobbs and Meier, 2000). Typically the differences are greater when there are more alternatives and when the alternatives have similar values for the criteria (Olson *et al.,* 1995). A very important advantage given by the MC-SDSS approach is represented by the possibility to integrate different MCA techniques inside a GIS environment, thus ensuring flexibility to the decision-making process.
During the choice phase alternatives are evaluated and, finally, during the review phase, detailed analyses, such as the sensitivity analysis, are deemed appropriate in order to obtain some recommendations.

## 4. Multicriteria- Spatial Decision Support Systems: the state of the art

One of the first experiences concerning the use of maps in decision-making processes refers to the work of McHarg (1969), where the basic concepts that would be later developed in Geographic Information Systems (Charlton and Ellis, 1991) are set forth.
Whereas DSS and GIS can work independently to solve some simple problems, many complex situations demand the two systems to be integrated in order to provide better solutions (Li *et al*., 2004). In this context, it can be stated that the development of Spatial Decision Support Systems (SDSS) has been associated with the need to expand the GIS system capabilities for tackling complex, not well-defined, spatial decision problems (Densham and Goodchild, 1989). The concept of SDSS evolved in the mid 1980s (Armstrong *et al*., 1986), and by the end of the decade many works concerning SDSS were available (Densham, 1991; Goodchild, 1993; Densham and Armstrong, 1987; Armstrong, 1993). Over the course of the 1990s there has been considerable growth in the research, development and applications of SDSS and in recent years these common decision support functions have been expanded to include optimization (Aerts *et al.,* 2003, Church

*et al.,* 2004), simulation (Wu, 1998), expert systems (Leung, 1997), multicriteria evaluation methods (Feick and Hall, 2004; Malczewski, 1999; Thill, 1999; Janssen and Rietveld, 1990; Carver, 1991; Eastman *et al*., 1993; Pereira and Duckstein, 1993; Jankowski and Richard, 1994; Laaribi *et al*., 1996; Malczewski, 1996) on-line analysis of geographical data (Bedord *et al.*, 2001) and visual-analytical data exploration (Andrienko *et al.*, 2003), with the aim of generating, evaluating, and quantifying trade-offs among decision alternatives. The field has now grown to the point that it is made up of many threads with different, but related names, such as collaborative SDSS, group SDSS, environmental DSS and SDSS based on spatial knowledge and on expert systems (Malczewski, 2006).
With specific reference to GIS-based multicriteria decision analysis, the full range of techniques and applications has been recently discussed in the aforementioned study developed by Malczewski (2006).
The amount of papers on Multicriteria- Spatial Decision Support Systems were few for many years, but in the past decade, presenting and solving spatial multicriteria problems have had a substantial growth, and have opened windows to research in different fields.
With the aim of demonstrating the vitality and the variety of the research in the MC-SDSS field, the present study tries to extend the abovementioned survey of Malczewski (2006) by exploring the literature production until present days. In order to achieve this objective a search has been done using the SCOPUS scientific database and the combination of keywords illustrated in paragraph 2.
The result of the search, in terms of the number of published articles in the period 1990-2011, is summarized in Figure 2.

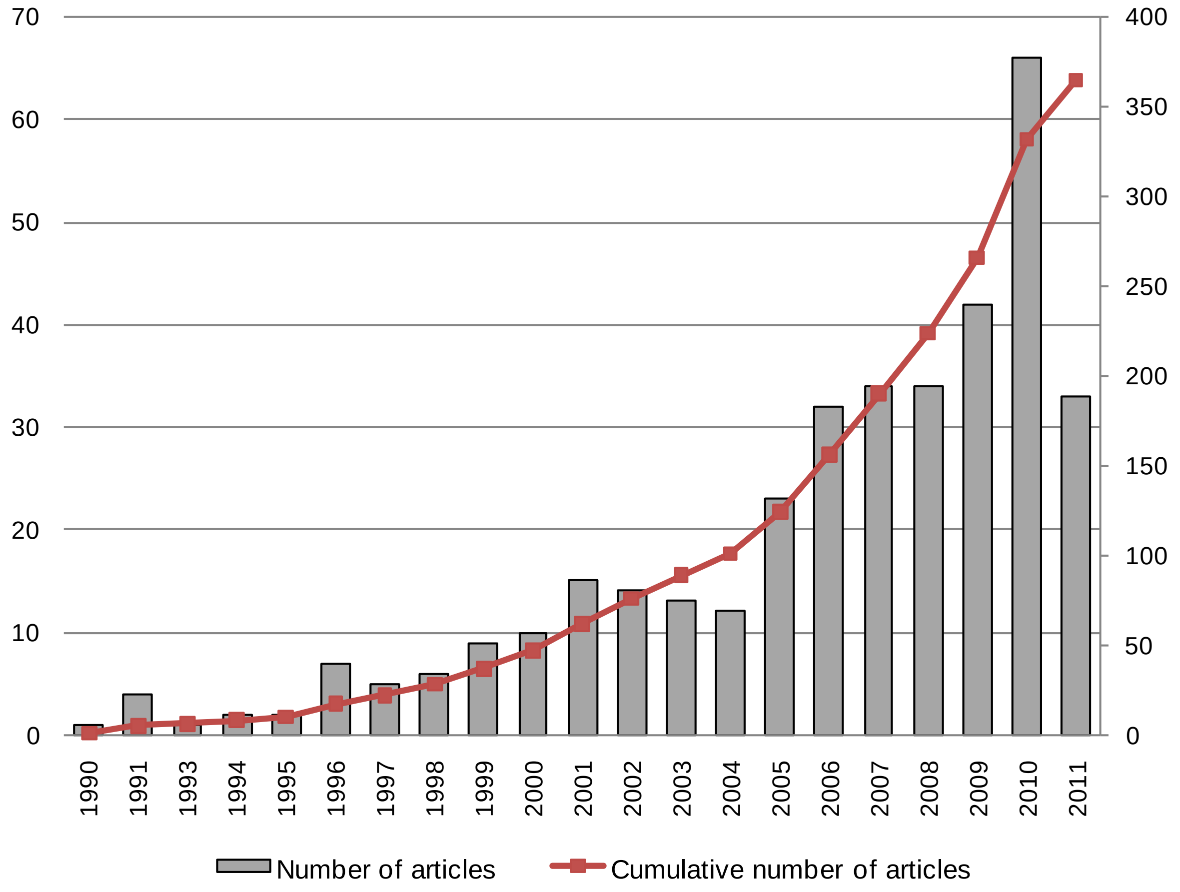


***Figure 2*** *– Development of MC-SDSS in terms of the number of refereed articles published in the period 1990-2011 and the accumulation of those articles (source: SCOPUS, 2011)*

Mention should be made to the fact that a clear interest in MC-SDSS research did not emerge until the 1990s, although a few publications related to spatial multicriteria analysis were published previously (for more details, please refer to Malczewski, 2006).

