Integration of Geographical Information Systems and Multi-Criteria Decision Analysis

Coğrafi Bilgi Sistemleri ve Çok Ölçütlü Karar Analizinin Bütünleştirilmesi

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Abstract: *This paper presents strategies for integrating geographical information systems (GIS) and multi-criteria decision analysis (MCDA) and introduces a tool, GIS-MCDA, written in Visual Basic (VB) in ArcGIS for GIS-based MCDA. The GIS-MCDA deals with raster-based data sets and includes standardization, weighting and decision analysis methods. Simple additive weighting (SAW), weighted product method (WPM), technique for order preference by similarity to ideal solution (TOPSIS), analytic hierarchy process (AHP), and ordered weighted average (OWA) for decision analysis; and ranking, rating and pair-wise comparison for weighting and linear scale transformation for standardization can be applied by using this tool. The maximum score and score range procedures can be used for linear scale transformation. Additionally, an application of the GIS-based MCDA to determine the flood vulnerability of the South Marmara Basin in Turkey is examined.*

Keywords: *Multi-criteria decision analysis, geographical information systems, flood vulnerability*

Öz*: Bu bildiride, coğrafi bilgi sistemleri (CBS) ve çok ölçütlü karar analizinin (ÇÖKA) bütünleştirilmesi için çeşitli yaklaşımlar ve ArcGIS yazılımı ortamında Visual Basic (VB) programlama dilinde yazılan, CBS-tabanlı ÇÖKA uygulamalarının gerçekleştirilebildiği GIS-MCDA modülü anlatılmaktadır. GIS-MCDA modülünde raster veriler kullanılmakta ve çok sayıda normalleştirme, ağırlık belirleme ve karar analizi yöntemi uygulanabilmektedir. Karar analizi için basit ağırlıklı toplam, ağırlıklı çarpım, TOPSIS, analitik hiyerarşi ve sıralı ağırlıklı ortalama; ağırlık belirleme için sıralama, puanlama ve ikili karşılaştırma ve normalleştirme için doğrusal ölçek dönüşümü yöntemleri kullanılabilmektedir. Doğrusal ölçek dönüşümünde "en büyük değer" ve "en küçük ve en büyük değer" ile normalleştirme gerçekleştirilebilmektedir. Bu bildiride ayrıca, bir CBS tabanlı ÇÖKA uygulaması, Türkiye-Güney Marmara Havzası taşkın duyarlılığının belirlenmesi örneğinde incelenmiştir.*

Anahtar sözcükler: *Çok ölçütlü karar analizi; coğrafi bilgi sistemleri, taşkın duyarlılığı*

Introduction

Many decision tasks are concerned with spatial preferences and/or patterns (Chen, Blong, & Jacobson, 2001). Decision problems that involve spatial data and information are referred to as *spatial decision problems*. Spatial decision problems often require that a large number of feasible alternatives be evaluated based on multiple criteria; thus, spatial decisions are multi-criteria in nature (Massam, 1980; Rajabifard, Feeney, & Williamson, 2003).

Although GIS provide extensive spatial analysis and data visualization power to their users, such systems offer a limited capacity for tackling complex spatial decision problems (Densham & Goodchild, 1989). MCDA methods linked with GIS can be used to make such decisions (Chen, Blong, & Jacobson, 2001).

GIS-based MCDA

Spatial multi-criteria analysis requires both data on criterion values and the geographical locations of alternatives. The data are processed using GIS and MCDA techniques to obtain information for making decisions. Consequently, the terms GIS-based MCDA and spatial MCDA are used interchangeably (Malczewski, 1999).

GIS-based MCDA involves the utilization of geographical data, the decision maker's preferences and the aggregation of the data and preferences according to specified decision rules. GIS-based MCDA aggregates multidimensional geographical data and information into one-dimensional values (Jankowski, 1995; Malczewski, 1999; 2006).

