# TECHNIQUE FOR ORDER PREFERENCE BY SIMILARITY TO IDEAL SOLUTION (TOPSIS) FOR SPATIAL DECISION PROBLEMS

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**KEY WORDS:** multi-criteria decision analysis, geographical information systems, technique for order preference by similarity to ideal solution (TOPSIS)

**ABSTRACT:**

Many decision tasks in disaster management are concerned with spatial patterns and spatial decision problems often require that a large number of feasible alternatives be evaluated based on multiple criteria. Although Geographical Information Systems (GIS) provide extensive spatial analysis and data visualization power to users, such systems offer a limited capacity for tackling complex spatial decision problems. Multi-criteria Decision Analysis (MCDA) methods linked with GIS can be used to make such decisions. This paper focuses on the GIS-based Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method which is one of the most popular methods in MCDA. The TOPSIS method was implemented ArcObjects/VBA in ArcGIS environment as ArcGIS-TOPSIS tool and it was tested in a real-world situation for settlement site selection in Atakum-Samsun, Turkey.

## 1. INTRODUCTION

Many decision tasks in disaster management are concerned with spatial preferences and/or patterns. 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; Chen et al., 2001; Rajabifard et al., 2003).

Although Geographical Information Systems (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 and Goodchild, 1989). Multi-criteria Decision Analysis (MCDA) methods linked with GIS can be used to make such decisions (Chen et al., 2001).

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is one of the most popular methods in MCDA. In this paper, a tool, ArcGIS-TOPSIS, developed in the ArcGIS 9.2 environment was introduced, the theoretical background that is necessary to develop the tool was explained, and a real-world case study of decision analysis to select settlement site in Atakum-Samsun, Turkey was examined.

## 2. 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).

### 2.1 Standardization of Criteria Values

Because of the different scales upon which criteria are measured, it is necessary to standardize the factors (Eastman et al., 1995). Linear scale transformation is the most frequently used deterministic method to transform input data into commensurate criterion layers (Malczewski, 1999; Chakhar and Mousseau, 2008). A number of linear scale transformations exist. The two most often used procedures are maximum score (Eqs. (1) and (2)) and score range (Eqs. (3) and (4)).

$$x_{ij}^{'} = \frac{x_{ij}}{x_j^{\max}} \tag{1}$$

$$x_{ij}^{'} = 1 - \frac{x_{ij}}{x_j^{\max}} \tag{2}$$

$$x_{ij}^{'} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \tag{3}$$

$$x_{ij}^{'} = \frac{x_{ij}^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \tag{4}$$

Where $x'_{ij}$ is the standardized score for the *i*th alternative and *j*th criterion, $x_{ij}$ is the raw score, and standardized scores range from 0 to 1 (Malczewski, 1999).

Eqs. (1) and (3) are used when the criterion is maximized. If the criterion is minimized, Eqs. (2) and (4) are used (Malczewski, 1999).

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**2.2 Determination of Criteria Weights**

MCDA problems involve criteria of varying importance to decision-makers. Consequently, information about the relative importance of the criteria is required. This is usually achieved by assigning a weight to each criterion. The derivation of weights is a central step in eliciting the decision-maker's preferences. A weight can be defined as a value assigned to an evaluation criterion that indicates its importance relative to other criteria under consideration. As the value of the weight increases, the criterion's importance in the overall utility also increases. The weights are usually normalized to sum to 1. In the case of *n* criteria, a set of weights is defined as follows (Malczewski, 1999):

$$w = (w_1, w_2, ..., w_j, ..., w_n),\ \Sigma w = 1 \tag{5}$$

A number of criteria weighting procedures have been proposed in the MCDA literature. Some of the most popular procedures in the spatial MCDA are ranking, rating and pairwise comparison (Malczewski, 1999; Ananda and Herath, 2006).

The simplest method to assess the importance of weights is to arrange them in rank order. Every criterion under consideration is ranked in the order of the decision-maker's preference. Once the ranking is established for a set of criteria, several procedures are available to generate numerical weights from rank order information. One of the most popular approaches is rank sum. Rank sum weights are calculated according to Eq. (6):

$$w_j = \frac{n - r_j + 1}{\Sigma(n - r_k + 1)} \tag{6}$$

Where $w_j$ is the normalized weight for the *j*th criterion, *n* is the number of criteria under consideration (k=1,2,…,*n*), and $r_j$ is the rank position of the criterion (Malczewski, 1999).