From Figure 2 it is possible to notice that 365 source titles were discovered and that there is a growing trend of this topic during recent years. As a matter of fact, from 2000 the number of studies has been increasing and several applications can be found in different fields (Malczewski, 2006).
About 93% of the sources are journal articles and conference papers. This means that this topic is mostly of interest to researchers.
Furthermore, over the last five years the volume of refereed publications on MC-SDSS has continued to grow very rapidly and of the 365 articles founded, those published in the last five years (209) accounts for 57% of the total. This is the reason why the classification of the literature developed in the following paragraph will focus on the period 2007-2011.
It's worth mentioning that the diffusion of the MC-SDSS research is also indicated by the large number and diversity of refereed journals serving as outlets for the MC-SDSS articles. Over the years, according to SCOPUS, the articles have appeared in 174 different journals, thus testifying MC-SDSS vitality and acceptance.
Table 1 summarizes the most active journals in the MC-SDSS field from 1990 until 2011.

***Table 1*** *– The list of refereed journals that have published four or more articles on MC-SDSS in 1990-2011 (source: SCOPUS, 2011)*

| Rank | Journal | N. of articles | % |
|---|---|---|---|
| 1 | *International Journal of Geographical Information Science* | 15 | 4,1 |
| 2 | *Landscape and Urban Planning* | 14 | 3,8 |
| 3 | *Journal of Environmental Management* | 13 | 3,6 |
| 4 | *Environmental Management* | 9 | 2,5 |
| 5 | *Computers Environment and Urban Systems* | 8 | 2,2 |
| 6 | *Environmental Monitoring and Assessment* | 6 | 1,6 |
| 7-9 | *Cybergeo* | 5 | 1,4 |
| 7-9 | *Applied Geography* | 5 | 1,4 |
| 7-9 | *Decision Support Systems* | 5 | 1,4 |
| 10-19 | *Environmental Geology* | 4 | 1,1 |
| 10-19 | *Transactions in GIS* | 4 | 1,1 |
| 10-19 | *Management Information Systems* | 4 | 1,1 |
| 10-19 | *Transportation Research Record* | 4 | 1,1 |
| 10-19 | *Environmental Modelling and Software* | 4 | 1,1 |
| 10-19 | *Journal of Geographical Systems* | 4 | 1,1 |
| 10-19 | *International Journal of Applied Earth Observation and Geoinformation* | 4 | 1,1 |
| 10-19 | *Journal of the Indian Society of Remote Sensing* | 4 | 1,1 |
| 10-19 | *Water Resources Management* | 4 | 1,1 |
| 10-19 | *Environmental Planning B Planning Design* | 4 | 1,1 |
| | *Others* | 245 | 67,1 |
| | Total | 365 | 100 |

The *International Journal of Geographical Information Science* and the *Landscape and Urban Planning* one still lead with 29 publications (7,9%), thus confirming the trend highlighted in Malczewski's survey (Malczewski, 2006).
Furthermore, it's interesting to put in evidence that the most active subject areas in the MC-SDSS field have been the following, respectively (SCOPUS, 2011):
- Environmental Science (184 articles);
- Earth and Planetary Sciences (102 articles);
- Social Sciences (89 articles);
- Agricultural and Biological Sciences (69 articles);
- Computer Science (52 articles);
- Engineering (51 articles).

## 5. Classification of the MC-SDSS literature between 2007 and 2011

This paragraph reviews some of the efforts and developments in the MC-SDSS field. In order to see this trend over recent years the SCOPUS database has been used as the largest abstract and citation database on the 15th of September 2011.
Among the 365 articles arising from the search based on the combination of keywords illustrated in paragraph 2, those articles that have been published between 2007 and 2011 (209) have been downloaded and carefully reviewed.
Leaving aside those papers that were clearly irrelevant, Table 2 presents the result of the classification procedure for the 196 articles that were reviewed thoroughly.
Mention should be made to the fact that not all the articles were available as full text. Consequently, those articles for which only the abstract was available are highlighted in grey.
All articles were classified with reference to the dichotomies existing between Multi- Objective Decision Analysis and Multi- Attribute Decision Analysis, between raster data and vector data, and between the value focused thinking approach and the alternative focused thinking one. Moreover, the classification considers the aggregation rule used, the extent of the GIS and MCDA integration and the type of application domain and decision problem.
Unfortunately, not all the articles provide information regarding the aspects explored in the present literature classification. As a consequence, some spaces in Table 2 are left empty.
Detailed statistical reports are showed with reference to the aforementioned dichotomies in the following subsections.
Attention has to be paid to the fact that, for the seek of the readability of the table, the identification number in Table 2 refers to the bibliographic reference section at the end of the paper.

***Table 2*** *– Literature classification*[2]

| Identification number | GIS-MADA | GIS-MODA | Aggregation rule | Techniques used and extent of integration | Application domain | Type of decision problem | Vector data | Raster data | Alternative focus | Value focus | Case study | Theoretical study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | x | | WLC | GIS+AHP (LC) | Hydrology and water management | Land suitability analysis | | | | x | x | |
| 2 | x | | WLC | GIS+MCA (LC) | Environment/Ecology | Site selection | | | | x | x | |
| 3 | x | | WLC | ILWIS (TC) | Environment/Ecology | Vulnerability assessments | | x | | x | x | |
| 4 | x | | WLC | GIS+AHP (LC) | Forestry | Risk assessments | | | | x | x | |
| 5 | x | | WLC | GIS+AHP (LC) | Transportation | Vehicle routing | | x | | x | x | |
| 6 | x | | WLC | GIS+ANP (LC) | Hydrology and water management | Impact assessments | | | | x | x | |
| 7 | x | | Algorithm | GIS+SAW/ELECTRE/TOPSIS | Hydrology and water management | Site selection | | | x | | x | |
| 8 | | | | GIA+MCA(LC) | | | | | | | | x |
| 9 | x | | OWA | GIS+MCA | Transportation | Vehicle routing | x | | | x | x | |

[2] The acronyms used in the table refer to the following terms:
AHP: Analytic Hierarchy Process
GIS: Geographic Information Systems
LC: Loose Coupling
MCA: Multicriteria Analysis
OWA: Ordered Weighted Average
TC: Tight Coupling
WLC: Weighted Linear Combination
NO: No integration