Physically, there are three possible modes to integrate GIS and MCDA tools: (i) loose integration (ii) tight integration and (iii) full integration (Figure 1) (Chakhar & Martel, 2003; Chakhar & Mousseau, 2008).

Loose integration mode: The integration of GIS software and a stand-alone MCDA software is made by the use of an intermediate system.

Tight integration mode: A particular MCDA model is directly added to the GIS software. The MCDA model constitutes an integrated but autonomous part with its own database. The use of the interface of the GIS part alone increases the interactivity of the system.

Full integration mode: A fully GIS-MCA integrated system that has a unique interface and a unique database. Here, the MCDA method is activated directly from the GIS interface, as any GIS basic function. The GIS database is extended so as to support both the geographical and descriptive data, on the one hand, and the parameters required for the multi-criteria evaluation techniques, on the other hand.
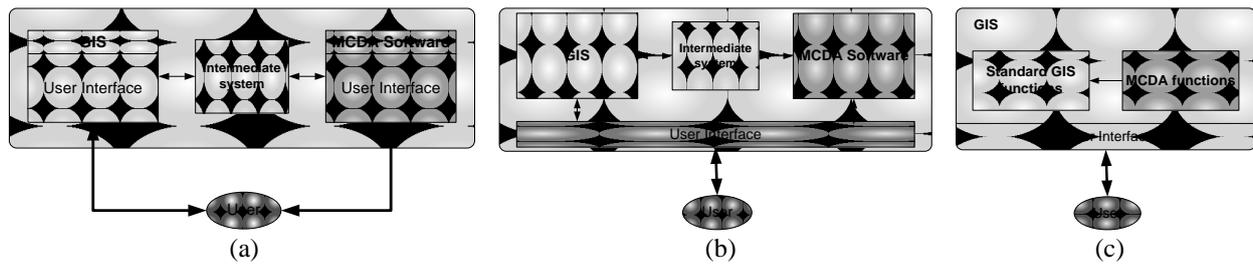

Figure 1. Integration modes of GIS and MCDA (a) loose (b) tight and (c) full integration
(Chakhar & Mousseau, 2008)

The GIS-MCDA Tool

The GIS-MCDA has been written in VB using ArcObjects, which is the development platform for ArcGIS. The tool deals with raster-based data sets and allows the user to input raster layers, runs the MCDA functions, and displays the analysis result as a layer in ArcMap. The functions and the components of the GIS-MCDA are illustrated in Figure 2a. The GIS-MCDA tool includes standardization, weighting and multi-criteria analysis methods (Figure 2b). SAW, WPM, TOPSIS, AHP, and OWA for multi criteria analysis, and ranking, rating and pair-wise comparison for weighting and linear scale transformation for standardization can be applied with this tool. The maximum score and score range procedures can be used for linear scale transformation.
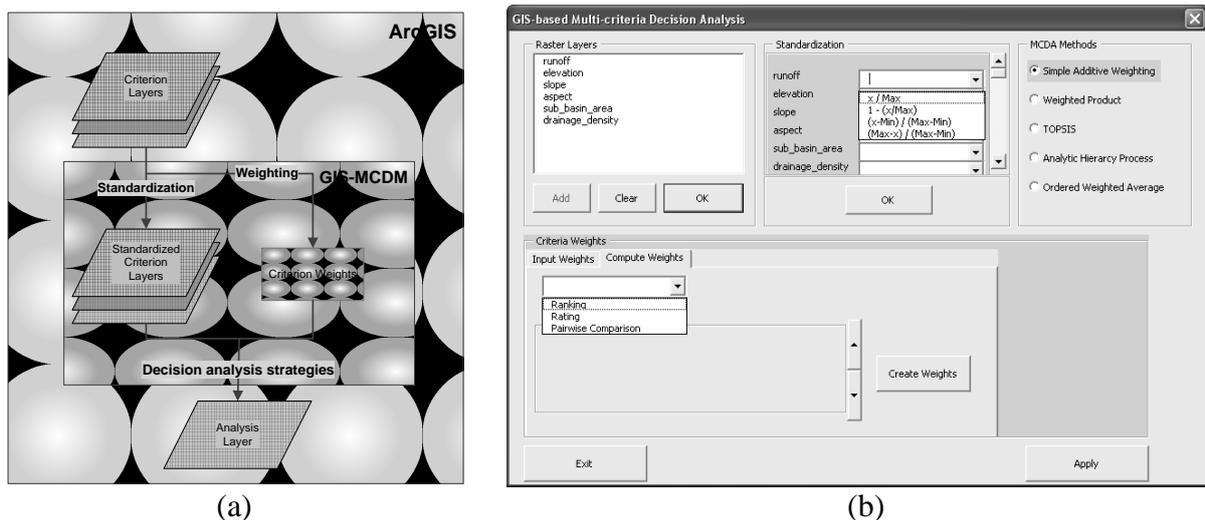

