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Ranking Cloud Service Providers using SWARA-MARCOS in Type-2 Neutrosophic Number Set Environment

Mai Mohamed [1,*], Shaimaa Ayman [1], Rui Yong [2], and Jun Ye [2]

[1] Faculty of Computers and Informatics, Zagazig University, Zagazig 44519, Sharqiyah, Egypt.
Emails: mmgaafar@zu.edu.eg, sh.ayman021@fci.zu.edu.eg.
[2] School of Civil and Environmental Engineering, Ningbo University, Ningbo, Zhejiang, China.
Emails: yongrui@nbu.edu.cn, yejun1@nbu.edu.cn.

* Correspondence: mmgaafar@zu.edu.eg.

Abstract: Cloud computing is a model for allowing suitable, on-demand network access to a shared store of resources such as servers, networks, storage, apps, and services, modified according to specific needs or requirements. The main goal of cloud technology development is to increase the use of resources that work together to achieve reliability at the lowest cost. Cloud service providers (CSPs) have gained popularity in recent years due to their accessibility and availability, as well as the growing quantity of cloud service providers (CSPs) that appear. Choosing (CSPs) has grown to be a challenging decision for many companies. The paper aims to rank a set of cloud service providers based on the multi-criteria decision-making (MCDM) method. The suggested method's applicability is verified by comparing the outcomes with two established methodologies: SWARA and MARCOS methods under the type-2 neutrosophic number set (T2NNS) environment to calculate the importance of evaluation criteria and ranking the alternatives of cloud providers. A sensitivity analysis was executed to check the robustness of this model by examining the effect of criteria weights on the ranking of the alternatives.

Keywords: Cloud Computing, Cloud Service Provider, Type-2 Neutrosophic Number Set, Multi-Criteria Decision-Making, SWARA, MARCOS.

1. Introduction

The rapid progress in information technology has led to the emergence of a novel approach in the field of distributed computing known as cloud computing, which has quickly gained huge popularity. High-performance computing was traditionally handled by costly grids, clusters, or supercomputers. There were drawbacks to each of these choices, such as higher infrastructure costs or less efficient use of available resources [1]. Cloud computing services through the Internet users can access collected computer resources including software applications, processing power, and storage. The collection of resources available to consumers on request is referred to as "the cloud". As cloud computing grows, next-generation systems aim to become more pervasive, global, and present everywhere [2]. One benefit of cloud computing for businesses is its wide flexibility. It eliminates the need to spend money on physical infrastructure, allows for the quick reduction of resources when not in use, and allows at last minute changes without risking productivity. There are four types of cloud computing: public, private, community, and hybrid. Public cloud: depending on the service providers, this type of cloud is created and maintained by businesses in the education sector, and the government. It is accessible to the general public for usage like Azure, and AWS [3]. Private cloud: a single customer is the only one who has access to it, while education, business, and security agencies can use it privately like VMware, and IBM [4]. Community clouds: are used for business or security reasons, and they are developed and managed by a specific community. It is managed by one or two organizations like Salesforce, and Google Cloud [5]. The hybrid cloud: improves computing resource information and application availability by merging many cloud models, such as private, public, and community [6].

The rapid development of the software industry has encouraged many major cloud resource providers, referred to as cloud service providers (CSPs), to offer their services and become more competitive. By keeping pace with operating systems, software, and data architecture, cloud providers control user data. Now, users can pay for what they use as needed computing services, like Infrastructure as a Service (IaaS) as appear in Figure 1, Platform as a Service (PaaS), and Software as a Service (SaaS) from any location in the world, because of the cloud computing model. This model works especially well for companies whose resource requirements are as irregular as those whose needs change according to varies seasonally. As a result, some businesses and startups have become cloud users by totally renting cloud computing infrastructure from cloud providers instead of spending high beginning expenses on hiring specialized staff and buying customized computing equipment. To use the services, the user can make monthly or yearly payments. The increased flexibility that cloud computing offers enterprises is one of its main benefits.