| Identification number | GIS-MADA | GIS-MODA | Aggregation rule | Techniques used and extent of integration | Application domain | Type of decision problem | Vector data | Raster data | Alternative focus | Value focus | Case study | Theoretical study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | x | | Algorithm | GIS+MCA (NO) | Urban/Regional Planning | Site selection | | | | x | x | |
| 11 | x | | WLC | GIS+MCA (LC) | Undesirable facilities location (waste) | Land suitability analysis | | x | | x | x | |
| 12 | | | | GIS+MCA(LC) | Hydrology and water management | Impact assessments | | | | | | x |
| 13 | x | | Algorithm | GIS+MCA | Hydrology and water management | Land suitability analysis | | | | x | x | |
| 14 | x | | WLC | ILWIS (TC) | Transportation | Resources allocation | | x | x | | x | |
| 15 | x | | | IDRISI (TC) | Urban/Regional Planning | Site selection | | x | | x | x | |
| 16 | x | | WLC | GIS+DEFINITE | Undesirable facilities location (waste) | Land suitability analysis | | x | | x | x | |
| 17 | | x | | | Hydrology and water management | Risk assessments | | | | | | x |
| 18 | | x | | GIS+MCA(LC) | Hydrology and water management | Scenario evaluation | | | x | | x | |
| 19 | x | | WLC | IDRISI (TC) | Transportation | Site selection | | x | | x | x | |
| 20 | | | | GIS+MCA(LC) | Undesirable facilities location (waste) | Site selection | | | | x | x | |
| 21 | | | | | Environment/Ecology | Land suitability analysis | | | | x | x | |
| 22 | x | | WLC | ILWIS (TC) | Hydrology and water management | Land suitability analysis | | x | | x | x | |
| 23 | x | | WLC | GIS+MCA(LC) | Forestry | Risk assessments | | | | x | x | |
| 24 | x | | Algorithm | GIS+AHP (LC) | Environment/Ecology | Land suitability analysis | | x | | x | x | |
| 25 | x | | WLC | GIS+MCA(LC) | Agriculture | Land suitability analysis | | | | x | x | |
| 26 | | x | Algorithm | GIS+Cellular Automata+AHP | Agriculture | Land suitability analysis | | x | | x | x | |
| 27 | x | | Algorithm | GIS+TOPSIS (LC) | Hydrology and water management | Impact assessments | | x | | x | x | |
| 28 | x | | WLC | ILWIS(TC) | Transportation | Vehicle routing | | x | | x | x | |
| 29 | | | | | Forestry | Risk assessments | | | | x | x | |
| 30 | x | | WLC | GIS+AHP (LC) | Environment/Ecology | Site selection | | x | | x | x | |
| 31 | x | | WLC | GIS+AHP (LC) | Urban/Regional Planning | Site selection | | x | | x | x | |
| 32 | x | | WLC | AHP+GIS+Python (LC) | Agriculture | Land use allocation | | x | | x | x | |
| 33 | x | | WLC | ILWIS (TC) | Hydrology and water management | Land suitability analysis | | x | | x | x | |
| 34 | | | OWA | WebGIS+MCA | Urban/Regional Planning | Site selection | | | x | | | x |
| 35 | | | | GIS+MCA(LC) | Hydrology and water management | Site selection | | | | x | x | |
| 36 | x | | WLC | GIS+TOPSIS(TC) | Forestry | Site selection | | | | x | x | |
| 37 | x | | WLC | GIS+AHP (LC) | Urban/Regional Planning | Land suitability | | x | | x | x | |

| Identification number | GIS-MADA | GIS-MODA | Aggregation rule | Techniques used and extent of integration | Application domain | Type of decision problem | Vector data | Raster data | Alternative focus | Value focus | Case study | Theoretical study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | analysis | | | | | | |
| 38 | x | | WLC | GIS+AHP (LC) | Agriculture | Land suitability analysis | | x | | x | x | |
| 39 | x | | WLC | ILWIS (TC) | Hydrology and water management | Land suitability analysis | | x | | x | x | |
| 40 | x | | | GIS+AHP(LC) | Undesirable facilities location (industry) | Site selection | | | | x | x | |
| 41 | x | | Boolean overlay | GIS+MCA(LC) | Environment/Ecology | Site selection | | | | x | x | |
| 42 | x | | WLC | AHP+GIS (LC) | Undesirable facilities location (energy) | Land suitability analysis | | x | | x | x | |
| 43 | x | | WLC+ boolean tecniques | GIS+WLC+boolean tecniques (LC) | Hydrology and water management | Site selection | | x | | x | x | |
| 44 | x | | WLC | GIS+AHP(LC) | Hydrology and water management | Land suitability analysis | | | | x | x | |
| 45 | x | | WLC | GIS+AHP(LC) | Urban/Regional Planning | Land suitability analysis | | x | | x | x | |
| 46 | x | | WLC/Ideal Point/Rank Order | Proximity Adjusted Preferences | Other (house selection) | Site selection | | | x | | x | x |
| 47 | x | | WLC | GIS+WLC (LC) | Undesirable facilities location (energy) | Land suitability analysis | | x | | x | x | |
| 48 | x | | Qualitative assessment on an ordinal scale | GIS+MCA (LC) | Geology/Geomorphology | Site selection | | x | | x | x | |
| 49 | x | | | GIS+MCA(LC) | Hydrology and water management | Land suitability analysis | | | | x | x | |
| 50 | x | | K-means clustering | GIS+AHP/ PROMETHEE (LC) | Environment/Ecology | Vulnerability assessments | | x | | x | x | |
| 51 | x | | Boolean tecniques | GIS+Boolean tecniques (LC) | Agriculture | Site selection | x | | | x | x | |
| 52 | x | | WLC | AHP+GIS (LC) | Forestry | Land suitability analysis | | | | x | x | |
| 53 | x | | WLC | GIS+WLC (LC) | Geology/Geomorphology | Risk assessments | x | | | x | x | |
| 54 | x | | WLC | GIS+WLC (LC) | Geology/Geomorphology | Impact assessments | | | | x | x | |
| 55 | x | | Kalman filter algorithm + fuzzy tecniques | GIS+Kalman filter+fuzzy sets (LC) | Geology/Geomorphology | Vulnerability assessments | | | | x | x | |
| 56 | x | | WLC | GIS+MCA(LC) | Undesirable facilities location (waste) | Land suitability analysis | | x | | x | x | |
| 57 | x | | WLC | GIS+WLC (LC) | Transportation | Vehicle routing | x | | x | | x | |
| 58 | x | | WLC | GIS+WLC (LC) | Hydrology and water management | Land suitability analysis | | | | x | x | |
| 59 | | | | GIS+MCA (LC) | Forestry | Resources allocation | | | | | x | x |
| 60 | x | | Fuzzy weighted sum model | GIS+fuzzy set theory+AHP (LC) | Natural hazard | Risk assessments | | x | | x | x | |

