Studies in Informatics and Control, 26(2) 183-192, June 2017 ISSN: 1220-1766 eISSN: 1841-429X
https://doi.org/10.24846/v26i2y201706

An Extended TOPSIS Approach for Ranking Cloud Service Providers

Constanţa Zoie RĂDULESCU [1], **Iulia Cristina RĂDULESCU**[2]

[1] National Institute for Research and Development in Informatics,
8-10, Mareşal Averescu, Bucharest, 011455, Romania
radulescucz@yahoo.com
[2] University Politehnica of Bucharest,
313 Splaiul Independentei, 060042, Romania
iulia.radulescu1702@yahoo.com

Abstract: There are many Cloud Service Providers (CSPs) in the global cloud computing market and customers may need to use scientific decision making methods for evaluating and ranking the CSPs according to their own requirements. Among the several approaches that have been proposed to solve the CSPs evaluation and ranking problem, there are Multi Attribute Decision Making (MADM) methods. One of the most commonly used MADM method is Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS). In this paper, we extend the TOPSIS method by using the Minkowski distance. We propose an Extended TOPSIS (E-TOPSIS) approach by varying the parameter *p* in the Minkowski distance. The applicability of the proposed E-TOPSIS approach is presented in a case study for CSPs evaluation and ranking in relation to a set of Service Measurement Index - SMI criteria. An analysis of E-TOPSIS solutions and the CSPs order change relative to parameter *p* variation is realized. A comparison of the E-TOPSIS solutions with TOPSIS solution is presented.

Keywords: Cloud Services Providers, multi-criteria, TOPSIS method, Minkowski distance.

1. Introduction

When an organization wants to migrate to the cloud environment an important problem is to choose the CSP which best fits its requirements. Since in the cloud market the CSPs number is increasing, the organization needs to be assisted by decision methods for CSPs evaluation, ranking and selection. Several approaches have been proposed to solve the CSPs ranking problem, including Multi Attribute Decision Making (MADM) methods. One of the most used MADM methods is Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS).

In the paper [5] a Multi-Attribute Group Decision Making (MAGDM) method was proposed to help organizations evaluate which cloud computing vendor might be more suitable for their needs. It is argued that the objective attributes, i.e., cost, as well as the subjective attributes, such as TOE factors (Technology, Organization, and Environment) should be considered in the decision making process for CSP selection. In the above mentioned paper a new subjective/objective integrated MAGDM approach for solving decision problems was proposed. This approach integrates statistical variance (SV), improved TOPSIS method, simple additive weighting (SAW), and Delphi–AHP in order to determine the integrated weights of attributes and of decision-makers.

The number of available cloud computing services and platforms has increased dramatically in recent years. Notable examples are Google's File System (GFS), Amazon's Dynamo, and Microsoft's Azure. Due to the rapid market and technological changes, network-related enterprises must monitor the trends of technological development from time to time. A high-tech enterprise needs to make strategic decisions based on acquired information on technology volatility in order to chart its direction in the marketplace. This involves determining the market segment in which it will compete and the competitive position that it will take [2].

In order to evaluate and compare the candidate services while supporting tradeoffs between performance–costs and potential risks in different time periods, in [6] is considered a cloud service interval neutrosophic set (CINS). The operators and calculation rules, with theoretical proofs are provided. The problem of time-aware trustworthy service selection is formulated as a multi-criteria decision-making

(MCDM) problem of creating a ranked services list.

For IaaS cloud service selection in which the top ranked services according to users' criteria are determined in different time slots (defined as non-overlapping periods of time), in [9] a multi-criteria decision making (MCDM) approach is proposed. This approach used the TOPSIS and ELECTRE methods.

Sachdeva [11] proposed a hybrid TOPSIS method combined with an intuitionistic fuzzy set in order to select an appropriate cloud solution to manage big data projects in a group decision making environment.

Cloud clients need trustworthy service providers who comply with Service Level Agreements (SLA) and do not deviate from their promises. The paper [13] presents the design of a trust evaluation framework that uses the compliance monitoring mechanism to determine the trustworthiness of service providers. The compliance values are computed and then processed using an improved TOPSIS method to obtain trust on the service providers.

The paper [1] describes a user centric service-oriented modeling approach which is featured by integrating fuzzy TOPSIS method and Service Component Architecture (SCA) to facilitate web service selection and composition. It effectively satisfies a group of service consumers' subjective requirements and preferences in a dynamic environment.