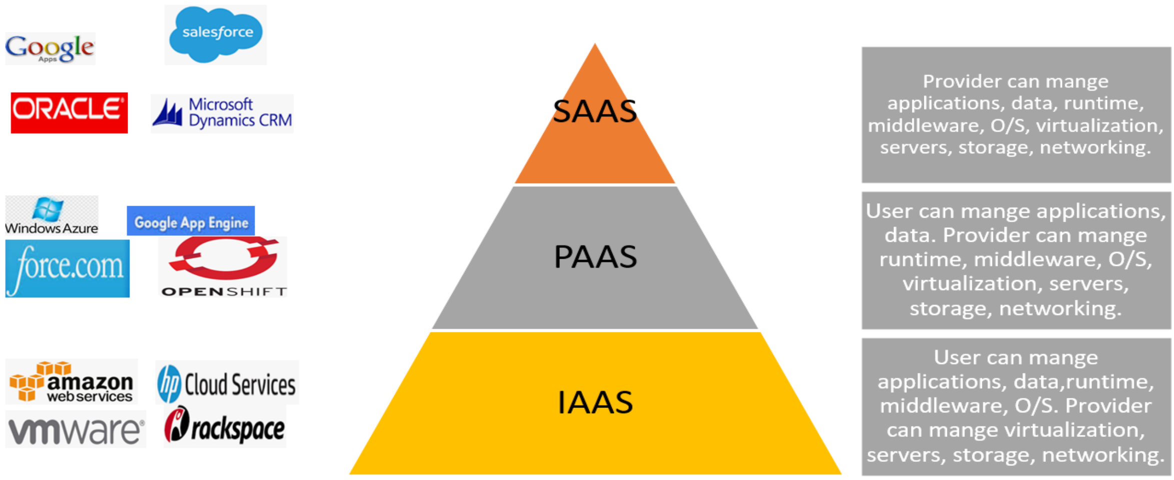

Figure 1. Cloud computing service models and their providers [7].

IAAS: provides companies with on-demand automatic server, storage, computing, and network infrastructure deployment. Companies may now control the networking, storage, and server saving them the trouble of building the IT infrastructure [8, 9].

PAAS: It helps companies manage the entire application without worrying about IT infrastructure. Cloud tools and services for developing applications, testing, and continuous deployment are provided by service providers.

SAAS: It allows companies to rent servers and subscribe to the programs when needed rather than purchase and maintain online applications. It achieves a growing level of acceptance in the marketplace [9].

The remainder of the paper is organized as follows: A summary of related work is given in Section 2. Section 3 explains the preliminary steps. Section 4 offers an overview of the suggested framework. In the framework of cloud computing, CSPs are ranked in Section 5 using SWARA and MARCOS based on the type-2 neutrosophic number sets (T2NNSs). Section 6 gives a case study. Section 7 presents a sensitivity analysis. Section 8 presents the conclusion.