| Identification number | GIS-MADA | GIS-MODA | Aggregation rule | Techniques used and extent of integration | Application domain | Type of decision problem | Vector data | Raster data | Alternative focus | Value focus | Case study | Theoretical study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 61 | x | | OWA+fuzzy | GIS+OWA+fuzzy techniques (LC) | Urban/Regional Planning | Site selection | | | x | | x | |
| 62 | | | | GIS+MCA (LC) | Agriculture | Land suitability analysis | | | | | x | |
| 63 | x | | WLC | GIS+ELECTRE TRI (LC) | Urban/Regional Planning | Vulnerability assessments | | | | x | x | |
| 64 | x | | | GIS+AHP(LC) | Undesirable facilities location (waste) | Land suitability analysis | | | | x | x | |
| 65 | x | | | GRASS+Rank Order(LC) | Hydrology and water management | Site selection | x | | | x | x | |
| 66 | x | | WLC | GIS+WLC (LC) | Urban/Regional Planning (industry) | Land suitability analysis | | x | | x | x | |
| 67 | x | | | GIS+MCA (LC) | Agriculture | Site selection | | | | x | x | |
| 68 | | x | | GIS+MCA (LC) | Environment/Ecology | Scenario evaluation | | | | x | x | |
| 69 | x | | Neural network based approach for continuous k nearest neighbor | GIS+optimization algorithm (LC) | | | | | | | | x |
| 70 | x | | WLC | GIS+WLC (LC) | Urban/Regional Planning | Impact assessments | | x | | x | x | |
| 71 | x | | Boolean overlay/ WLC | GIS+AHP/Rank Order | Hydrology and water management | Vulnerability assessments | | | | x | x | |
| 72 | x | | WLC | GIS+AHP (LC) | Urban/Regional Planning | Risk assessments | x | | | x | x | |
| 73 | | | | | | | | | | | | |
| 74 | | x | WLC | GIS+WLC (LC) | Transportation | Resources allocation | | | | x | x | |
| 75 | x | | | GIS+MCA (LC) | Hydrology and water management | Site selection | | | | x | x | |
| 76 | x | | WLC | GIS+AHP (LC) | Urban/Regional Planning | Land suitability analysis | | x | x | | x | |
| 77 | x | | OWA+fuzzy techniques | GIS+OWA+fuzzy (LC) | Urban/Regional Planning | Land suitability analysis | | | x | | x | x |
| 78 | | x | WLC | GIS+AHP (LC) | Forestry | Site selection | | x | | x | x | |
| 79 | x | | WLC | GIS+WLC (LC) | Hydrology and water management | Land suitability analysis | | x | | x | x | |
| 80 | x | | WLC | GIS+WLC (LC) | Urban/Regional Planning | Land use allocation | | x | | x | x | |
| 81 | x | | WLC | GIS+AHP (LC) | Hydrology and water management | Risk assessments | | | | x | x | |
| 82 | x | | WLC | ILWIS (TC) | Undesirable facilities location (waste) | Land suitability analysis | | x | | x | x | |
| 83 | x | | Fuzzy tecniques | AGROLAND (TC) | Agriculture | Land suitability analysis | | x | | x | x | |
| 84 | x | | WLC | GIS+WLC (LC) | Geology/Geomorphology | Risk assessments | | x | | x | x | |
| 85 | x | | WLC | GIS+WLC (LC) | Urban/Regional Planning | Land suitability analysis | | | | x | x | |

| Identification number | GIS-MADA | GIS-MODA | Aggregation rule | Techniques used and extent of integration | Application domain | Type of decision problem | Vector data | Raster data | Alternative focus | Value focus | Case study | Theoretical study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 86 | x | | WLC | GIS+WLC (LC) | Hydrology and water management | Land suitability analysis | | | x | | x | |
| 87 | x | | WLC | ILWIS 3.3 (TC) | Forestry | Land suitability analysis | | x | | x | x | |
| 88 | x | | WLC | GIS+AHP (LC) | Urban/Regional Planning | Land suitability analysis | | | | x | x | |
| 89 | | x | | GIS+MCA(LC) | Urban/Regional Planning | Site selection | | | | x | x | |
| 90 | x | | WLC | GIS+AHP (LC) | Natural hazard | Risk assessments | | | | x | x | |
| 91 | x | | WLC | GIS+ WLC (LC) | Undesirable facilities location (waste) | Land suitability analysis | x | | | x | x | |
| 92 | x | | WLC | GIS+WLC (LC) | Hydrology and water management | Land suitability analysis | | | | x | x | |
| 93 | x | | WLC and log–linear formulation of Bayes' Rule | GIS+WLC+log-linear formulation (LC) | Geology/Geomorphology | Site selection | | x | | x | x | |
| 94 | x | | fuzzy tecniques | GIS+AHP (LC) | Transportation | Site selection | | x | | x | x | |
| 95 | x | | OWA | IDRISI (TC) | Urban/Regional Planning | Site selection | | | | x | x | |
| 96 | x | | WLC+OWA | GIS+WLC/OWA (LC) | Urban/Regional Planning | Land suitability analysis | | x | | x | x | x |
| 97 | x | | | GIS+MCA (LC) | Urban/Regional Planning | Site selection | | | | x | x | |
| 98 | x | | WLC | GIS+AHP (LC) | Environment/Ecology | Site selection | | | | x | x | |
| 99 | x | | WLC | GIS+AHP (LC) | Hydrology and water management | Land suitability analysis | | | | x | x | |
| 100 | x | | WLC | IDRISI (TC) | Geology/Geomorphology | Site selection | | x | | x | x | |
| 101 | x | | WLC | GIS+AHP (LC) | Environment/Ecology | Land suitability analysis | | | | x | x | |
| 102 | x | | WLC | GIS+AHP(LC) | Hydrology and water management | Land suitability analysis | x | | | x | x | |
| 103 | x | | WLC | GIS+WLC(LC) | Environment/Ecology | Land suitability analysis | | x | | x | x | |
| 104 | x | | WLC | Dump Traveler (GIS+AHP) (TC) | Transportation | Vehicle routing | | x | | x | x | |
| 105 | | | | GIS+MCA(LC) | Environment/Ecology | Impact assessments | | | | x | x | |
| 106 | | | | GIS+ AHP(LC) | Urban/Regional Planning | Site selection | | | x | | x | |
| 107 | x | | WLC | GIS+WLC(LC) | Geology/Geomorphology | Risk assessments | | x | | x | x | |
| 108 | x | | Index Overlaying logic | GIS+AHP(LC) | Urban/Regional Planning | Site selection | | | | x | x | |
| 109 | x | | | GAIA Map (GAIA+ PROMETHEE)(LC) | Urban/Regional Planning | Site selection | | | x | | x | |
| 110 | x | | WLC | GIS+WLC(LC) | Hydrology and water management | Site selection | | | | x | x | |
| 111 | x | | WLC | GIS+HIVIEW(LC) | Waste Management | Impact assessments | | x | x | | x | |

| Identification number | GIS-MADA | GIS-MODA | Aggregation rule | Techniques used and extent of integration | Application domain | Type of decision problem | Vector data | Raster data | Alternative focus | Value focus | Case study | Theoretical study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 112 | x | | WLC | GIS+AHP(LC) | Undesirable facilities location (waste) | Land suitability analysis | | | | x | x | |
| 113 | x | | WLC | GIS+WLC(LC) | Undesirable facilities location (waste) | Land suitability analysis | | | | x | x | |
| 114 | x | | | GIS+MCA(LC) | Environment/Ecology | Site selection | | | | x | x | |
| 115 | x | | WLC | GIS+WLC(LC) | Urban/Regional Planning | Impact assessments | | | | x | x | |
| 116 | x | | WLC | GIS+WLC(LC) | Environment/Ecology | Risk assessments | | | x | | x | |
| 117 | x | | WLC | GIS+AHP(LC) | Hydrology and water management | Impact assessments | | | | x | x | |
| 118 | x | | | GIS+AHP(LC) | Undesirable facilities location (waste) | Land suitability analysis | | | | x | x | |
| 119 | | | | GIS+ELECTRE TRI(LC) | | | | | | | | x |
| 120 | x | | WLC | GIS+FUZZY AHP(LC) | Urban/Regional Planning | Site selection | | | x | | x | |
| 121 | x | | WLC | GIS+WLC(LC) | Forestry | Land suitability analysis | | x | x | | x | |
| 122 | | x | | GIS+MCA(LC) | Urban/Regional Planning | Scenario evaluation | | | | x | x | |
| 123 | x | | WLC | GIS+WLC(LC) | Environment/Ecology | Site selection | | | | x | x | |
| 124 | x | | WLC | GIS+AHP(LC) | Undesirable facilities location (waste) | Land suitability analysis | | | | x | x | |
| 125 | x | | OWA | IDRISI+ AHP(TC) | Forestry | Site selection | | x | | x | x | |
| 126 | x | | WLC | GIS+AHP(LC) | Environment/Ecology | Land suitability analysis | | | | x | x | |
| 127 | | | | GIS+MCA(LC) | Natural hazard | Land suitability analysis | | | | x | x | |
| 128 | x | | Disjunctive approach e WLC | GIS+MCA(LC) | Natural hazard | Risk assessments | | x | | x | x | |
| 129 | x | | WLC | GIS+AHP(LC) | Environment/Ecology | Land suitability analysis | | | | x | x | |
| 130 | x | | WLC | ILWIS(TC) | Transportation | Vehicle routing | | x | | x | x | |
| 131 | | | | GIS+MCA(LC) | Hydrology and water management | Risk assessments | | | | x | x | |
| 132 | x | | Algorithm | GIS+MCA(LC) | Natural hazard | Scenario evaluation | | | x | | x | |
| 133 | x | | WLC | IDRISI(TC) | Urban/Regional Planning | Land suitability analysis | | x | | x | x | |
| 134 | x | | WLC | GIS+WLC(LC) | Urban/Regional Planning | Land suitability analysis | | x | | x | x | |
| 135 | x | | | GIS+MCA(LC) | Natural hazard | Site selection | | | x | | x | |
| 136 | x | | | GIS+MCA(NO) | Transportation | Impact assessments | | | x | | x | |
| 137 | x | | WLC | IDRISI(TC) | Environment/Ecology | Site selection | | x | | x | x | |
| 138 | x | | WLC | ILWIS (TC) | Agriculture | Land suitability analysis | | x | | x | x | |

