Multi-criteria Evaluation of Cloud Service Providers with the Integrated Fuzzy Group Decision-making Approaches

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Abstract

Recently, the rapid development of technology has revealed new needs such as data retention, storage, privacy, and easy access. Due to the development of technology, the emergence of concepts such as industry 4.0, the internet of things, and big data, many sectors require cloud computing systems. Cloud service performance has a significant impact on a company's future. However, since there are various cloud services, the selection of a suitable cloud service is a very difficult process. In this study, we determined the ranking of cloud service providers using the integrated fuzzy analytical hierarchical process (FAHP) and fuzzy technique for order preference by similarity to ideal solution (FTOPSIS). The obtained ranking was compared with the ranking obtained from the integrated FAHP and the distance from the average solution (EDAS) method. Based on the brainstorming and literature review with five decision-makers having expertise in information technology, a decision model with eight criteria and five alternatives is proposed. The main contribution of this study is to provide an accurate and efficient way based on the integrated fuzzy group decision-making approach for the selection of the best provider. A real-time cloud case study from a food company is illustrated to explain the potential of our proposed framework and methodology. Finally, sensitivity analysis is applied to demonstrate the robustness of our proposed methodology.

Keywords
Cloud service selection, fuzzy environment, cloud computing, MCDM

1. Introduction
Cloud computing has gained tremendous popularity among medium and small enterprises because they do not only need to invest a large amount of capital in the infrastructure of their installation and maintenance but also can have various benefits like scalability, elasticity, reliability, etc. Especially, it has gained more importance for service sectors (health, educational, etc.) as well as manufacturing sectors after the World Health Organization, 2020 (WHO) declared the COVID-19 a pandemic on January 30, 2020. Thus, the pandemic has forced people to work from their homes, but they need to communicate, collaborate online. The main purpose of CSPs is to provide services from computing power to application over the Internet that can be accessed anytime and anywhere (Tiwari and Kumar, 2021). Although this field has attracted the increasing attention of researchers because of its current issues and challenges, it is a hard task for cloud users to select a suitable cloud service provider (CSP) to fulfill the quality of services (QoSs) requirements of the enterprises (Saha et al., 2021). Since the cloud users overcome this challenge, they require to select the right CSP due to various cloud services offered by many organizations like Google, Amazon, Microsoft, etc., in the cloud market.

Multi-criteria decision-making (MCDM) methods are very much popular for solving decision-making problems with multiple conflicting attributes (Neeraj et al., 2021). Some MCDM methods are used to determine the criteria of weights for the considered problem while some of them can be utilized to rank the alternatives by using the preference weights that express the importance and the effects of criteria on the evaluation results (Pamucar and Ecer, 2020). Although AHP is an efficient approach among decision-making methods, the uncertainty of decision in the problem is not considered in determining pairwise comparison. Therefore, to determine the criteria weights in this study, fuzzy AHP is considered to overcome this difficulty, allowing decision-makers to use fuzzy ranking in place of exact ranking

(Enea and Piazza 2004). Then, the weights are adopted in fuzzy TOPSIS to find out the best alternative for achieving the desired levels based on five cloud services. The results obtained from the integrated fuzzy AHP and fuzzy TOPSIS are compared with the results obtained from the integrated fuzzy AHP and EDAS approaches.

Table 1. An overview of previous MCDM approaches applied to cloud service selection problems.