In the rating method, the decision-maker estimates weights based on a predetermined scale; for example, a scale of 0 to 100 can be used (Malczewski, 1999). Rating weights are calculated according to Eq. (7):

$$w_j = \frac{w_j^*}{\Sigma w_j^*} \tag{7}$$

Where $w_j$ is the normalized weight for the *j*th criterion and $w_j$* is the score for the *j*th criterion (Ananda and Herath, 2006).

The pairwise comparison method was developed by Saaty (1980) in the context of the analytic hierarchy process (AHP) (Eastman et al., 1998). This method involves pairwise comparisons to create a ratio matrix (Malczewski, 1999). Pairwise comparisons are determined by the scale with values from 1 to 9 (Table 1) (Saaty, 1980, 2004).

The matrix has the form (de Montis, 2005):

$$A = \begin{bmatrix} a_{11} & a_{12} & ... & a_{1n} \\ a_{21} & a_{22} & ... & a_{2n} \\ ... & ... & ... & ... \\ a_{n1} & a_{n2} & ... & a_{nn} \end{bmatrix} \tag{8}$$

Where $a_{ii} = 1,\ a_{ji} = \frac{1}{a_{ij}}$ and $a_{ij} \neq 0$

| Intensity of Importance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance |
| 7 | Very strong importance |
| 9 | Extreme importance |
| 2, 4, 6, 8 | Intermediate values |
| Reciprocals | Values for inverse comparison |

Table 1. Scale for pairwise comparison (Saaty, 1980, 2004).

The weights are determined by normalizing the eigenvector associated with the maximum Eigenvalue of the (reciprocal) ratio matrix (Malczewski, 1999).

A very important aspect of this method is that a measure of inconsistency follows from the calculations performed on the pairwise judgment. This measure, called the consistency index (*CI*) by Saaty, is zero when all judgments are perfectly consistent (Kent and Williams, 1988).

*CI* can be calculated from the ratio matrix as follows:

$$CI = \frac{\lambda - n}{n - 1} \tag{9}$$

Where $\lambda$ is simply the average value of the consistency vector, and *n* is the number of criteria (Malczewski, 1999).

To determine $\lambda$, the weighted sum vector is calculated as the product of the weights and their respective columns of the original pairwise comparison matrix (e.g. first weight and first column) and the values for each row are summed, and the consistency vector is determined by dividing the weighted sum vector by the criterion weights (Malczewski, 1999).

Consistency ratio (*CR*) is the ratio of the *CI* to the random index (*RI*) as in Eq. (10) (Malczewski, 1999):

$$CR = \frac{CI}{RI} \tag{10}$$

| *n* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| *RI* | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 |

| *n* | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|
| *RI* | 1.45 | 1.49 | 1.51 | 1.48 | 1.56 | 1.57 | 1.59 |

Table 2. Random Index (Malczewski, 1999)

**2.3 TOPSIS Method**

The technique for order preference by similarity to ideal solution (TOPSIS) was developed by Yoon and Hwang (1981). The basic concept of this method is that the selected alternative should have the shortest distance to the positive ideal solution and the farthest distance from the negative ideal solution (Triantaphyllou, 2000).

The TOPSIS method assumes that each criterion tends toward a monotonically increasing or decreasing utility (Triantaphyllou, 2000; Garvey, 2008). Therefore it is easy to define the positive ideal and negative ideal solutions. The Euclidean distance approach was proposed to evaluate the relative closeness of the alternatives to the ideal solution. Thus, the preference order of the alternatives can be derived by a series of comparisons of these relative distances (Triantaphyllou, 2000).

The distance between the ideal point and each alternative can be calculated using Eq. (11). Using the same separation measure, the distance between the negative ideal point and each alternative can be determined (Eq. (12)) (Malczewski, 1999).

$$s_{i+} = \left[ \sum_{j=1}^{n} (v_{ij} - v_{+j})^2 \right]^{0.5} \qquad (11)$$

$$s_{i-} = \left[ \sum_{j=1}^{n} (v_{ij} - v_{-j})^2 \right]^{0.5} \qquad (12)$$

The relative closeness to the ideal point can be calculated by Eq. (13):

$$c_{i+} = \frac{s_{i-}}{s_{i+} + s_{i-}} \qquad (13)$$

Where $v_{ij}$ is the weighted standardized criterion value of the $i$th alternative that is calculated by multiplying standardized criterion value by the corresponding weight, and $v_{+j}$ is the ideal value and $v_{-j}$ is the negative ideal value for the $j$th criterion (Malczewski, 1999).