2. Related Work

An extensive literature review has been done to understand the main concept study of cloud computing and the providers' services. Although there are a lot of definitions of cloud computing, the NIST definition is the most popular [10], which describes cloud computing as technologies that allow storage, networking, applications, and services to be quickly provisioned and released with little administrative effort. Using cloud service providers (CSPs) in the finance industry has several advantages, in 2021 Cloud Path survey indicates that bank managers understand enhanced company flexibility and freedom to adapt to market needs as the advantages of cloud-based operations [11]. In this study [12] they introduce an efficient analytical technique based on data envelopment analysis (DEA) to evaluate the Industry 4.0 CSPs' sustainability. They offer not only an effective strategy with solid backing from academia but also important management insights for practitioners to evaluate the sustainability of CSPs for Industry 4.0. Liu S et al. [13] selected the cloud service provider in MCDM using the SV-TOPSIS-SAW approach. Martens et al. [14] take risk and cost into account when developing a complex mathematical model for the cloud computing decision problem. Athraa et al. [15] introduced a hybrid MADM framework, FFS-FUCOM, and Grey-TOPSIS methodologies to rank CSPs using Quality of Service (QoS) attributes. Users can access the data at any time and need to be aware of the security protocols and how to defend themselves against threats like denial-of-service (DoS) attacks [16]. The taxonomic framework created by Rimal et al. [17] can categorize particular cloud providers. By the CSA CAIQ framework, cloud providers additionally make available service-specific capabilities of security, compliance, data governance, etc. through a public repository called STAR [18]. David et al. [19] PrPl was created for usage with both rented cloud machines and servers that users supply, Users use cloud services like Microsoft Azure and Amazon EC2 to store their private data. Each user has their virtual machine (VM) server running in the cloud. After that, content is divided up among user servers into groups, with the group's founder in charge of communication and membership.

Many criteria must be taken into evaluation for several CSPs. Several alternatives are evaluated in comparison to several criteria to determine which is the optimal alternative [20].

The set of criteria needed for the evaluation of cloud service providers (CSPs) are as follows:

C1- Downtime is a major drawback of cloud computing. Cloud providers may have technical problems such as data center maintenance requirements, poor Internet access, and power cuts. This can cause the internet service to go down temporarily.

C2- Speed: Make sure the cloud service provider has high-performance computing (HPC) servers if your company depends on super-fast cloud services.

C3- Security is challenging to access private data on the cloud because of the ability to safeguard all data from hackers. Strong encryption on files and databases is a feature of cloud computing that might lessen vulnerability to hacker attacks.

C4- Flexibility: Companies could use it to quickly expand storage and resources to meet demand. Similarly, resources can be quickly depleted if not in use on the cloud.

C5- Cost Reduction: For small and medium companies, cloud computing minimizes IT expenses, users can set up even basic apps, like email, and most of them are available for free with Google Apps.

Also, the set of alternative cloud service providers (CSPs) needed for the evaluation are as follows:

A1- Amazon Web Services: five times as much computing capacity as competing cloud service providers. Different data centers are available in different locations Offer the option to set up their security firewall to be either private or public based on requirements [1].

A2- Microsoft Azure: offers a competitive advantage in the commercial world because of its speed in important areas. It has an excellent disaster recovery mechanism that can operate in demanding environments [21].

A3- Google Cloud Platform: Compared to other cloud platforms, this one offers more affordable pricing, requiring users to pay only for the compute time they utilize [22].

A4- IBM Cloud: recovering from disasters rather quickly and integrating (IaaS) and (PaaS). The distribution of the workload is methodical to provide users with a satisfactory application response [23].

A5- Salesforce: The first real-time cloud platform for creating dependable, quick, and secure multitenant customized or business apps. Cloud solutions are provided for business services, marketing, sales, and other purposes [24].

A6- VMWare: the basic structure of VMware's cloud solution is its vCloud suite, which offers an API-based platform for managing and controlling clouds [25].

A7- Alibaba Cloud: is the proportion of applied resources to actual resources used and provides cloud computing DBaaS, SaaS, PaaS, and IaaS [26].

3. Preliminaries

This section defines the preliminary steps that were taken to design the framework. The theory of neutrosophic sets introduces T2NNS. Its definition is a generalization of the set definition found in set theory.

3.1 Type-2 Neutrosophic Number Set

A neutrosophic set has three membership functions to represent: the truth membership function (T), the indeterminacy membership function (I), and the falsity membership function (F) [27].