| Identification number | GIS-MADA | GIS-MODA | Aggregation rule | Techniques used and extent of integration | Application domain | Type of decision problem | Vector data | Raster data | Alternative focus | Value focus | Case study | Theoretical study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 139 | x | | WLC | GIS+AHP(LC) | Undesirable facilities location (energy) | Land suitability analysis | | | | x | x | |
| 140 | x | | Algorithm | GIS+ELECTRE TRI(LC) | Urban/Regional Planning | Land suitability analysis | | x | | x | x | x |
| 141 | x | | Algorithm | GIS+MCA(LC) | Geology/Geomorphology | Land suitability analysis | x | | | x | x | |
| 142 | | x | WLC + ideal point analysis + FAO framework | GIS+AHP(LC) | Urban/Regional Planning | Land use allocation | | x | | x | x | |
| 143 | | | | GIS+MCA(LC) | Undesirable facilities location (energy) | Land suitability analysis | | | | | x | x |
| 144 | x | | OWA | GIS+ AHP(LC) | Forestry | Site selection | | | | x | x | |
| 145 | | | | GIS+MCA(LC) | Urban/Regional Planning | Plan evaluation | | x | x | | x | |
| 146 | x | | WLC | GIS+AHP(LC) | Undesirable facilities location (industry) | Land suitability analysis | | | | x | x | |
| 147 | | x | Linear integer programming model | GIS+MCA(LC) | Urban/Regional Planning | Site selection | | x | | x | x | |
| 148 | x | | WLC | ILWIS(TC) | Urban/Regional Planning | Site selection | | x | | x | x | |
| 149 | x | | WLC | GIS+AHP(LC) | Hydrology and water management | Site selection | | | | x | x | |
| 150 | | | Algorithm | Choice Modeler(TC) | | | | | | | | x |
| 151 | | | | GIS+MCA(LC) | Urban/Regional Planning | Site selection | | | | x | x | |
| 152 | | | | GIS+MCA (LC) | Urban/Regional Planning | Plan evaluation | | | | | x | |
| 153 | | | | GIS+MCA(LC) | Hydrology and water management | Site selection | | | | x | x | |
| 154 | x | | WLC | GIS+AHP(LC) | Hydrology and water management | Land suitability analysis | | x | | x | x | |
| 155 | x | | WLC+ likelihood frequency ratio | GIS+AHP(LC) | Natural hazard | Risk assessments | x | | | x | x | |
| 156 | | x | Algorithm | GIS+MCA(LC) | Environment/Ecology | Site selection | | x | x | | x | |
| 157 | x | | Boolean tecniques | GIS+Fuzzy MCA (NO) | Undesirable facilities location (waste) | Site selection | | x | | x | x | |
| 158 | | x | OWA | GIS+Fuzzy AHP(LC) | Urban/Regional Planning | Land suitability analysis | | x | x | | x | x |
| 159 | x | | Linear integer programming model | GIS+AHP(LC) | Undesirable facilities location (industry) | Land suitability analysis | | | x | | x | |
| 160 | x | | Ideal point | GIS+MCA(LC) | Environment/Ecology | Site selection | | | | x | x | |
| 161 | x | | WLC | IDRISI(TC) | Environment/Ecology | Land suitability analysis | | x | | x | x | |
| 162 | x | | WLC | GIS+MCA(LC) | Environment/Ecology | Impact assessments | | | x | | x | |
| 163 | | | | GIS+MCA(LC) | Urban/Regional Planning | Scenario evaluation | | | | x | x | |
| 164 | x | | WLC | GIS+MCA(LC) | Environment/Ecology | Land | | | | x | x | |

| Identification number | GIS-MADA | GIS-MODA | Aggregation rule | Techniques used and extent of integration | Application domain | Type of decision problem | Vector data | Raster data | Alternative focus | Value focus | Case study | Theoretical study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | suitability analysis | | | | | | |
| 165 | x | | WLC | GIS+AHP(LC) | Environment/Ecology | Site selection | x | | x | | x | |
| 166 | x | | WLC | GIS+Fuzzy AHP(LC) | Environment/Ecology | Land suitability analysis | | | | x | x | |
| 167 | x | | WLC | IDRISI (TC) | Environment/Ecology | Land suitability analysis | | | | x | x | |
| 168 | x | | Algorithm | GIS+AHP(LC) | Urban/Regional Planning | Site selection | | x | | x | x | |
| 169 | x | | WLC | GIS+AHP(LC) | Environment/Ecology | Land suitability analysis | | | | x | x | |
| 170 | x | | WLC | GIS+AHP(LC) | Natural hazard | Risk assessments | | x | | x | x | |
| 171 | x | | WLC | IDRISI (TC) | Urban/Regional Planning | Land suitability analysis | | | | x | x | |
| 172 | x | | Algorithm | GIS+MCA(LC) | Environment/Ecology | Impact assessments | | | | x | x | |
| 173 | x | | | GIS+MCA(LC) | Environment/Ecology | Site selection | | x | x | | x | |
| 174 | x | | WLC | GIS+MCA(LC) | Environment/Ecology | Site selection | | x | | x | x | |
| 175 | x | | WLC | GIS+AHP(LC) | Hydrology and water management | Land suitability analysis | | | | x | x | |
| 176 | x | | Boolean overlay | GIS+MCA(LC) | Hydrology and water management | Land suitability analysis | x | | | x | x | |
| 177 | x | | Algorithm | GIS+outranking methods(LC) | Transportation | Vehicle routing | | | | x | x | x |
| 178 | x | | WLC | GIS+AHP(LC) | Urban/Regional Planning | Impact assessments | | | x | | x | |
| 179 | | x | WLC | IDRISI(TC) | Environment/Ecology | Site selection | | x | | x | x | |
| 180 | | | Algorithm | GIS+MCA(LC) | Transportation | Vehicle routing | | | | x | x | |
| 181 | x | | OWA | GIS+outranking methods(LC) | Environment/Ecology | Land suitability analysis | | | x | | x | |
| 182 | x | | | GIS+MCA(LC) | Urban/Regional Planning | Land suitability analysis | | | | x | x | |
| 183 | x | | Algorithm | GIS+MCA(LC) | Transportation | Vehicle routing | | | x | | x | |
| 184 | x | | OWA | GIS+OWA(LC) | Other (epidemiology) | Site selection | | | | x | x | |
| 185 | | | | GIS+MCA(LC) | Hydrology and water management | Impact assessments | | | | x | x | |
| 186 | x | | WLC | ILWIS(TC) | Agriculture | Site selection | | x | | x | x | |
| 187 | x | | | GIS+ANP (NO) | Natural hazard | Scenario evaluation | | | x | | x | |
| 188 | x | | WLC | GIS+AHP (LC) | Urban/Regional Planning | Scenario evaluation | | x | | x | | x |
| 189 | x | | | GIS+HIVIEW (NO) | Urban/Regional Planning | Scenario evaluation | | | x | | x | |
| 190 | | x | Algorithm | GIS+MCA(LC) | Urban/Regional Planning | Land suitability analysis | | | | x | x | |
| 191 | x | | WLC | IDRISI (TC) | Transportation | Land suitability analysis | | x | | x | x | |
| 192 | x | | WLC | ILWIS+IDRISI(TC) | Natural hazard | Risk assessments | | x | | x | x | |