## 3. PROGRAMMING IN ARCGIS USING VISUAL BASIC FOR APPLICATIONS

ArcGIS is an integrated family of GIS software products for building a complete GIS. It is based on a common library of shared GIS software components called ArcObjects (ESRI, 2006a). ArcObjects are set of computer objects specifically designed for programming with ArcGIS Desktop applications. ArcObjects include things like data frames, layers, features, tables, cartographic symbols, and the pieces that make up these things: points, lines, polygons, records, fields, colours, and so on (Burke, 2003).

ArcGIS and its extensions (such as spatial analyst and 3-D analyst) provide GIS capabilities, such as data input, storage, management, manipulation, analysis, and output. There are several ways to extend the functionality of ArcGIS Desktop by using one of the developer toolkits and a development language (.NET, VB, Visual C++). Some of the common examples include writing custom commands, tools, toolbars, dockable windows, and custom layers. These customizations are compiled as dynamic link libraries (.dll) and can be distributed to other users (ESRI, 2006b).

ArcGIS includes an integrated macro development environment, Visual Basic for Applications (VBA). VBA is not a stand-alone application; it is embedded within all ArcGIS applications (ArcMap, ArcCatalog, ArcGlobe, and ArcScene). VBA, a simplified version of Visual Basic (VB), is one of many object-oriented programming languages (Burke, 2003; ESRI, 2006b).

## 4. THE ARCGIS-TOPSIS TOOL

The ArcGIS-TOPSIS was 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 TOPSIS function, and displays the analysis result as a layer in ArcMap. The functions and the components of the ArcGIS-TOPSIS are illustrated in Figure 1.

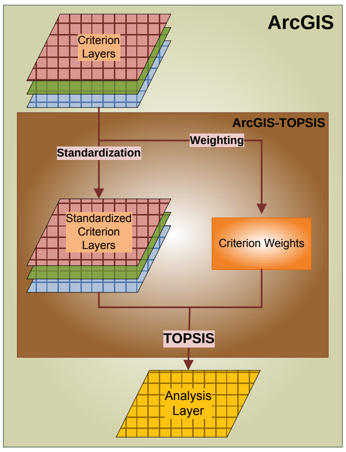


Figure 1. The general structure of the ArcGIS-TOPSIS interface

The ArcGIS-TOPSIS tool also includes standardization, weighting methods (Figure 2). 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.

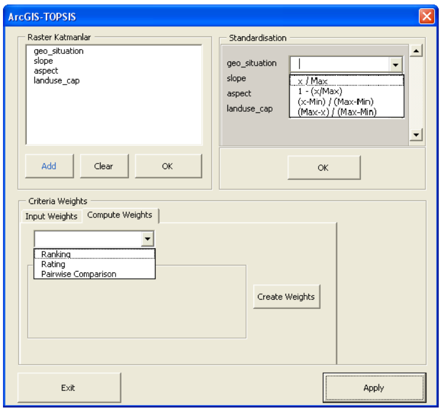


Figure 2. The ArcGIS-TOPSIS interface in the ArcGIS 9.2

The ArcGIS-TOPSIS requires that the values contained in different criterion layers be transformed to comparable units. The criterion layers may have qualitative (e.g., land use) and/or quantitative (e.g., slope) properties. Once the quantitative raster criterion layers are generated in ArcGIS, they can be standardized and processed by the ArcGIS-TOPSIS.

The ArcGIS-TOPSIS enables the user both to input weights manually and to calculate weights. Computed weights can be saved as a .txt file. In the ranking method, every criterion is ranked on the ordinal scale from 1 to the number of the criteria. Weights are computed according to Eq. (6). In the rating method, every criterion is scored on a scale. Weights are computed according to Eq. (7). In the pairwise comparison interface, when the elements above or below the diagonal are entered, the rest are automatically filled when the complete button is selected. The calculate button computes the weights and consistency ratio (CR) associated with the pairwise comparison matrix. The display button shows the screenshot of weights and consistency analysis. The ArcGIS-TOPSIS aggregates standardized criterion layers and the criterion weights according to TOPSIS decision rule. The resulting raster layer is added to the current ArcGIS session.