Definition 1. Suppose X is a universe of discourse, U is a neutrosophic set, T_U, I_U, F_U represent the degree of truth membership (T), the degree of indeterminacy membership (I), and the degree of falsity membership (F) of the element x.

$$U = \left\{\langle (T_{T_U}(\mathrm{x}), T_{I_U}(\mathrm{x}), T_{F_U}(\mathrm{x})), (I_{T_U}(\mathrm{x}), I_{I_U}(\mathrm{x}), I_{F_U}(\mathrm{x})), (F_{T_U}(\mathrm{x}), F_{I_U}(\mathrm{x}), F_{F_U}(\mathrm{x}))\rangle | \mathrm{x} \in \mathrm{X}\right\} \tag{1}$$

Where $\mathrm{X} \rightarrow [0,1]^3$, $\mathrm{x} \in \mathrm{X} : 0 \leq (T_{T_U}(\mathrm{x}), T_{I_U}(\mathrm{x}), T_{F_U}(\mathrm{x})) \leq 3$, $0 \leq (I_{T_U}(\mathrm{x}), I_{I_U}(\mathrm{x}), I_{F_U}(\mathrm{x})) \leq 3$, $0 \leq (F_{T_U}(\mathrm{x}), F_{I_U}(\mathrm{x}), F_{F_U}(\mathrm{x})) \leq 3$.

Definition 2. Let two T2NNSs U_1, U_2 be defined as the following operations:

Addition $$U_1 \oplus U_2 = \{\langle (T_{T_{U1}}(\mathrm{x}) + T_{T_{U2}}(\mathrm{x}) - T_{T_{U1}}(\mathrm{x}) . T_{T_{U2}}(\mathrm{x})), (T_{I_{U1}}(\mathrm{x}) + T_{I_{U2}}(\mathrm{x}) - T_{I_{U1}}(\mathrm{x}) . T_{I_{U2}}(\mathrm{x})), (T_{F_{U1}}(\mathrm{x}) + T_{F_{U2}}(\mathrm{x}) - T_{F_{U1}}(\mathrm{x}) . T_{F_{U2}}(\mathrm{x}))\rangle, (I_{T_{U1}}(\mathrm{x}) . I_{T_{U2}}(\mathrm{x}), I_{I_{U1}}(\mathrm{x}) . I_{I_{U2}}(\mathrm{x}), I_{F_{U1}}(\mathrm{x}) . I_{F_{U2}}(\mathrm{x})), (F_{T_{U1}}(\mathrm{x}) . F_{T_{U2}}(\mathrm{x}), F_{I_{U1}}(\mathrm{x}) . F_{I_{U2}}(\mathrm{x}), F_{F_{U1}}(\mathrm{x}) . F_{F_{U2}}(\mathrm{x}))\} \tag{2}$$

Multiplication $$U_1 \otimes U_2 = \Big\{(T_{T_{U1}}(\mathrm{x}). T_{T_{U2}}(\mathrm{x}), T_{I_{U1}}(\mathrm{x}). T_{I_{U2}}(\mathrm{x}), T_{F_{U1}}(\mathrm{x}) . T_{F_{U2}}(\mathrm{x})), \Big(\big(I_{T_{U1}}(\mathrm{x}) + I_{T_{U2}}(\mathrm{x}) - I_{T_{U1}}(\mathrm{x}). I_{T_{U2}}(\mathrm{x})\big), \big(I_{I_{U1}}(\mathrm{x}) + I_{I_{U2}}(\mathrm{x}) - I_{I_{U1}}(\mathrm{x}). I_{I_{U2}}(\mathrm{x})\big), \big(I_{F_{U1}}(\mathrm{x}) + I_{F_{U2}}(\mathrm{x}) - I_{F_{U1}}(\mathrm{x}). I_F(\mathrm{x})\big)\Big), \Big(\big(F_{T_{U1}}(\mathrm{x}) + F_{T_{U2}}(\mathrm{x}) - F_{T_{U1}}(\mathrm{x}). F_{T_{U2}}(\mathrm{x})\big), \big(F_{I_{U1}}(\mathrm{x}) + F_{I_{U2}}(\mathrm{x}) - F_{I_{U1}}(\mathrm{x}). F_{I_{U2}}(\mathrm{x})\big), \big(F_{F_{U1}}(\mathrm{x}) + F_{F_{U2}}(\mathrm{x}) - F_{F_{U1}}(\mathrm{x}). F_F(\mathrm{x})\big)\Big) \Big\} \tag{3}$$