Zavadskas et al. [18] present a novel method called WASPAS-G method, which is based on multiple attribute Weighted Aggregated Sum Product Assessment with grey attributes scores. The proposed method was applied in a case study of evaluation and selection of a right construction contractor, which has to be the most appropriate to stakeholders' preferences.

For the same selection problem, three hybrid methods SWARA-TOPSIS, SWARA-ELECTRE III and SWARA-VIKOR were used in [17].

In the current paper, we extend the TOPSIS method by using the Minkowski Distance. We propose an Extended TOPSIS (E-TOPSIS) approach by varying the parameter *p* in the Minkowski distance. The applicability of the proposed E-TOPSIS approach is presented in a case study for CSPs evaluation and ranking according to a set of Service Measurement Index (SMI) criteria. An analysis of the E-TOPSIS solutions and the CSPs order change relative to parameter *p* variation is realized. A comparison of the E-TOPSIS solutions with TOPSIS solution is presented.

2. Service Measurement Index

An evaluation of CPs is based on the Service Measurement Index (SMI) suggested by the Cloud Service Measurement Index Consortium (CSMIC) [20, 21]. SMI has been created as a standard method for measuring cloud services. The method is based on critical business and technical user requirements. The SMI starts with a hierarchical framework. The top level is divided into seven clusters and each cluster is further refined by three or more criteria [7, 8, 16]. The seven criteria are defined below [16]:

- Accountability criteria used to measure the properties related to a service provider organization. These properties may be independent of the service being provided.
- Agility criteria indicating the impact of a service upon the user ability to change direction, strategy or tactics quickly with minimal disruption.
- Assurance criteria that indicate the degree of service availability as specified.
- Financial criteria used to measure the amount of money spent on the service by the user.
- Performance criteria that indicate the performance characteristics of the provided services.
- Security and privacy criteria that indicate the effectiveness of a service provider in controlling access to services, service data and physical facilities from which services are provided.
- Usability indicates the ease mode with which a service can be used.

During the service negotiation process, the cloud user and the CSP agree on the contract called Service Level Agreement (SLA). SLA contains different Quality of Service (QoS) rules to be followed by the CPs.

There are several cloud management platforms with cloud management software, specifically designed for users, which consider multiple CSPs. Examples of these services include Rightscale, Red Hat Cloud forms, Servicemesh Agility Platform and ElasticBox [10].

3. Extended TOPSIS approach

Among the many approaches of MADM, it is possible to consider a subgroup of methods that involves costs and benefits aspects. One of them is the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). TOPSIS was first proposed in 1981 by Hwang and Yoon [3]. This approach is employed for four main reasons [2, 19]:

1. the TOPSIS logic is rational and understandable;
2. the computation processes are straightforward;
3. the concept permits the pursuit of the best alternatives for each criterion depicted in a simple mathematical form;
4. the importance weights are incorporated in the comparison procedures.

Also the number of steps in TOPSIS method remains the same regardless of the number of attributes [4]. If we query the Science Direct database, a total of 950 documents appear with the input TOPSIS in title, abstract or key words, for the period 2000 – 2017.

However the TOPSIS method presents certain drawbacks. One of the problems that may be ascribed to TOPSIS is that it can cause the phenomenon known as rank reversal. The rank reversal situation is very common in classic algorithms of MCDM methods such as AHP, TOPSIS, ELECTRE or PROMETHEE. In this phenomenon the alternatives' order of preference changes when an alternative is added or removed from the set of candidate alternatives. In some cases this may lead to what is called total rank reversal, where the order of preferences is totally inverted: the best alternative becomes the worst if an alternative is included or removed from the process. Such a phenomenon in many cases may not be acceptable [15]. This phenomenon of rank reversal also occurs when the parameter p varies in the Minkowski distance.

TOPSIS method adopts the concepts of "ideal" and "anti-ideal" solutions as suggested by Hwang and Yoon [3] and computes the relative distances from the ideal and anti-ideal solutions for each alternative. The best alternative should be as close as possible to the ideal solution and as far as possible from the anti-ideal solution in a multi-dimensional computing space.

The TOPSIS method uses the Euclidean distance to measure the relative distances from the ideal and anti-ideal solutions for each alternative.

