A review of Spatial Multi Criteria Decision Making

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Abstract

Nowadays a wide range of operational and research activities in different fields of Geographic Information Systems (GIS) consist of decision making problems. Decision making is the main element in the spatial analysis in geographic studies and skills related to the success of the planning process. This paper has been written in the field of GIS and decision making. This paper provides a survey of the literature on multiple criteria decision making (MCDM) applications to GIS problems undertaken after 2000. This provides a unified source of references that could be useful for students, researchers and practitioners. The paper ends with an assessment of the literature presented, aiming to reach some conclusions, as well as indicate future trends in this line of research.

Key words: Geographic Information Systems (GIS); Multi Criteria Decision Making (MCDM), Spatial Decision Making.

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1. Introduction

The GIS-based multi criteria decision making (GIS–MCDM) can be defined as a process that transforms and combines geographical data (map criteria) and value judgments (decision-makers' preferences and uncertainties) to obtain appropriate and useful information for decision making. The chief rationale behind integrating GIS and MCDM is that these two distinct areas of research can complement each other. While GIS is commonly recognized as a powerful and integrated tool with unique capabilities for storing, manipulating, analyzing and visualizing spatial data for decision making, MCDM provides a rich collection of procedures and algorithms for structuring decision problems, designing, evaluating and prioritizing alternative decisions. It is in the context of the synergetic capabilities of GIS and MCDM that one can observe the benefits for advancing theoretical and applied research on the integration of GIS and MCDM (Malczewski, 2006). Interest in coupling GIS and MCDM methods has increased considerably in recent years (Feick & Hall, 2004).

There are some articles that have reviewed the literature related to GIS-MCDM (Malczewski, 2006, 2004; Chakhar & Martel, 2003). The main aim of the paper is to survey and classify the GIS-MCDM articles published 2000 onwards. The literature review was done by an expansive search on such academic databases as Science Direct, Emerald, EBSCO, IEEE, Springer, Taylor & Francis, and Wiley-Blackwell. The paper is organized as follows: next sections describe the main problem specifications of personnel selection and the relation between personnel selection problem and multi criteria decision making. In the section 3 respectively, we review the existing literature of application MCDM on GIS. In section 4 analyze papers and describe some future perspectives of MCDM for GIS and recommendations. Finally conclusion and further steps present in section 5.

2.Classification of MCDM methods

Decision making is the process of selecting a possible course of action from all the available alternatives (Zeleny, 1981). The task of decision making is intimately associated with every area of human life. Figueira et al. (2005) has classified the whole set of decision making problems, based upon two dimensions: the nature of outcomes (stochastic versus deterministic), and the nature of constrains (whether they are explicit or implicit). In addition to the above two dimensions, there may be other dimensions as well. One may consider the number of decision makers as a dimension (a single decision maker versus a group of decision makers). Another important dimension may be the number of criteria (single criterion versus multiple criteria). One of the most used methods in decision making area is Multiple Criteria Decision Making (MCDM). MCDM problems become more and more popular in this developed world around us (Zeleny, 1981). In fact, over the past four/five decades, MCDM methods have grown leaps and bounds. Despite wide diversity of MCDM problems, the whole set of problems has been classified into two major categories: Multiple Objective Decision Making (MODM) and Multi Attribute Decision Making (MADM) (Kahraman, 2008).

3. Overview of the applications of MCDM in 4 area of spatial problems

In this paper, an overview is developed along some sub sections: (1) Landslide; (2) Flood risk assessment; (3) Site selection; (4) Vulnerability assessment.

3.1 Landslide

There are numerous studies on mapping landslide susceptibility through the use of spatial analysis and some of them used MCDM, which is the most fundamental approach in decision making.

Jiang and Eastman (2000) and others describe two of the most common procedures in MCDM that are used to aggregate criteria in a spatial decision support system (SDSS). The first procedure is the Boolean overlay, which involves a combination of maps (criteria) by logical operators such as intersection (AND) or union (OR) while the second procedure is the weighted linear combination (WLC), which involves numeric standardization of evaluation criteria aggregated by weighted average. Indeed, applications of both aggregation techniques in landslide susceptibility mapping have been widely implemented using various modelling frameworks (Gorsevski, et al., 2006; Komac, 2006; Ayalew, et al., 2004; Lee & Choi, 2004; van Westen, et al., 2000; Barredo, et al., 2000). Ayalew et al. (2004), Rashed and Weeks (2003), and Gorsevski et al. (2006) have employed MCDM in the area of natural hazard risk assessment. For example, using landslide controlling parameters such as litho logy, slope gradient, aspect, elevation and plan and profile curvature Ayalew et al. (2004) have demonstrated the use of MCDM in situation where the preferences of experts are necessary components of natural risk evaluation process. The number of geospatial problems with different preference structures emphasizes the need for advancing theoretical and applied research in the area of MCDM in group settings.