| Identification number | GIS-MADA | GIS-MODA | Aggregation rule | Techniques used and extent of integration | Application domain | Type of decision problem | Vector data | Raster data | Alternative focus | Value focus | Case study | Theoretical study |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 193 | x | | | GIS+AHP(NO) | Transportation | Risk assessments | | x | | x | x | |
| 194 | x | | OWA+WLC | IDRISI(TC) | Undesirable facilities location (waste) | Land suitability analysis | | x | | x | x | |
| 195 | x | | WLC | GIS+MCA(LC) | Environment/Ecology | Site selection | | x | x | | x | |
| 196 | x | | WLC | GIS+AHP(LC) | Urban/Regional Planning | Site selection | | | | x | x | |

*Multiattribute Decision Making (MADM) Versus Multiobjective Decision Making (MODM)*

MCDA is an evaluation method that provides the means for ranking a number of hypotheses known as alternative choice possibilities, using a number of multiple criteria and conflicting objectives (Voogd, 1983). A wide range of methods and procedures are available within the framework of MCDA for designing, evaluating and prioritizing alternative decisions (Malczewski, 2006).

A full description of the MCDA methods and implementation details is beyond the scope of this paper. The interested reader is referred to Figueira *et al*. (2005b) for an overview of these techniques.

The classification developed in Table 2 highlights which articles are based on a MADM approach and which ones are based on a MODM approach.

Multi-attribute decision problems are assumed to have a predetermined, limited number of alternatives and solving this type of problem is a selection process as opposed to a design process. Multi-objective problems are continuous in the sense that the best solution may be found anywhere within the region of feasible solutions (Malczewski, 2006).

The result of the survey on the recent literature concerning MC-SDSS (Table 2) puts in evidence that most of the applications (158) underpins on a MADM approach, accounting for 80,6% of the total, while only 14 applications (7,1%) are based on a MODM approach.

*Aggregation rule*

The primary issue in spatial multicriteria analysis is concerned with how to combine the information from several criteria to form a single index of evaluation. Spatial multicriteria analysis may be achieved via a number of procedures. The first involves Boolean overlay whereby all criteria are reduced to logical statements of suitability and then combined by means of one or more logical operators such as intersection (AND) and union (OR). The second is known as weighted linear combination (WLC) wherein continuous criteria (factors) are standardized to a common numeric range, and then combined by means of a weighted average. With a weighted linear combination, factors are combined by applying a weight to each, followed by a summation of the results to yield a suitability map, i.e.:

$$Sj = \sum Wi * Xi \tag{1}$$

where *S* represents the suitability for pixel *j*; *Wi* is the weight of factor *i* and *Xi* is the standardized criterion score of factor *i*.

The result is a continuous mapping of suitability that may then be masked by one or more Boolean constraints to accommodate qualitative criteria.

A third option for MCE, known as ordered weighted average (OWA) can also be used (Eastman and Jiang, 1996). This method offers a complete spectrum of decision strategies along the primary dimensions of degree of trade off involved and degree of risk in the solution. However, the simple

Boolean operations sometimes are not suitable because they do not provide sufficient flexibility required for the analysis. Another approach, the fuzzy technique, specifies a more continuous suitability range for each criteria. According to the fuzzy approach the image shows a continuous suitability range as a distance decay function and this reflects a better real simulation than the Boolean method. This approach combines decision or classification scores from multiple information sources into a single composite score by applying a fuzzy integral with respect to a designated fuzzy measure, representing differential weighting of scores derived from a variety of information sources. However, for continuous factors, a weighted linear combination is the most commonly used method (Voogd, 1983; Zopounidis and Doumpos, 2002).

It is beyond the scope of this paper to document the range of aggregation rules available in the field of MC-SDSS, but it's worth mentioning that other approaches exist as for instance the ideal/reference point methods (Pereira and Duckstein, 1993) and the outranking methods (Joerin *et al*., 2011); the interested reader can refer to Malcewski (1999) and Eastman (2006) for a detailed explanation.

Table 3 summarizes the result of the present literature survey with reference to the aggregation rule used and highlights that, although a considerable number of decision rules has been proposed in the MCDA literature, the use of the combination rules in the MC-SDSS applications has been limited to a few well known approaches. It's interesting to notice that the Weighted Linear Combination method still leads the ranking, thus confirming the trend highlighted in Malczewski's study (2006).

***Table 3*** *– Classification of the MC-SDSS articles according to the aggregation rule used*

| Aggregation rule | Number of articles | % |
|---|---|---|
| WLC | 110 | 56,12 |
| OWA | 12 | 6,12 |
| Boolean overlay | 6 | 3,06 |
| Ideal/reference point methods | 3 | 1,53 |
| Rank Order | 1 | 0,51 |
| Algorithms | 18 | 9,18 |
| Others | 14 | 7,14 |

*Level of integration between GIS and MCDA*

Four categories are usually identified based on the extent of integration between GIS and MCDA: (i) no integration, (ii) loose coupling, (iii) tight coupling, and (iv) full integration (Malczewski, 1999).

In the loose-coupling approach, the two systems (GIS and MCDA) exchange files such that a system uses data from the other system as the input data. A tight-coupling strategy is based on a single data or model manager and a common user interface. Thus, the two systems share not only the communication files but also a common user interface. A more complete integration can be achieved by creating user-specified routines using generic programming languages. The routines can then be added to the existing set of commands or routines of the GIS package. This coupling strategy is referred to as a full integration approach (Malczewski, 2006).