References	Applied MCDM methods	Category
Neeraj et al. (2021)	AHP & PROMETHEE II & TOPSIS & VIKOR	Single MCDM
Tiwari and Kumar (2021)	Gaussian TOPSIS	
Lai et al. (2020)	CoCoSo method	
Kumar et al. (2020)	TOPSIS	
Sidhu and Singh (2019)	PROMETHEE	
Nawaz et al. (2018)	BWM	
Ginting et al. (2017)	TOPSIS	
Alismaili et al. (2016)	PAPRIKA	
Ding et al. (2014)	MAUT	
Choi and Jeong (2014)	ELECTRE	
Ergu and Peng (2014)	ELECTRE	
Ramachandran et al. (2014)	AHP	
Kumar et al. (2021)	TOPSIS & BWM	Hybrid MCDM method
Saha et al. (2021)	ANP & VIKOR	
Youssef (2020)	TOPSIS & BWM	
Singh and Sidhu (2017)	AHP & TOPSIS	
Serrai et al. (2016)	BWM & VIKOR	
Alimardani et al. (2014)	ANP & DEMATEL & TOPSIS	
Huang et al. (2012)	ANP & GRA & DEMATEL	
Hussain et al. (2021)	BWM	Fuzzy MCDM method
Ilieva et al. (2020)	MARCOS	
Liu et al. (2021)	GRA-ELECTRE III	
Abdel-Basset et al. (2018)	AHP	
Basu and Ghosh (2018)	TOPSIS	
Paunovic et al. (2018)	AHP	
Gireesha et al. (2020)	IVIF & WASPAS	Fuzzy hybrid MCDM method
Jatoth et al. (2019)	AHP and grey TOPSIS	
Buyukozkan et al. (2018)	IVIF & AHP & COPRAS & MULTIMOORA & TOPSIS	
Alam et al. (2018)	TFN & AHP & WASPAS	
Li et al. (2018)	Rough ANP and rough TOPSIS	
Lee and Seo (2016)	Fuzzy Delphi & Fuzzy AHP	

AHP: Analytic Hierarchy Process, **ANP**: Analytic Network Process, **BWM**: Best–worst method, **CoCoSo**: Combined Compromise Solution, **COPRAS**: The Complex Proportional Assessment, **ELECTRE**: Elemination and Choice Translating Reality English, **GRA**: Gray Relational Analysis, **IVIF**: The Interval-Valued Intuitionistic, **MAUT**: Multi-Attribute Utility Theory, **MARCOS:** Measurement Alternatives and Ranking according to Compromise Solution, **MULTIMOORA**: Multi-Objective Optimization on the basis of Ratio Analysis plus full multiplicative form, **PAPRIKA**: Potentially All Pairwise Rankings of All Possible Alternatives, **PROMETHEE**: Preference Ranking Organization Method for Enrichment Evaluations, **TOPSIS**: Technique for Order Preference by Similarity to Ideal Solution, **VIKOR**: VIseKriterijumska Optimizacija I Kompromisno Resenje, **WASPAS**: Weighted Aggregated Sum Product Assessment

The remainder of this paper is structured as follows. Section 2 provides an overview of the previous work on cloud service provider selection problems. In Section 3, some basic knowledge and methodologies are presented. Section 4 provides a case study concerning the cloud service provider evaluation problem using the proposed hybrid MCDM approaches and presents sensitivity analysis to demonstrate the robustness of our proposed methodology. In Section 5, conclusions and future research directions are remarked.

2. Literature Review

Cloud computing has popularity because the cloud service selection problem is a relatively new but exciting area of research. There are various solution approaches in the literature for solving this problem including MCDM-based, optimization-based, logic-based, QoS prediction, recommendation systems, etc. MCDM is one of the popular methods in solving cloud services provider's selection problems because these methods are successfully applied in decision making, weighting, and selecting the most appropriate alternatives (Pomerol and Barba-Romero, 2000). Table 1 lists a summary of studies on cloud service selection problems using MCDM approaches. As seen in Table 1, there are only a few studies on cloud service selection including the hybrid MCDM approaches under fuzzy environment. Recent studies also indicate an increasing interest in uncertainty-aware hybrid MCDM models for cloud service evaluation and selection. This paper is an attempt to explore various issues pertaining to the evaluation of the cloud service providers, use the integrated approach of fuzzy AHP and fuzzy TOPSIS, and compare the obtained results.

3. Methodology

This study aims to select the best appropriate CSP among various cloud services using the integrated AHP, TOPSIS, and EDAS techniques under a fuzzy environment.

3.1 Fuzzy AHP

AHP is a regulated method for solving complex decision problems by determining the relative importance of a set of activities in a problem. Due to some shortcomings of AHP such as an unbalanced scale of judgment and the usage of crisp-information decision applications, several researchers integrated fuzzy theory with AHP to improve the uncertainty. Fuzzy AHP is based on the fuzzy interval arithmetic with triangular fuzzy numbers and confidence index with interval mean approach to determine the weights for evaluative elements (Vinodh et al., 2014). In this study, the scale used is the triangular fuzzy numbers (TFNs) scale from one to nine as displayed in Table 2. The steps in Fuzzy AHP are presented as follows:

Table 2. Definition and membership function of fuzzy number (Anagnostopoulos et al., 2007).