## 5. CASE STUDY: SETTLEMENT SITE SELECTION

This section presents a real-world case study for selection of settlement site using the TOPSIS method. The study area is Atakum-Samsun in Turkey (Figure 3). The area is about 11.6 $km^2$.


Figure 3. Location of the study area

Firstly, the effective factors were evaluated and slope, aspect, geological situation and land use capability classes were taken into account in this study. 1/1000-scale topographical maps, 1/25000-scale land use capability class maps, geological situation data were used to prepare the criterion layers. Secondly, criterion layers were standardized and all criteria were weighted and last, TOPSIS was applied.

Before standardization, the aspect, land use capabilities classes and geological situation layers were rated because of theirs qualitative values (Table 3). The maximum score procedure was used to standardize all criteria. Eq. (1) was used to standardize the aspect, land use capabilities classes and geological situation layers, while Eq. (2) was used for slope layer.

| Land Use Capability Classes | Score | Geological Situation | Score |
|---|---|---|---|
| Class VI | 10 | Convenient areas | 10 |
| Class IV | 7 | Drilling required area | 6 |
| Class III | 2 | Measured area | 2 |

| Aspect | Score |
|---|---|
| Northeast | 10 |
| East | 9 |
| North | 8 |
| South | 7 |
| Southeast | 6 |
| Southwest | 5 |
| West | 3 |
| Northwest | 2 |

Table 3. Scores of aspect, land use capabilities classes, geological situation layers

The weights were automatically calculated by the pairwise comparison method in the ArcGIS-TOPSIS. Figure 4 shows the pairwise comparison matrices.

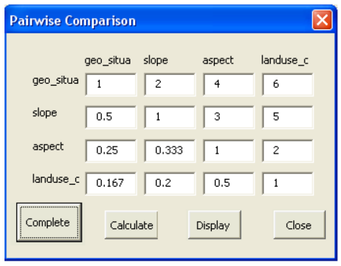


Figure 4. Creating a pairwise comparison matrix

The weights and consistency ratio are given in Figure 5. Because the consistency ratio is smaller than 0.10, the judgments are consistent (Eq. (10)).

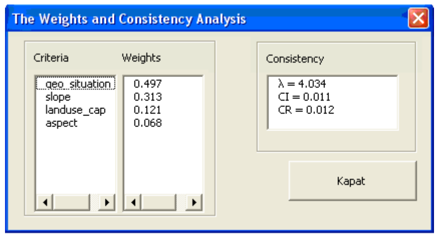


Figure 5. A screenshot of weights and consistency analysis of pairwise comparison.

Using the standardized criteria and weights, TOPSIS was implemented to produce a layer of settlement site selection. The cell values ranged from 0.091 to 1, where the higher value represents higher suitability for settlement (Figure 6).

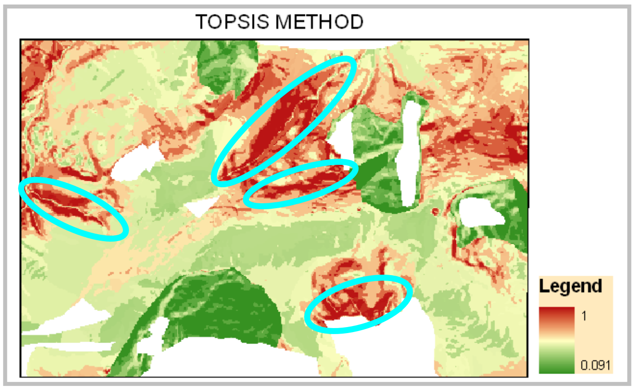


Figure 6. Decision analysis layer using TOPSIS

## 6. CONCLUSION

This paper presents a tool that integrates GIS and TOPSIS method. The tool has capabilities, including criterion standardization, criterion weighting and decision analysis with TOPSIS. The paper also presents an application of GIS-based TOPSIS by applying the ArcGIS-TOPSIS tool to a real-world problem that involved selection of settlement site in Atakum-Samsun, Turkey. Because the methods performed by ArcGIS-TOPSIS are generic, the tool can be used for many other decision applications, including natural resource management, land-use planning and suitability evaluation.

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