We extend the TOPSIS method by considering the Minkowski distance as metric instead of Euclidean distance. The phenomenon of rank reversal occurs when the parameter p varies in the Minkowski distance.

The extended TOPSIS approach is called E-TOPSIS.

The Minkowski distance of order p between two points $\mathbf{x} = (x_1, x_2, ..., x_n) \in \Re^n$ and $\mathbf{y} = (y_1, y_2, ..., y_n) \in \Re^n$ is defined as:

$$\rho(\mathbf{x}, \mathbf{y}) = \left(\sum_{i=1}^{n} |x_i - y_i|^p \right)^{1/p} \quad (1)$$

The Minkowski distance is typically used for *p=1* (Manhattan distance) and for *p=2*. For *p=2* the distance is the Euclidian distance used in TOPSIS method.

By varying t times the parameter p in the E-TOPSIS approach we get t solutions.

The steps of the proposed E-TOPSIS approach are presented in the following.

Step 1. Criteria and sub-criteria identification and selection.

Define the set of n criteria: $C = \{C_1, C_2, ..., C_n\}$.

For each criterion is defined a maximization or minimization type.

Let T be the set of maximization criteria (benefit criteria).

Let T' be the set of minimization criteria (cost criteria).

Step 2. Alternatives identification and selection.

Define a set of m alternatives:

$A = \{A_1, A_2, ..., A_m\}$

Step 3. Construction of evaluation matrix. Given the sets A (of alternatives) and C (of evaluation criteria) then build a m x n matrix $E = (e_{ij})$ called the evaluation matrix.

The entry e_{ij}, $i = 1,2,...,m,\ j = 1,2,...,n$ represents the evaluation of the i-th CSP alternative by means of the j-th criterion.

The evaluation matrix may include quantitative, qualitative, or both types of information. The entries of each column have the same measurement unit. The alternatives are evaluated for the distinct criteria using different measurement units and scales.

$$E = \begin{array}{c|cccc} & w_1 & w_2 & \cdots & w_n \\ & C_1 & C_2 & \cdots & C_n \\ \hline A_1 & e_{11} & e_{12} & \cdots & e_{1n} \\ A_2 & e_{21} & e_{22} & \cdots & e_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ A_m & e_{m1} & e_{m2} & \cdots & e_{mn} \end{array} \tag{2}$$

The steps 1- 4 define the input data in E-TOPSIS approach:

- The criteria set $C = \{C_1, C_2, ..., C_n\}$;
- The criteria weights: $w = (w_j),\ j = 1,2,...,n$
- The sets of maximization/minimization criteria – T for benefit criteria and T' for cost criteria;
- The alternatives set $A = \{A_1, A_2, ..., A_m\}$
- The evaluation matrix $E = (e_{ij})$;
- The parameter p in Minkowski distance;
- The interval of parameter p variation $p \in [l, h]$ and a step sp used for varying the parameter p.

The problem is:

- to find for every p in the interval $p \in [l, h]$ a E-TOPSIS solution (alternatives ranking relative to a set C of criteria),
- to analyze the obtained solutions and rank reversal.

Step 4. *E* matrix normalization.

The alternatives are evaluated for the distinct criteria using different measurement units and scales. To bring the elements of the evaluation matrix *E* to have compatible units is used a normalization process. The normalization method proposed to be applied for our approach is the vector normalization.

The entries of the normalized matrix:

$$\overline{E} = (\overline{e}_{ij}), \quad i = 1,2,...,m, \quad j = 1,2,...,n$$

are calculated as:

$$\overline{e}_{ij} = \frac{e_{ij}}{\sqrt{\sum_{k=1}^{m} e_{kj}^2}} \tag{3}$$

Step 5. Criteria prioritization. The weight for each criterion is calculated.

The vector of *n* weights is: $w = (w_j)$.

We consider three methods for calculating the weights associated with the criteria:

1. Mean weight (MW);
2. Entropy weight (EW) (Shannon);
3. Coefficient-variation weight (CW) (Sinha).

Mean weight (MW) method assigns equal weights to criteria:

$$w_j^{MW} = \frac{1}{n}, \quad j = 1,2,...,n \tag{4}$$

It reflects a neutral attitude of the decision maker and ensures the objectivity of evaluating process.