Intensity of Importance	Fuzzy number	Definition	Membership function
1	$\tilde{1}$	Equally important	(1,1,1)
3	$\tilde{3}$	Moderately important	(2,3,4)
5	$\tilde{5}$	Strongly important	(4,5,6)
7	$\tilde{7}$	Very strongly important	(6,7,8)
9	$\tilde{9}$	Extremely important	(8,9,9)

Step 1: Establishing the evaluation hierarchy systems for evaluating the best alternative among the considered alternatives taking into account the various criteria.
Step 2: Determining the evaluation dimensions weights using Triangular Fuzzy numbers (TFNs). This present research uses TFNs for the pair-wise comparisons and finds the fuzzy weights. TFN is represented with three points (*l*, *m*, *u*). *l* and *u* describe the lower and upper bounds of the fuzzy number $\tilde{A}$, and *m* is the modal value for $\tilde{A}$. Linguistic variables take on values defined in Table 2. The membership function $\mu_{\tilde{A}}(x)$ is given by

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m, \\ (u-x)/(u-m), & m \le x \le u, \\ 0, & otherwise. \end{cases} \tag{1}$$

Step 3: Obtaining the weights of the criteria. Determination of weights for evaluation criteria contains the following steps:

- The pair-wise comparison matrix showing the preference of one criterion over the other is constructed by entering the judgmental values given in Table 2 by the decision makers. Since the values are linguistic variables, a triplet of triangular fuzzy numbers are entered, as following matrix $\tilde{A}$:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \quad (2)$$

- Geometric mean method is used to combine the synthetic pair-wise comparison matrices as defined below:

$$\tilde{r}_i = \left(\tilde{a}_{i1} \times \cdots \times \tilde{a}_{ij} \times \cdots \times \tilde{a}_{in}\right)^{\frac{1}{n}} \quad (3)$$

where $\tilde{a}_{ij}$ is fuzzy comparison value of dimension *i* to criterion *j*, thus, $\tilde{r}_i$ is a geometric mean of fuzzy comparison value of criterion *i* to each criterion.

Step 4: The weight for each criterion is determined considering the normalization of the matrix.

$$\tilde{w}_i = \tilde{r}_i \times \left(\tilde{r}_1 + \cdots + \tilde{r}_i + \cdots + \tilde{r}_n\right)^{-1} \quad (4)$$

where $\tilde{w}_i$ is the fuzzy weight of the *i*th criterion, can be indicated by a TFN, $\tilde{w}_i = \left(lw_i, mw_i, uw_i\right)$. The lw_i , mw_i ,and uw_i stand for the lower, middle, and upper values of the fuzzy weight of the *i*th dimension.

Step 5: The Best Non-Fuzzy Performance (BNP) value for each weight is determined. BNP value for a weight (*l*, *m*, *u*) is defined by

$$BNP = \left[\left(u-l\right)+\left(m-l\right)\right]/3 + l \quad (5)$$

Step 6: The criteria are ranked based on the BNP values. The criterion having larger BNP value is considered to have a greater impact when compared with other criterion.

3.2 Fuzzy TOPSIS

TOPSIS developed by Hwang and Yoon (1981) is one of the classical multi-criteria decision making methods. The primary concept of TOPSIS approach is based on the fact that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution (Vinodh et al., 2014). The steps involved in fuzzy TOPSIS are presented as follows:

Step 1: Calculate the importance weights of criteria from fuzzy AHP.
Step 2: Creating of fuzzy evaluation matrix. The decision makers use linguistic variables given in Table 3 to evaluate the ratings of alternatives with respect to criteria.

Table 3. Linguistic Variables and TFNs (Solangi et al., 2021).