3.2 Flood risk assessment

The application of MCDM in general and especially spatial MCDM in the context of flood risk management is still rare. Brouwer and van Ek (2004) evaluate long term flood risk management options in the Netherlands with MCDM using the DEFINTE software. Bana and Costa (2004) used the MACBETH approach for the evaluation of alternative flood control measures in Portugal. Akter and Simonovic (2005) finally deal with flood risk management and MCDM in the Red River Basin in Canada. They focus on methodologies to incorporate multiple stakeholders' opinions in MODM. Simonovic and Nirupama (2005) expand this approach by integrating fuzzy set techniques in order to deal with uncertainties in the evaluation criteria. A rather similar approach, also based on SCP, is used by Thinh and Vogel (2006) for land use suitability assessment in the Dresden region (Saxony), also including flood risk as a criterion. However, most of the multi criteria approach in the context of flood risk focus on the evaluation of flood mitigation measures instead of flood risk mapping. Meyer et al. (2009) developed a GIS-MCDM method for flood risk assessment and mapping in Germany with consideration of inundation probability.

3.3 Site selection

One of the most common GIS based strategies that have been designed to facilitate decision making in site selection is MCDM. The Analytic Hierarchy Process (AHP) method, originally developed by Saaty (1980), is a flexible and easily implemented MCDM technique and its use has been largely explored in the literature with many examples in locating facilities (Wang, et al., 2009b; Dey & Ramcharan, 2008; Tuzkaya, et al., 2008; Kontos, et al., 2005) and in land suitability analysis (Yang, et al., 2008). AHP techniques have been used by Dey and Ramcharan (2008) for the site selection of limestone quarry operations to support cement production in Barbados; by Gemitzi et al. (2007), Kontos et al. (2005), and Sener et al. (2006) for ranking potential MSW landfill areas; and by Wang et al. (2009b) combined with spatial information technologies for landfill site selection. The integration of GIS and AHP is a powerful tool to solve the landfill site selection problem (Sener, et al., 2011; Sener, et al., 2006).

Bobbio (2002) experienced a deliberative democracy process in an area in the Province of Torino (6829 km2), Italy, where local communities were involved in a decision concerning the sitting of an incinerator and a landfill for MSW. The process lasted 17 months and ended with an agreed choice. The author worked on the third phase of the decision-making process (choosing the best alternative) considering 14 criteria for the incinerator and 13 criteria for the landfill. Vatalis and Manoliadis (2002) overlaid GIS digital maps to find the suitable landfill sites in Western Macedonia, Greece.

Kontos et al. (2005) investigated the sitting of MSW landfills with a spatial multiple criteria analysis methodology in an area of 480 km2 in the Island of Lemnos, Greece. The authors worked on the macro sitting level considering 11 criteria. In particular, AHP was used to perform a pair-wise comparison based on a review of relevant landfill sitting literature. Kontos et al. (2005) used the pair wise comparison matrix and criteria weights vector to calculate the suitability index estimated using the method of simple additive weighting (SAW). Kontos et al. (2005) evaluated the suitability of the study region to select an optimal landfill site using a spatial MCDM methodology. Hansen (2005) presents a GIS based MCDM to identify the best sites for the construction of new wind farms. Zambon et al. (2005) describe a GIS based MCDM method for evaluating alternative places for the location of thermoelectric power plants in Sao Paulo state (Brazil).

Sener et al. (2006) used GIS and MCDM to determine appropriate landfill sites. Mahini and Gholamalifard (2006) described a MCDM method, called weighted linear combination (WLC), in a GIS environment to evaluate the suitability of the outskirts of Gorgan city (Iran) as a landfill site.

Gemitzi et al. (2007) have used a groundwater vulnerability index including a five discrete groundwater vulnerability classes in order to assess alternative choices for hazardous landfill sites.