Shannon and Weaver's [12] entropy (EW) is a measure of uncertainty in information theory. Its value reflects the weight of its corresponding criterion in terms of the amount of the information it contains and indicates the inherent contrast intensity of the corresponding criteria. It is defined as:

$$w_j^{EW} = \frac{dw_j}{\sum_{k=1}^{n} dw_k}, \quad j = 1,2,...,n \tag{5}$$

where:

$$dw_j = 1 - ew_j, \tag{6}$$

$$ew_j = -\sum_{i=1}^{m} pw_{ij} \ln(pw_{ij}) / \ln(m), \ 0 \le ew_j \le 1 \tag{7}$$

$$pw_{ij} = \overline{e}_{ij} / \sum_{k=1}^{m} \overline{e}_{kj} \ , \ i = 1,2,...,m \tag{8}$$

Coefficient-variation weight method (CW) [14] calculates the weights as:

$$w_j^{CW} = \frac{cv_j}{\sum_{k=1}^{n} cv_k}, \quad j = 1,2,...,n \tag{9}$$

where:

$$cv_j = cs_j / me_j, \tag{10}$$

$$cs_j = \sqrt{\sum_{i=1}^{m} \left(\overline{e}_{ij} - me_j\right)^2 / (m-1)}\ , \tag{11}$$

$$me_j = \sum_{i=1}^{m} \overline{e}_{ij} / m\ . \tag{12}$$

We choose the weights calculated according to one of the presented methods, weights that best fit the problem of alternatives ranking.

Denote with $w = (w_j),\ \ j = 1,2,...,n$ the chosen weights. Then the entries of the weight normalized matrix:

$$\overline{\overline{E}} = (\overline{\overline{e}}_{ij}), \quad i = 1,2,..., m, \quad j = 1,2,..., n$$

are calculated as:

$$\overline{\overline{e}}_{ij} = \overline{e}_{ij} \times w_j \tag{13}$$

Step 6. Determine the positive ideal and negative ideal solutions.

The positive and negative ideal solutions A^+ and A^- are calculated as:

$$A^+ = (a_j^+),\ a_j^+ = \begin{cases} \max\limits_i \overline{\overline{e}}_{ij} & if \quad C_j \in T \\ \min\limits_i \overline{\overline{e}}_{ij} & if \quad C_j \in T' \end{cases} \tag{14}$$

$$A^- = (a_j^-), \quad a_j^+ = \begin{cases} \min\limits_i \overline{\overline{e}}_{ij} & if \quad C_j \in T \\ \max\limits_i \overline{\overline{e}}_{ij} & if \quad C_j \in T' \end{cases} \tag{15}$$

$j = 1,2,..., n,$

where T is the set of benefit criteria and T' is the set of cost criteria.

Step 7. Calculate the separation measures.

By varying the parameter *p* from Minkowski distance in the interval $[l, h]$ we obtain a *t* number of solutions. Let *sp* be a step to vary the parameter *p*.

Then:

$$t = (h - l) * sp + 1 \tag{16}$$

$$p = l, l + sp, l + sp * 2,..., h, \tag{17}$$

$$h = l + \frac{t-1}{sp} \tag{18}$$

For each value of the parameter *p* in the interval $[l, h]$ and for each alternative

$i = 1,2,..., m$ are calculated the Minkowski distances from the positive and negative ideal solution:

$$d_{ik}^{\ +} = \left[\sum_{j=1}^{n} \left|\overline{\overline{e}}_{ij} - a_j^+\right|^p\right]^{1/p} \tag{19}$$

$$d_{ik}^{\ -} = \left[\sum_{j=1}^{n} \left|\overline{\overline{e}}_{ij} - a_j^-\right|^p\right]^{1/p}, \tag{20}$$

$p = l, l + sp, l + sp * 2,..., h,$

$i = 1,2,..., m, \quad k = 1,2,..., t\ .$

Step 8. Calculate the relative closeness to the ideal solution. The relative closeness to the ideal solution is calculated in the matrix: $s = (s_{ik})$.

$$s_{ik} = \frac{d_{ik}^{\ -}}{d_{ik}^{\ +} + d_{ik}^{\ -}}, \quad i = 1,2,..., m, k = 1,2,..., t\ . \tag{21}$$

Each column of the matrix $s = (s_{ik})$ represents a TOPSIS solution for a value of parameter *p*. There are *t* E-TOPSIS solutions. A E-TOPSIS solution is the assessment of alternatives in the context of selected criteria.