Likert scale	Linguistic Variables	TFN
1	Very Poor (VP)	(1,1,3)
3	Poor (P)	(1,3,5)
5	Fair (F)	(3,5,7)
7	Good	(5,7,9)
9	Very Good	(7,9,9)

Step 3: Normalize fuzzy decision matrix. The normalized fuzzy decision matrix is indicated by $\tilde{R}$ and expressed by $\tilde{R} = \left[\tilde{r}_{ij}\right]_{m \times n}, i = 1,..,m; j = 1,...,n$.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{u_j^+}, \frac{b_{ij}}{u_j^+}, \frac{c_{ij}}{u_j^+}\right), u_j^+ = \max_i u_{ij} \quad (6)$$

Step 4: Obtain the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).

$$(FPIS)A^+ = \left(\tilde{v}_i^+, \cdots, \tilde{v}_j^+, \cdots, \tilde{v}_n^+\right), (FNIS)A^- = \left(\tilde{v}_i^-, \cdots, \tilde{v}_j^-, \cdots, \tilde{v}_n^-\right), \& \tilde{v}_i = \left(1,1,1\right) \times \tilde{w}_j \quad (7)$$

Step 5: The distance from FPIS (d^+) and gap from FNIS (d^-) are denoted by

$$d_j^+ = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_i^+\right) \& d_j^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_i^-\right) \quad (8)$$

where $d(a,b)$ is the distance measurement between two fuzzy numbers a and b. It is denoted by

$$d\left(\tilde{a},\tilde{b}\right)=\sqrt{\frac{1}{3}\left[\left(a_1-b_1\right)^2+\left(a_2-b_2\right)^2+\left(a_3-b_3\right)^2\right]} \tag{9}$$

Step 6: The closeness coefficient (CC_i) of each alternative is determined and alternatives are ranked accordingly. As CC_i gets closer to 1, alternative A_i gets closer to FPIS and gets far from FNIS. The relative closeness is indicated by

$$CC_i=\frac{d_i^-}{d_i^+ + d_i^-} \tag{10}$$

3.3 The EDAS Method

The EDAS method introduced by Ghorabaee et al. (2015) is consistent and has been achieved good results when it is compared with the other MCDM methods (i.e, like VIKOR, TOPSIS, Simple Additive Weighting (SAW), and COPRAS) in the literature. Thus, in the present study, the results obtained from the integrated fuzzy AHP and fuzzy TOPSIS are compared with the results of the integrated fuzzy AHP and the EDAS method. The steps involved in the EDAS method are presented as follows:

Step 1: Calculate the importance weights of criteria from fuzzy AHP. The decision matrix (K) is constructed and the performance rating of the alternative ith on the criterion jth is created as follows:

$$K=\left[K_{ij}\right]_{n\times m}=\begin{bmatrix} K_{11} & K_{12} & \cdots & K_{1m} \\ K_{21} & K_{22} & \cdots & K_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ K_{n1} & K_{n2} & \cdots & K_{nm} \end{bmatrix} \tag{11}$$

Step 2: The matrix of average solutions ($AV=\left[AV_j\right]_{1\times m}$) is created using the Eq (12).

$$AV_j=\frac{\sum_{i=1}^{n} K_{ij}}{n} \tag{12}$$

Step 3: The positive distance from average (PDA) and the negative distance from average (NDA) matrices according to the type of criteria (benefit and cost) are computed shown as follows:

$$PDA=\left[PDA_{ij}\right]_{n\times m}\Rightarrow PDA_{ij}=\begin{cases} \dfrac{\max\left(0,\left(K_{ij}-AV_j\right)\right)}{AV_j}, & i\in B \\ \dfrac{\max\left(0,\left(AV_j-K_{ij}\right)\right)}{AV_j}, & i\in N \end{cases} \tag{13}$$

$$NDA=\left[NDA_{ij}\right]_{n\times m}\Rightarrow NDA_{ij}=\begin{cases} \dfrac{\max\left(0,\left(AV_j-K_{ij}\right)\right)}{AV_j}, & i\in B \\ \dfrac{\max\left(0,\left(K_{ij}-AV_j\right)\right)}{AV_j}, & i\in N \end{cases} \tag{14}$$