The result of the survey on the recent literature concerning MC-SDSS (Table 2) puts in evidence that most of the applications (148) makes use of the loose coupling approach, accounting for 75,5% of the total, while 30 applications (15,3%) makes use of a tight coupling approach and only 6 applications (3%) do not use any integration between the two systems.

From the analysis of Table 2 it's also interesting to highlight that the method that is most frequently integrated within the GIS environment is the Analytical Hierarchy Process (AHP, Saaty, 1980). As a matter of fact, since the incorporation of the AHP calculation block in the IDRISI 3.2 software package, it has become much easier to apply this technique to solve spatial problems. Nevertheless, mention can be made of some recent experimentation based on the integration between GIS and the ANP (Saaty, 2005), which is particularly suitable for dealing with complex decision problems that are characterized by interrelationships among the elements at stake

(Nekhay *et al*., 2009; Neaupane and Piantanakulchai, 2006; Levy *et al*., 2007; Ferretti, 2011a; Ferretti and Pomarico, 2011).

*Application domain and decision problems*

Another important aspect that testifies the vitality of the research in the MC-SDSS field is represented by the wide range of decision and management situations in which they have been applied over the last 20 years.
Table 4 shows a cross-classification of the MC-SDSS articles according to the type of decision (and management) problems and application domain while Figure 3 presents the results of the classification graphically.

***Table 4*** *– Classification of the MC-SDSS articles according to the application domain and decision problem*

| | | Decision problem type | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Land use allocation | Site selection | Land suitability analysis | Risk assessments | Impact assessments | Vulnerability assessments | Scenario evaluation | Plan evaluation | Resource allocation | Vehicle routing | Total | % |
| Application domain | Agriculture | 1 | 3 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **10** | 5,26 |
| | Undesirable facilities location (energy) | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **4** | 2,11 |
| | Undesirable facilities location (waste) | 0 | 2 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **13** | 6,84 |
| | Undesirable facilities location (industry) | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **4** | 2,11 |
| | Hydrology and water management | 0 | 8 | 16 | 3 | 5 | 1 | 1 | 0 | 0 | 0 | **34** | 17,89 |
| | Urban/ regional planning | 2 | 16 | 15 | 1 | 3 | 1 | 4 | 2 | 0 | 0 | **44** | 23,16 |
| | Geology and geomorphology | 0 | 3 | 1 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | **9** | 4,74 |
| | Environment/ecology | 0 | 14 | 12 | 1 | 3 | 2 | 1 | 0 | 0 | 0 | **33** | 17,37 |
| | Forestry | 0 | 4 | 3 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | **11** | 5,79 |
| | Transportation | 0 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 9 | **15** | 7,89 |
| | Natural Hazard | 0 | 1 | 1 | 6 | 0 | 0 | 2 | 0 | 0 | 0 | **10** | 5,26 |
| | Waste management | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | **1** | 0,53 |
| | Others | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **2** | 1,05 |
| | Total | **3** | **56** | **73** | **17** | **14** | **5** | **8** | **2** | **3** | **9** | **190** | 100,00 |
| | % | 1,58 | 29,47 | 38,42 | 8,95 | 7,37 | 2,63 | 4,21 | 1,05 | 1,58 | 4,74 | 100,00 | |

Major application areas were found to be in urban/regional planning (23,16%), hydrology and water management (17,89%) and environment/ ecology (17,37%). These applications accounted for 58,42% of the total. The rest of the MC-SDSS applications were found in areas such as undesirable facilities location (11,06%), transportation (7,89%), forestry (5,79%), natural hazard (5,26%) and agriculture (5,26%).
The survey also showed that the MC-SDSS approach was most often used for tackling land suitability problems (Table 4 and Figure 3). As a matter of fact, almost 40% of the articles were concerned with land suitability analysis.
In the context of land suitability analysis, it is worth highlighting the difference between the site selection problem and the site search problem (Cova and Church, 2000). The aim of site selection analysis is to identify the best site for some activity given the set of potential (feasible) sites. In this type of analysis all the characteristics (such as location, size, relevant attributes, etc.) of the

candidate sites are known. The problem is to rank or rate the alternative sites based on their characteristics so that the best site can be identified. If there is not a pre-determined set of candidate sites, the problem is referred to as site search analysis. The characteristics of the sites (their boundaries) have to be defined by solving the problem. The aim of the site search analysis is to explicitly identify the boundary of the best site. Both the site search problem and land suitability analysis assume that there is a given study area and the area is subdivided into a set of basic unit of observations such as polygons (areal units) or rasters. The land suitability analysis problem involves classification of the units of observations according to their suitability for a particular activity. The explicit site search analysis determines not only the site suitability but also its spatial characteristics such as its shape, contiguity, and/or compactness by aggregating the basic units of observations according to some criteria (Malczewski, 2004).

In this literature survey, the term land suitability analysis has been used in a broader sense that includes the site search problem.

According to the present classification, land suitability analysis were most frequently used in such application domains as: hydrology and water management (21,92%), urban/ regional planning (20,55%), and environment/ ecology (16,44%). In addition, site selection problems (30%) and risk assessment problems (9%) were found in a substantial portion of the MC-SDSS articles.