Step 9. Alternatives ranking and analysis of solutions stability.
The alternatives are ranked in descending order according to each column of matrix ***s*.**

The ranks of the alternatives for every solution are calculated in the matrix:
$r = (r_{ik}), \quad i = 1,2,..., m, \quad k = 1,2,..., t$ where r_{ik} = rank of s_{ik} in the set $\{s_{1k}, s_{2k},..., s_{mk}\}$.

Changes in the order of alternatives relative to the parameter *p* are analyzed.

4. Case study: CSPs evaluation and ranking based on E-TOPSIS

In this case study the E-TOPSIS approach is used for the evaluation and ranking of ten Cloud Services Providers - CSPs. In order to make the CSPs evaluation and ranking a subset of three criteria is defined. For each criterion is defined a set of sub-criteria. The criteria for CSPs selection are SMI criteria. The criteria can be divided in two categories: quantitative and qualitative. The qualitative criteria are evaluated in linguistic terms.

Examples for cloud qualitative criteria are security, CP reputation, usability, agility.

Examples for cloud quantitative criteria are costs, and response time. The criteria, sub-criteria, max or min, and type of sub-criteria are presented in Table 1:

Table 1. The criteria, sub-criteria, max or min and type

Criteria	Sub-Criteria	Symbol	Benefit (max) or cost (min) criteria	Type
Performance:		**C1**		
	Functionality	c11	max	qualitative
	Response time	c12	min	quantitative
Costs:		**C2**		
	Storage Cost	c21	min	quantitative
	Memory Cost	c22	min	quantitative
	Acquisition Cost	c23	min	quantitative
Security and privacy:		**C3**		
	Access control	c31	max	qualitative
	Data integrity	c32	max	qualitative

The set of benefit criteria is $T=\{c11, c31, c32\}$ and the set of costs criteria is $T^{'}=\{c12,c21,c22,c23\}$.

The Criteria and Sub-criteria weights are calculated using three methods: Mean weight (MW), Entropy weight (EW), Coefficient-variation weight (CW). (Table 2).

Table 2. The Criteria and Sub-criteria weights

Criteria and sub-criteria Symbol	EW		CW		MW	
	Criteria Weights	Sub-criteria Weights	Criteria Weights	Sub-criteria Weights	Criteria Weights	Sub-criteria Weights
C1	**0.021**		**0.083**		**0.286**	
c11		0.005		0.030		0.143
c12		0.016		0.053		0.143
C2	**0.793**		**0.666**		**0.429**	
c21		0.265		0.224		0.143
c22		0.223		0.201		0.143
c23		0.305		0.241		0.143
C3	**0.186**		**0.251**		**0.286**	
c32		0.121		0.144		0.143
c33		0.065		0.107		0.143

The "Costs" criterion has the highest weights in both EW and CW methods (without considering the MW method), 0.793 (EW) and 0.666 (CW). For the “Cost” criterion, the “Acquisition cost” sub-criterion has the highest weight of 0.305 (EW) and 0.241 (CW). On the second place, the weight for “Security and privacy” criterion are 0.186 (EW) and 0.251 (CW). Among the “Security and privacy” criteria, the “Access control” sub-criterion has the weight of 0.121 (EW) and 0.144 (CW) versus the “Data integrity” sub-criterion 0.065 (EW) and 0.107 (CW). On the last place is the weights for “Performance” criterion with 0.021 (EW) and 0.083 (CW). It can be noted that the EW method has the largest differences between weights. We will choose the importance weights calculated by the EW method because they better outline the differences between the SMI sub-criteria.

Given the sets of ten CSPs and the seven evaluation sub-criteria an *10* x *7* evaluation matrix $E = (e_{ij})$ is built. The entry e_{ij}, represents the evaluation of the *i*-th CSP by means of the *j*-th sub-criterion. The CSPs are evaluated for the distinct sub-criteria using different measurement units and scales. To bring the elements of the evaluation matrix *E* to compatible units is used a normalization process. Then is calculated the weight normalized matrix (Table 3):

$$\overline{\overline{E}} = (\overline{\overline{e}}_{ij}), \quad i = 1,2,...,10, \quad j = 1,2,...,7$$

The positive ideal and negative ideal solutions A^+ and A^- are determined.