Step 4: The weighted sum of positive and negative distances for all alternatives is calculated for all alternatives, denoted as follow:

$$SP_i=\sum_{j=1}^{m}\left(\tilde{w}_j\times PDA_{ij}\right) \tag{15}$$

$$SN_i = \sum_{j=1}^{m} \left(\tilde{w}_j \times NDA_{ij} \right) \tag{16}$$

Step 5: The normalized values of SP_i and SN_i for all alternatives are calculate as shown in Eqs. (17) and (18):

$$NSP_i = \frac{SP_i}{\max_i \left(SP_i \right)} \tag{17}$$

$$NSN_i = 1 - \frac{SN_i}{\max_i \left(SN_i \right)} \tag{18}$$

Step 6: The appraisal score AS_i for all alternatives is calculated as follows:

$$AS_i = \frac{1}{2} \left(NSP_i + NSN_i \right) \tag{19}$$

Step 7: Rank the alternatives with respect to the decreasing values of appraisal scores AS_i, since the alternative with the highest appraisal score is the best alternative.

4. Case Study

The case study contains the selection of best cloud service provider among five alternatives using the integrated fuzzy AHP and fuzzy TOPSIS technique. The results obtained from this integrated method is compared with the results of the integrated fuzzy AHP and EDAS. The case study of the proposed integrated model is applied in a food company in Bursa, Turkey.

4.1 Data Collection

A set of eight criteria, $C = \{C_1, C_2, \ldots , C_8\}$ and five cloud service providers (CSPs), $A = \{A_1, A_2, \ldots , A_5\}$, were evaluated by the expert panel comprising of five decision-makers (DMs) for organizations in a cloud service. Cloud service providers are considered as Google, Amazon, Azure, Oracle, and IBM. The evaluation criteria are obtained through a literature survey, the support of five decision-makers (DMs) who have experience and expertise in cloud computing, and other appropriate methods. All DMs are cloud solution architects in different firms. The proposed hierarchical structure for the evaluation of cloud service providers is shown in Fig. 1. These criteria consist of cost, reliability, scalability, security, elasticity, high availability, performance, and service variety. The data were collected from the experts via two stages of questionnaires: (*i*) comparison of criteria, (*ii*) evaluation of the alternatives.

4.2 Computation Using Integrated Fuzzy AHP-Fuzzy TOPSIS and Comparative Analysis

Step 1: After interview with the DMs, the pair-wise comparison matrix for the fuzzy AHP process was constructed and the linguistic values provided from the DMs are transferred to the corresponding fuzzy numbers given in Table 2. All pair-wise comparison matrices are integrated computing the geometric mean method developed by Buckley (1985) for the fuzzy AHP process and given in the Table 4.

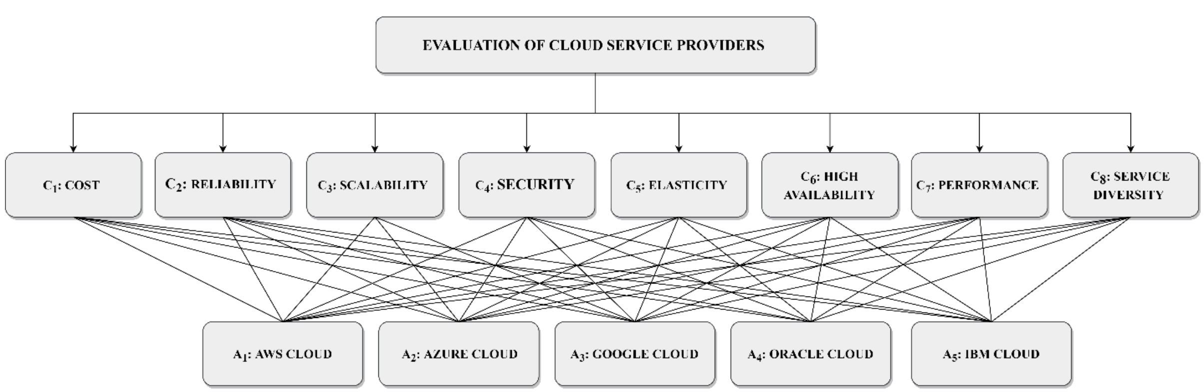

Figure 1. The hierarchical structure of the evaluation of cloud service providers.