AHP and TOPSIS have been used by Oenuet and Soner (2008) for solid waste transshipment site selection in Turkey. Sumathi et al. (2008) studied the sitting of MSW landfills using a MCDM and overlay analysis using a GIS in an area of 293 km2 in the district of Pondicherry, India. The authors worked on the macro/micro-siting level considering 11 criteria. AHP was employed wherein a consistent weight set was extracted through the pair wise comparison by decision makers in their consideration of each factor against one another. Feedback from a team with expertise in multi disciplinary fields of local environmental management of the Pondicherry was sought in the process. Chang et al. (2008) and Akbari et al. (2008) combined GIS and a convoluted MCDM process to select a landfill site. Nas et al. (2008) selected an MSW landfill site for Konya, Turkey using GIS and an evaluation of several criteria. Integrating land suitability analysis in urban greenery was further investigated by Zucca et al. (2008). They investigated a site selection process for setting up a local park. Delgado et al. (2008) performed a land suitability analysis for MSW sanitary landfill sitting in an area of 400 km2 in the Cuitzeo Lake Basin, Mexico. The authors worked on the macro siting level considering 11 criteria. The authors did not use AHP but a Boolean logic model. In particular, panelists were asked to discuss the importance of the criteria, and provide a qualitative ranking subsequently transformed into quantitative weights normalized to one. Radiarta, et al. (2008) demonstrated the use of GIS to model site selection for scallop culture in Funka Bay based on a certain important criteria and showed acceptable results.

Nobre et al. (2009) described a geo spatial multi criteria methodology, based on geographic information systems technology, for identification of the best location to deploy a wave energy farm. Wang et al. (2009a) developed a case study on MSW landfill sitting using spatial information technologies and AHP in an area of 16807.8 km2 corresponding to the territory of Beijing, China. The authors worked on the macro sitting level considering 13 criteria. AHP was used to establish the relative importance of hierarchy elements. Decision-makers evaluated the importance of pairs of grouped elements in terms of their contribution to the higher hierarchy. Sharifi et al. (2009) integrated MCDM for a GIS-based hazardous waste landfill sitting in an area of 28,817 km2 corresponding to the Kurdistan Province, western Iran. The authors worked on the macro sitting level considering 14 non exclusionary criteria which were weighted with the 9-point rating system and using the information provided by regional experts. Guiqin et al. (2009) used spatial information technologies and AHP for landfill site selection in Beijing, China.

Geneletti (2010) proposed and tested an approach involving the stakeholders' opinion in an inert landfill sitting process in an area of 196 km2 in the south western part of Trentino, Italy.

3.4 Vulnerability assessment

Eco environmental vulnerability has become a central focus of the global change and sustainability research communities. It has also become a popular topic in the domain of environmental resource research, especially eco environmental vulnerability assessment (L. Li, et al., 2009). Integrated analysis of eco environmental vulnerability helps to ascertain the key eco environmental characteristics of a study area. Furthermore, results of systemic assessments can help to identify particular problems within the study area so that appropriate measures can be taken to address these. Nevertheless, regional analysis of eco environmental condition and vulnerability represents a significant assessment challenge. There is no widely accepted theoretical and methodological system for eco environmental vulnerability assessment. A primary problem of regional vulnerability assessment is the integration of information from many different sources into an overall ranking of relative vulnerability. Therefore, it is crucial to select detailed assessment methods. Several methods have previously been employed and developed for vulnerability assessment. Among them, the analytic hierarchy process (AHP) is one of the most commonly used method of assessment (Ying, et al., 2007; Li, et al., 2007), which works on a premise that decision making of complex problems can be handled by structuring the complex problem into a simple and comprehensible hierarchical structure. Li, et al. (2007) utilized the GIS model approach to research the current condition of eco environment quality for typical area of red soil hilly region. Li et al. (2009) established an environmental information system database. Based on the database, an eco environmental vulnerability assessment method using integrated fuzzy AHP (FAHP) and GIS was developed for the Danjiangkou Reservoir Area. According to eco environmental conditions and entropic effects, vulnerability was classified into five levels: potential, light, medium, heavy and very heavy.

4. Future perspectives

The main problems are related to the choice of method for combining different evaluation criteria, standardization of criterion maps, and the specification of criterion wrights. Different methods may produce different results. There is no commonly acceptable method for assigning the weights of relative importance to the criterion maps. Again, it is likely that different weighting methods would result in different overall land-use suitability patterns. Some researchers suggest that these problems can be, at least partially, resolved by using the AI based methods. However, there are not enough real world applications using the AI methods to verify their usefulness for tackling complex land use planning problems. Arguably, the major limitation of these methods is their ‘black box’ style of analyzing spatial problems.

There are several plans to incorporate MCDM methods supporting imprecision, uncertainty and fuzziness. The integration of such methods in a spatial decision making has the potential to enhance its analytical strength.

Spatial decision problems naturally involve several different kinds of stakeholders. However, the majority of the Spatial-MCDM articles consider individual decision maker's approaches and only a few works are devoted to Group spatial decision making.

There is increasing interest in the development of Web-based Spatial-MCDM. Research on this topic is worthwhile since it promotes the sharing and access of geographical information and facilitates spatial decision making.

5. Conclusions

Application of MCDM in Spatial decision making is widespread and growing. This review identified 4 sub areas since 2000. It was found that the annual publication rate has been steadily growing since the late 2005s.

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