By varying the parameter *p* in the interval [1;10] with step=0.25 we obtained *t*=37 E-TOPSIS solutions.

For each CSP, are calculated the Minkowski distances from the positive and negative ideal solution d_{ik}^{+} and d_{ik}^{-}

$i = 1,2,...,10,\ k = 1,2,...,37$

Table 3. Weight normalized matrix

CSPs	**Criteria**						
	c11	**c12**	**c21**	**c22**	**c23**	**c31**	**c32**
CSP1	0.0037	0.0049	0.0609	0.0709	0.1012	0.0926	0.0489
CSP2	0.0035	0.0047	0.0692	0.0630	0.0945	0.0891	0.0471
CSP3	0.0033	0.0053	0.0904	0.0787	0.0904	0.0962	0.0489
CSP4	0.0033	0.0055	0.0913	0.0945	0.1282	0.0749	0.0453
CSP5	0.0035	0.0051	0.0692	0.0551	0.0904	0.0572	0.0346
CSP6	0.0035	0.0051	0.0729	0.0630	0.0756	0.0997	0.0507
CSP7	0.0035	0.0051	0.0673	0.0472	0.0675	0.0855	0.0471
CSP8	0.0033	0.0051	0.0784	0.0787	0.0729	0.0820	0.0417
CSP9	0.0034	0.0049	0.1024	0.0787	0.0850	0.0855	0.0435
CSP10	0.0034	0.0047	0.1181	0.0630	0.1350	0.0820	0.0417

Then are calculated the relative closeness to the ideal solution in the matrix:

$$s = (s_{ik}), \quad i = 1,2,...,10, \quad k = 1,2,...,37.$$

The matrix contains 37 solutions, one solution for each value of the parameter *p*.

In the transposed matrix *s* each row contains a E-TOPSIS solution. The solutions: 1, 5, 9, 13, 17, 21, 25, 29, 33 and 37 of the transposed matrix *s* are presented in Table 4.

Table 4. Relative closeness to the ideal solution

Nr.Sol.	***p***	**CSP1**	**CSP2**	**CSP3**	**CSP4**	**CSP5**	**CSP6**	**CSP7**	**CSP8**	**CSP9**	**CSP10**
1	**1**	0.465	0.413	0.595	0.724	0.171	0.411	0.207	0.375	0.553	0.744
5	**2**	**0.443**	**0.397**	**0.539**	**0.695**	**0.223**	**0.384**	**0.245**	**0.365**	**0.523**	**0.715**
9	**3**	0.428	0.394	0.513	0.686	0.251	0.391	0.264	0.356	0.498	0.705
13	**4**	0.418	0.394	0.498	0.684	0.27	0.4	0.276	0.35	0.481	0.699
17	**5**	0.411	0.395	0.488	0.684	0.282	0.407	0.283	0.346	0.471	0.695
21	**6**	0.406	0.396	0.482	0.684	0.29	0.411	0.288	0.343	0.464	0.692
25	**7**	0.402	0.396	0.478	0.685	0.297	0.413	0.291	0.342	0.461	0.689
29	**8**	0.399	0.396	0.475	0.686	0.301	0.415	0.293	0.34	0.458	0.688
33	**9**	0.397	0.396	0.473	0.687	0.305	0.416	0.294	0.339	0.457	0.686
37	**10**	0.395	0.396	0.472	0.688	0.307	0.417	0.295	0.339	0.456	0.685

The alternatives for each column of the matrix *s* are ranked in descending order**.** The ranks of the CSPs for every solution are calculated in the $r = (r_{ik}), \quad i = 1,2,...,10, \quad k = 1,2,...,37$ matrix. By analyzing the *r* matrix we notice that the order of alternatives changes as parameter *p* varies. The changes in the order of alternatives (CSPs) in the transposed matrix *r* are presented in Table 5.

Table 5. Ranks of the alternatives (CSPs) for every solution

p	**CSP1**	**CSP2**	**CSP3**	**CSP4**	**CSP5**	**CSP6**	**CSP7**	**CSP8**	**CSP9**	**CSP10**
1 - 3.25	5	6	3	2	10	7	9	8	4	1
3.50-5.25	5	7	3	2	10	6	9	8	4	1
5.50-8.50	6	7	3	2	9	5	10	8	4	1
8.75-9	6	7	3	1	9	5	10	8	4	2
9.25-10	7	6	3	1	9	5	10	8	4	2

For $p=2$ is obtained the Euclidian distance used in TOPSIS method.