Table 4. The fuzzy pairwise comparison matrix for the fuzzy AHP.

	C_1			C_2			C_3			C_4		
C_1	1.000	1.000	1.000	2.124	2.477	2.798	2.208	2.063	1.994	0.803	0.970	1.084
C_2	0.357	0.404	0.471	1.000	1.000	1.000	1.084	1.572	1.974	0.425	0.288	0.220
C_3	0.502	0.485	0.453	0.506	0.636	0.922	1.000	1.000	1.000	0.275	0.214	0.175
C_4	0.922	1.031	1.246	4.536	3.471	2.352	5.706	4.682	3.641	1.000	1.000	1.000
C_5	0.422	0.499	0.631	1.431	1.380	1.320	2.569	2.221	1.821	0.359	0.407	0.478
C_6	0.514	0.495	0.453	0.768	0.811	0.871	0.889	1.000	1.246	0.303	0.331	0.506
C_7	0.714	0.740	0.803	1.563	1.552	1.585	2.639	2.290	1.888	0.339	0.379	0.922
C_8	0.307	0.334	0.380	0.404	0.474	0.600	0.443	0.422	0.582	0.261	0.278	0.651

	C_5			C_6			C_7			C_8		
C_1	1.585	2.005	2.369	2.208	2.020	1.947	1.246	1.351	1.401	2.631	2.993	3.253
C_2	0.758	0.725	0.699	1.149	1.234	1.303	0.631	0.644	0.640	1.667	2.112	2.477
C_3	0.549	0.450	0.389	0.803	1.000	1.125	0.530	0.437	0.379	1.719	2.118	2.498
C_4	2.091	2.460	2.787	2.724	3.022	3.301	2.290	2.639	2.954	3.333	3.591	3.838
C_5	1.000	1.000	1.000	1.849	2.215	2.547	0.871	0.811	0.768	2.187	2.551	2.874
C_6	0.393	0.451	0.541	1.000	1.000	1.000	0.833	0.774	0.735	1.431	1.874	2.221
C_7	1.303	1.234	1.149	1.361	1.292	1.201	1.000	1.000	1.000	2.169	1.983	1.913
C_8	0.348	0.392	0.457	0.450	0.533	0.699	0.523	0.504	0.461	1.000	1.000	1.000

Step 2: Fuzzy geometric mean and the weight of each dimension are calculated through Eqs. (3) and (4), respectively. The yielded values are given as follow:

$$\tilde{r}_1 = (1.592, \quad 1.732, \quad 1.833) \qquad \tilde{w}_1 = (0.166, \quad 0.190, \quad 0.208)$$
$$\tilde{r}_2 = (0.789, \quad 0.829, \quad 0.859) \qquad \tilde{w}_2 = (0.082, \quad 0.091, \quad 0.098)$$
$$\tilde{r}_3 = (0.640, \quad 0.638, \quad 0.646) \qquad \tilde{w}_3 = (0.067, \quad 0.070, \quad 0.073)$$
$$\tilde{r}_4 = (2.382, \quad 2.421, \quad 2.403) \qquad \tilde{w}_4 = (0.248, \quad 0.266, \quad 0.273)$$
$$\tilde{r}_5 = (1.088, \quad 1.140, \quad 1.192) \qquad \tilde{w}_5 = (0.113, \quad 0.125, \quad 0.136)$$
$$\tilde{r}_6 = (0.687, \quad 0.737, \quad 0.827) \qquad \tilde{w}_6 = (0.072, \quad 0.081, \quad 0.094)$$
$$\tilde{r}_7 = (1.183, \quad 1.154, \quad 1.251) \qquad \tilde{w}_7 = (0.123, \quad 0.127, \quad 0.142)$$
$$\tilde{r}_8 = (0.430, \quad 0.459, \quad 0.581) \qquad \tilde{w}_8 = (0.045, \quad 0.050, \quad 0.066)$$

These weights are used in both the fuzzy TOPSIS method and the EDAS method. When the BNP values are computed through Eq. (5), the ranking order of the criteria is obtained as $C_4 > C_1 > C_7 > C_5 > C_2 > C_6 > C_3 > C_8$.