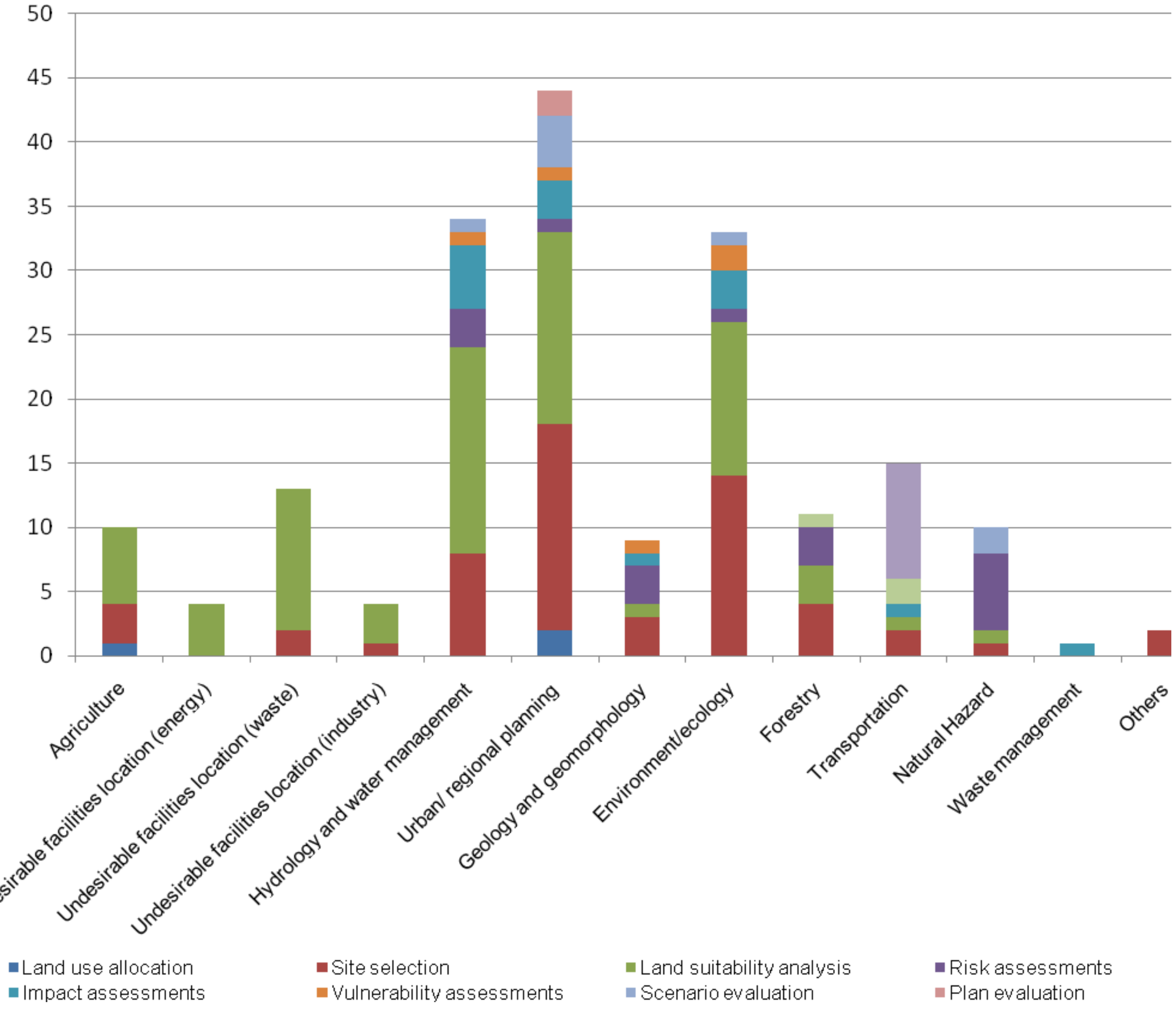


***Figure 3*** *– Distribution of the MC-SDSS articles according to the application domain and decision problem*

*Raster versus vector data*

The geographical information can be presented in two formats: vector and raster. In a vector layer the objects are represented by means of points, lines or polygons. Each layer has an associated table where, for each element, the information for different attributes is stored. A raster layer is a matrix of cells (called pixels) which contain a certain value and which can be represented by giving each pixel a color with respect to its value.
The result of the survey on the recent literature concerning MC-SDSS (Table 2) puts in evidence that most of the applications (158) use raster data models, accounting for 38,27% of the total, while only 12 applications (6,12%) use vector data models.

*Alternative focused approach versus value focused approach*

As highlighted by Sharifi and Retsios (2004), the quality of the decision depends on the sequence and quality of the activities that are carried out. Depending on the situation, there is a number of ways in which the sequence of activities can be organized. According to Keeney (1992), two major approaches can be distinguished: alternative focused, and value-focused. The alternative-focused approach starts with the development of alternative options, proceeds with the specification of values and criteria and then ends with evaluation and recommendation of an option. The value-focused approach on the other hand, considers the values as the fundamental element in the decision analysis. Therefore, it first focuses on the specification of values (value structure), then considering the values, it develops feasible options to be evaluated according to the predefined value and criteria structure. This implies that decision alternatives are to be generated so that the values specified for a decision situation are best achieved. In other words, the order of thinking is focused on what is desired, rather than on the evaluation of alternatives. In fact alternatives are considered as means to achieve the more fundamental values, rather than being an end to themselves (Sharifi and Retsios, 2004).
In the present survey the dichotomy between alternative focused approach and value focused approach has been investigated, highlighting that most of the applications (153) underpins on a value focused approach, accounting for 78,06% of the total, while only 32 applications (16,33%) underpins on an alternative focused approach.

*Theoretical approach versus practical application*

Finally, mention has to be made to the fact that most of the articles presents an application to a real case study (95,41%)  but it’s worth highlighting that among the theoretical studies (which account for 8,16% of the total) some very interesting researches have been developed aiming at investigating the possibility to integrate outranking methods and GIS [119; 177] and at developing new software [17; 34; 188].

## 6. Conclusions and directions for further research

The paper reviews the literature concerning MC-SDSS and highlights how this research field has been growing increasingly. The soaring attention and interest into these particular Decision Support Systems is probably due to the recognition of the need to consider more criteria in order to achieve solutions closer to reality and to the greater awareness of the importance of the spatial nature of the elements considered in the decision- making process. As a matter of fact, complex decision problems are frequently encountered in urban and land-use planning, typically involving the consideration of a wide range of incommensurable and conflicting criteria.
In this paper the author reviewed some of the recent works on MC-SDSS by classifying the literature production between 2007 and 2011. Particular attention has been paid to the dichotomies existing between Multi- Objective Decision Analysis and Multi- Attribute Decision Analysis, between raster data and vector data, and between the value focused thinking approach and the

alternative focused thinking one. Moreover, the classification has considered the aggregation rule used, the extent of the GIS and MCDA integration, and the type of application domain and decision problem.
The survey has revealed that urban/ regional planning, hydrology and water management and environment/ ecology were the most frequently used application domains in MC-SDSS studies. In addition, the study has putted in evidence that the types of problems with which MC-SDSS most frequently cope are the land suitability analysis and the site selection ones.
The study thus underlines the relevant role land suitability analyses play in spatial planning. In fact, these analyses allow us to determine and harmonize the guidelines for the various land use types and intensities, as well as to assess potential conflicts between population needs and resource availability.
Furthermore, the paper highlights the fundamental ability of the integrated MC-SDSS approach to support both the planning process and the evaluation one.
In the planning process, MC-SDSSs assist their users in articulating decision objectives and evaluation criteria, forming and articulating preferences and finding feasible alternatives. In the evaluation process, MC-SDSSs assist their users in comparing and assessing the generated alternatives so that better decision options can be identified. MC-SDSSs are thus able to efficiently support both the generation and the evaluation of alternatives.
At the same time the survey has revealed some challenges and trends in MC-SDSS research. First of all, considerable attention in the future has to be paid to the integration of the temporal dimension in spatial multicriteria analysis and to the validation of the models through sensitivity analysis.
As a matter of fact, carrying out a complete sensitivity analysis is quite a complex and difficult process to implement in the spatial multicriteria evaluation, especially with respect to error margins in each score, which corresponds basically to a pixel in the map (Zucca *et al*., 2008).
Furthermore, the literature survey has revealed that there is currently an increasing request for web based MC-SDSS and for tools supporting collaborative decisions in order to move participative processes forward.
Finally, based on the reviewed papers, it is possible to put in evidence some areas as further research. Firstly, it would be interesting to review the criteria used in the different types of applications domain and decision problems. Secondly, it would certainly be useful to survey which software have been developed and are currently the most used in the MC-SDSS applications.
Undoubtedly, many other researches exist on MC-SDSS and a future manual search based on the reference section of the papers identified by the automated search would be useful.
However, although the results of the classification are based on some simplifications, the present study hopes to help to facilitate future research in this area.
In conclusion, the undertaken survey highlights that any integration of MCDA and GIS constitutes a very promising line of research in the broad field of sustainability assessments of territorial transformation since the integrated approach allows to demonstrate the importance of “where” in addition to “what” and “how much”.

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