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Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS ☆

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Abstract

This paper focuses on the integration of GIS and an extension of the analytical hierarchy process (AHP) using quantifier-guided ordered weighted averaging (OWA) procedure. AHP_OWA is a multicriteria combination operator. The nature of the AHP_OWA depends on some parameters, which are expressed by means of fuzzy linguistic quantifiers. By changing the linguistic terms, AHP_OWA can generate a wide range of decision strategies. We propose a GIS-multicriteria evaluation (MCE) system through implementation of AHP_OWA within ArcGIS, capable of integrating linguistic labels within conventional AHP for spatial decision making. We suggest that the proposed GIS-MCE would simplify the definition of decision strategies and facilitate an exploratory analysis of multiple criteria by incorporating qualitative information within the analysis.

Keywords: Analytical hierarchy process; Ordered weighted averaging; GIS; Multicriteria evaluation; Linguistic quantifiers

1. Introduction

Spatial multicriteria decision problems typically involve a set of feasible decision alternatives that are evaluated on the basis of multiple, conflicting and incommensurate criteria. GIS-based multicriteria decision analysis (GIS-MCDA) can be defined as a process that integrates and transforms geographic data (map criteria) and value judgments (decision maker's preferences and uncertainties) to obtain overall assessment of the decision alternatives (Malczewski, 1999, 2006a).

Central to GIS-MCDA is the concept of decision rules or evaluation algorithms. A decision rule is the procedure that dictates the order of alternatives or which alternative is preferred to another in a decision problem (Starr and Zeleny, 1977). In the context of GIS-MCDA, a decision rule is a procedure that enables the decision maker to order and select one or more alternatives from a set of available alternatives (see Malczewski, 1999). There are two fundamental classes of decision (or combination) rules in GIS: the Boolean overlay operators

☆Module can be downloaded from the server at http://arcscripts.esri.com/details.asp?dbid=14894.

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and weighted summation procedures. They have been the most often used decision rules in GIS (Janssen and Rietveld, 1990; Eastman, 1997; Heywood et al., 2002; O'Sullivan and Unwin, 2003; Malczewski and Rinner, 2005). These approaches can be generalized within the framework of ordered weighted averaging (OWA) (Jiang and Eastman, 2000; Makropoulos et al., 2003; Malczewski et al., 2003; Malczewski and Rinner, 2005; Malczewski, 2006b). OWA is a family of multicriteria aggregation procedures. It has been developed in the context of fuzzy set theory (Yager, 1988). OWA involves two sets of weights: the weights of criterion importance and order weights. By changing the order weights, one can generate a wide range of outcome (decision strategy) maps. Over the last decade or so, several applications of OWA have been implemented in the GIS environment (Jiang and Eastman, 2000; Araújo and Macedo, 2002; Rinner and Malczewski, 2002; Makropoulos et al., 2003; Malczewski et al., 2003; Rashed and Weeks, 2003; Calijuri et al., 2004; Makropoulos and Butler, 2005; Malczewski, 2006b).

The analytical hierarchy process (AHP) proposed by Saaty (1980) is another well-known procedure which is based on the additive weighting model. The AHP method has been employed within the GIS environment in two distinct ways. First, it can be employed to derive the importance weights associated with criterion map layers. Then the weights can be aggregated with the criterion map layers in a way similar to weighted combination methods. This approach is of particular importance for spatial decision problems with a large number of alternatives that make it impossible to complete pairwise comparisons of the alternatives (Eastman et al., 1993; Marinoni, 2004). Second, the AHP method can be used to combine the priority for all levels of the hierarchical structure, including the level representing alternatives. In this case, a relatively small number of alternatives can be evaluated (Jankowski and Richard, 1994).

Yager and Kelman (1999) introduced an extension of the AHP using OWA operators (AHP_OWA), suggesting that the capabilities of AHP as a comprehensive tool for decision making can be improved by integration of the fuzzy linguistic OWA operators. The inclusion of AHP and OWA can provide a more powerful multicriteria decision-making tool for structuring and solving decision problems including spatial decision problems.

Both AHP and OWA procedures have been implemented individually in GIS environments. Eastman (1997) and Jiang and Eastman (2000) implemented OWA operators in GIS-IDRISI. Malczewski et al. (2003) implemented parameterized OWA procedures in ArcView 3.2 environment as a GIS-OWA module. Also, the AHP has been part of the IDRISI functionality for years. It also has been implemented in the ArcGIS environment as a VBA macro (Marinoni, 2004). However, there is still no implementation of the AHP_OWA operators using fuzzy linguistic quantifiers in GIS solutions.

There are two objectives of this paper: (1) to adapt the AHP_OWA procedures using fuzzy linguistic quantifiers for GIS-based multicriteria evaluation (MCE) procedures, and (2) to demonstrate the implementation of AHP_OWA procedures as an additional command in ArcGIS environment. Sections 2 and 3 provide an introduction to the concept of the AHP and OWA operators in a spatial decision-making context. Section 4 presents an illustrative example of the AHP_OWA. Then, in Section 5, we demonstrate the GIS-based linguistic quantifier-guided AHP_OWA. Section 6 exemplifies a real-world application of the GIS-based AHP_OWA. The final section presents concluding remarks.

2. The AHP

The AHP is a flexible and yet structured methodology for analyzing and solving complex decision problems by structuring them into a hierarchical framework (Saaty, 1980). The AHP procedure is employed for rating/ranking a set of alternatives or for the selection of the best in a set of alternatives. The ranking is done with respect to an overall goal, which is broken down into a set of criteria (objectives, attributes). The AHP procedure involves three major steps: (i) developing the AHP hierarchy, (ii) pairwise comparison of elements of the hierarchical structure, and (iii) constructing an overall priority rating.

2.1. The AHP hierarchy

The first step in the AHP procedure is to decompose the decision problem into a hierarchy that consists of the most important elements of the decision problem. In developing a hierarchy, the top level is the ultimate goal of the decision at hand. The