Step 3: The fuzzy decision matrix for the five cloud service providers was filled by the DMs. The decision matrix is obtained for the five alternatives and a set of eight criteria as given in Table 5. This table shows the linguistic variables and these variables are transferred to fuzzy values using Table 3. After combining one fuzzy decision matrix with arithmetic mean method, the obtained matrix is normalized through Eq. (6).

Step 4: The fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) are computed through Eq. (7). Then, with the help of Eq. (8), the distance from FPIS (d^+) and gap from FNIS (d^-) are calculated and the obtained results are indicated in Table 6. Consequently, the relative degree of closeness coefficient for every alternative is computed with Eq. (10). The closeness coefficients of each alternative and final ranking are shown in Table 6.

Table 5. Evaluating values of the alternatives given by the DMs with respect to eight criteria.

Alternatives	DMs	Criteria							
		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1	D_1	VG	VG	VG	VG	G	VG	G	VG
	D_2	VG	VG	VG	VG	VG	VG	VG	VG
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	D_5	VG	VG	VG	VG	G	VG	G	VG
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
A_5	D_1	F	F	F	F	F	F	P	P
	D_2	P	F	F	P	F	F	F	P
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	D_5	P	F	P	P	F	F	P	P

Table 6. Closeness coefficients (CC_i) of five cloud service providers.

Alternatives	d^+	d^-	CC_i	Ranking
A_1	0.113	0.392	0.776	1
A_2	0.170	0.340	0.667	2
A_3	0.305	0.242	0.443	3
A_4	0.390	0.117	0.231	5
A_5	0.348	0.181	0.342	4

Step 5: The importance weights of criteria from fuzzy AHP and the evaluation criteria and alternatives from Table 5 are obtained. In this study, while the criterion of cost (C_1) is a non-beneficial criterion, the remaining seven criteria are beneficial criteria. With the help of Eqs. (11)-(12), the elements of the average decision matrix and the average solution matrix are obtained as shown in Table 7.

Table 7. The elements of the average decision matrix and the average solution matrix.

	A_1	A_2	A_3	A_4	A_5	AV
C_1	9	7	3	5	3	5.4
C_2	9	7	5	7	5	6.6
C_3	9	9	5	7	7	7.4
C_4	9	7	3	5	3	5.4
C_5	7	7	5	5	5	5.8
C_6	7	7	7	7	5	6.6
C_7	7	5	3	5	5	5.0
C_8	7	9	3	5	5	5.8

Step 6: Then, we have results and final ranking of alternatives as given in Table 8. According to the obtained results, the ranking of alternatives is in relation to declining values, so the A_1 alternative is determined as the best suitable alternative.

Table 8. The weighted sum of distances, their normalized values, the appraisal scores, and ranking values.

Alternatives	NSP_i	NSN_i	AS_i	Ranking
A_1	1.000	0.486	0.743	1
A_2	0.502	0.218	0.360	4
A_3	0.281	1.000	0.640	2
A_4	0.076	0.187	0.131	5
A_5	0.265	0.728	0.496	3

4.3 Sensitivity Analysis and Discussion

After the computation of the appraisal scores and the determination of the ranking of the alternatives, it is necessary to show the stability of the model and the sensitivity of the findings to any change in the weights of particular criteria. This analysis provides to check the robustness of the results obtained through the integrated fuzzy AHP and fuzzy TOPSIS hybrid approach. It includes the 7 scenarios where the values of criteria are changed.

Table 9. The ranking of cloud services ranking with respect to each experiment by using each resolving criteria weights.