Figure 2. (a) The general structure of the GIS-MCDA interface (b) The GIS-MCDA interface in the ArcGIS 9.2

A Case Study

This section presents a real-world case study to determine flood vulnerability using the AHP method. The study area is the South Marmara Basin in Turkey. The area of the basin is about 6300 km^2. Six evaluation criteria were taken into account: runoff, elevation, slope, aspect, sub-basin area and drainage density. Annual rainfall data collected from

82 meteorological stations, 1/25000-scale topographical maps, digital elevation data and soil data, and ASTER-1B satellite images were used to prepare the criterion layers.

AHP was implemented to produce a flood vulnerability layer. The cell values ranged from 0.41 to 0.89, where the higher value represents higher vulnerability. To classify the cell values into groups, the natural breaks classification method in ArcGIS was used. The flood vulnerability was evaluated under five categories: very high (0.89-0.75), high (0.75-0.71), medium (0.71-0.65), low (0.65-0.59), and very low (0.59-0.41). To verify the results, flood-affected areas between the years 1970-1997 obtained from the General Directorate of State Hydraulic Works were overlaid with the final layer (Figure 3). It was determined that approximately 95 percent of flood-affected areas for the years 1970-1997 correspond to areas labeled with very high or high flood vulnerability. More detailed information can be found in Ozturk (2009).
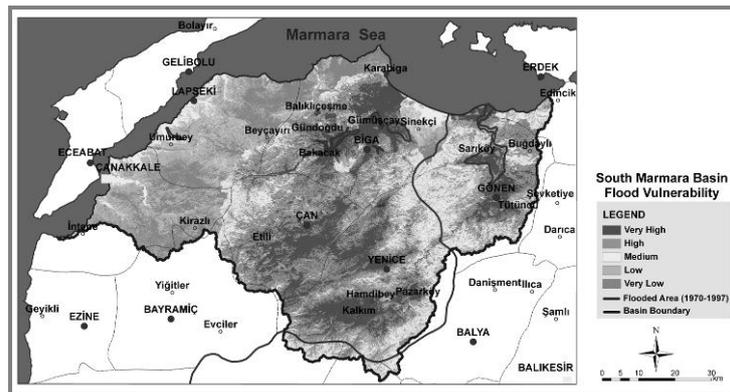

Figure 3. Flood vulnerability layer created using AHP

Conclusion

This paper presents a tool that integrates GIS and MCDA. The tool has a range of multi-criteria evaluation capabilities, including criterion standardization, criterion weighting and decision analysis procedures. The article also presents an application of GIS-based MCDA by applying the GIS-MCDA tool to a real-world problem that involved determining flood vulnerability in the South Marmara Basin in Turkey. The analysis gave realistic results. It is anticipated that such methodologies can play an important role in disaster management. In addition, because the methods performed by GIS-MCDA are generic, the tool can be used for many other decision applications, including natural resource management, land-use planning and suitability evaluation.

Future research will be focused on web-based spatial multi-criteria decision analysis systems since they promote the sharing and access of geographical information and multi-criteria collaborative spatial decision making.

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