The solutions are displayed in Figure 1. The solution of TOPSIS method is different from the stationary solution. By varying the parameter p in the interval [1;100.75] with step=0.25 we obtained $t=400$ solutions (Figure 2). The last change in order occurs for solution No. 34 with the parameter value $p = 9.25$.

When p has small values many variations in the order of alternatives can be observed. As p increases the solution tends to be stationary. The stationary solution and the CSPs ranks of E-TOPSIS and TOPSIS methods by varying the parameter p in the interval [1;10] with step=0.25 and p in the interval [1;100.75] with step=0.25, is presented in Table 6.

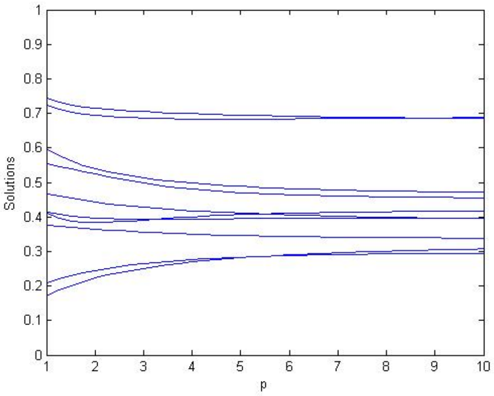

Figure 1. The solutions obtained by varying the parameter p in the interval [1;10]

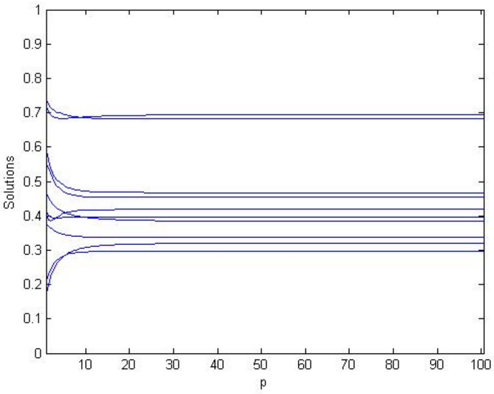

Figure 2. The solutions obtained varying the parameter p in the interval [1;100.75]

Table 6. CSPs ranks of E-TOPSIS and TOPSIS

Solutions	**CSPs**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
TOPSIS	0.443	0.397	0.539	0.695	0.223	0.384	0.245	0.365	0.523	0.715
E-TOPSIS (Sol. nr.37 for p=10)	0.395	0.396	0.472	0.688	0.307	0.417	0.295	0.339	0.456	0.685
E-TOPSIS (Sol. nr. 400, p=100.75)	0.384	0.396	0.468	0.695	0.320	0.418	0.297	0.337	0.454	0.682
TOPSIS rank	5	6	3	2	10	7	9	8	4	1
E-TOPSIS rank (Sol. nr.37, p=10)	7	6	3	1	9	5	10	8	4	2
E-TOPSIS rank (Sol. nr. 400, p=100.75)	7	6	3	1	9	5	10	8	4	2

5. Conclusions

In this paper was proposed an extended approach to the TOPSIS method called E-TOPSIS. The approach uses a real parameter *p* that varies in the interval $[l, h] \subset [1, 1000]$. The Euclidean distance from the TOPSIS method is replaced by the Minkowski distance of exponent (parameter) *p*. For each value of the parameter *p* we obtain a solution. One notes that the rank of the solution may change if the value of the parameter *p* changes. Values of the parameter *p* for which the ranking of the solution changes are determined. This proves the sensitivity of the ranking to the distance used in the E-TOPSIS approach.

The input data and the algorithm of the E-TOPSIS approach were described in steps.

A case study consisting in the evaluation of ten CPs services and ranking them with respect to seven SMI criteria was presented. The proposed E-TOPSIS approach facilitates selection of the appropriate cloud service provider.

Although the methods and the case study were related to a specific domain of CSPs evaluation, the same method can also be applied to other domains in order to solve multi criteria problems.

Acknowledgements

This research was supported by the PN 16 09 03 01 project of the Ministry of Research and Innovation.

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