No	Description	CC_i				
		A_1	A_2	A_3	A_4	A_5
Original	$C_4 > C_1 > C_7 > C_5 > C_2 > C_6 > C_3 > C_8$	**0.776**	0.667	0.443	0.231	0.342
1	C_1>the remaining criteria	**0.704**	0.632	0.426	0.302	0.382
2	C_2>the remaining criteria	**0.776**	0.670	0.448	0.231	0.342
3	C_3>the remaining criteria	**0.786**	0.670	0.455	0.221	0.295
4	C_5>the remaining criteria	**0.777**	0.664	0.432	0.230	0.309
5	C_6>the remaining criteria	**0.744**	0.700	0.428	0.288	0.350
6	C_7>the remaining criteria	**0.768**	0.686	0.430	0.239	0.317
7	C_8>the remaining criteria	**0.768**	0.730	0.487	0.228	0.341

The sensitivity analysis result indicates that the alternative A_1 (Amazon) is unaffected by the change of criteria weights. It is the best appropriate alternative when all scenarios are considered as shown in Figure 2. As seen in Table 9, the alternative A_1 has the highest CC_i value in the original condition, has saved its position in seven scenarios when weights of evaluation criteria were changed mutually. The alternative A_2 (Azure) has the second-highest score for all scenarios while the alternative A_4 (Oracle) has the lowest score.

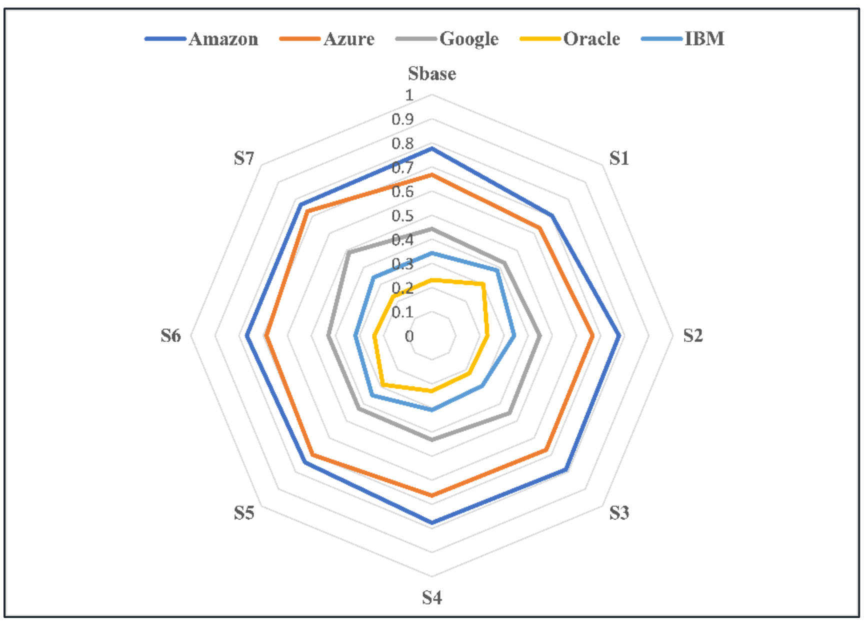

Figure 2. Outcome of sensitivity analysis.

5. Conclusion

The objective of this study is to present a decision analysis methodology based on the hybrid approach under a fuzzy environment for solving the evaluation of cloud service providers. In this study, evaluating and selecting the most suitable cloud solution implies considering a set of multiple and conflicting criteria which include subjective and qualitative judgments. In such processes, MCDM methods can be effectively employed to choose the best appropriate alternative. In this paper, the introduced integrated methodology considers two steps: Fuzzy AHP and Fuzzy TOPSIS. Then, this integrated approach is compared with the results of the integration of fuzzy AHP and EDAS method. A computational tool has been improved to consider multiple calculations, for sensitivity analysis to explore the sensitivity of outputs towards the changes in inputs. The proposed decision-making tool was performed for a real case study of a food company in Bursa. The ranking order of five cloud services is determined as $A_1 > A_2 > A_3 > A_5 > A_4$ in terms of the result obtained from the integrated fuzzy AHP and fuzzy TOPSIS. Given the integrated fuzzy AHP and EDAS method, it is obtained as $A_1 > A_3 > A_5 > A_2 > A_4$. The alternative A_1 (Amazon) is the best suitable option for the company.

In future studies, the performance of the proposed approach can be compared with the other multi-criteria methods like FUCOM and LBWA, BWM, ARAS, etc. under a fuzzy environment. Interval type-2 fuzzy MCDM, interval type-2 hesitant fuzzy set method, intuitionistic fuzzy set studied in recent years can be used for the same problem and the results can be compared in further studies.

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