Definition 3. The score functions $S(U)$ of a type-2 neutrosophic number (T2NN) is defined as:

$$S(U) = \frac{1}{12} \langle 8 + (T_{T_U}(\mathrm{x}) + 2(T_{I_U}(\mathrm{x})) + T_{F_U}(\mathrm{x})) - (I_{T_U}(\mathrm{x}) + 2(I_{I_U}(\mathrm{x})) + I_{F_U}(\mathrm{x})) - (F_{T_U}(\mathrm{x}) + 2(F_{I_U}(\mathrm{x})) + F_{F_U}(\mathrm{x})\rangle \tag{4}$$

Definition 4. Aggregate the crisp value by using the average:

$$X_U = \frac{[(T_{T_U}(x), T_{I_U}(x), T_{F_U}(x)), (I_{T_U}(x), I_{I_U}(x), I_{F_U}(x)), (F_{T_U}(x), F_{I_U}(x), F_{F_U}(x)]}{n} \tag{5}$$

Where n number of experts.

3.2 SWARA

Determination of the important weight for each criterion of the decision-makers. Step-wise Weight Assessment Ratio Analysis (SWARA) is one of the MCDM methods that was introduced by Kersuliene et al. [28].

Definition 5. The criteria have been arranged in descending order according to their expected importance.

Definition 6. Evaluate the relative importance of the j criterion for the (j −1) criterion for each specific criterion. Begin with the second criterion so that criterion j is compared with the previous criterion (j −1). S_j is the comparative significance of mean value 0≤ $S_j \leq 1$ [28].

Definition 7. Calculating the coefficient K_j of comparative importance by Eq. (6).

$$K_j = \begin{cases} 1 \;\; j = 1 \\ S_j + 1 \; j > 1 \end{cases} \;\; ; \; j = 1, \ldots\ldots, m \tag{6}$$

Definition 8. Calculating the initial weight of a criteria Q_j for every decision-maker by Eq. (7).

$$Q_j = \begin{cases} 1 \;\; j = 1 \\ \frac{Q_{j-1}}{K_j} + 1 \; j > 1 \end{cases} \;\; ; \; j = 1, \ldots\ldots, m \tag{7}$$

Definition 9. Calculating the relative weights W_j of the criteria every decision-maker by Eq. (8) and the summation of this weight equal 1.

$$W_j = \frac{Q_j}{\sum_{j=1}^{m} Q_j} \tag{8}$$

where W_j is the relative weight of criterion j , and m is the number of criteria.

3.3 MARCOS

Measurement of Alternatives and Ranking according to the Compromise Solution (MARCOS) method introduced by Željko et al. [29]. It depends on establishing a combination between reference values and alternatives (ideal and anti-ideal alternatives). We used this method for Selecting and ranking the alternatives with respect to decision variables. Let A = ($A1$, $A2$,...Am) the number of alternatives, C = ($C1$, $C2$, $C3$, $C4$, $C5$) the numbers of criteria.

Definition 10. Constitute the initial T2NN decision-making matrix and calculate the AAI, and AI by applying Eqs. (10), and (11).

$$X = \begin{matrix} \text{AAI} \\ A_1 \\ \vdots \\ A_n \\ AI \end{matrix} \begin{bmatrix} x_{aa1} & \cdots & x_{aam} \\ x_{11} & \ddots & x_{1m} \\ \vdots & & \vdots \\ x_{n1} & \cdots & x_{nm} \\ x_{ai1} & \ldots & x_{aim} \end{bmatrix} \tag{9}$$

Where AAI = Anti-Ideal solution is the worst alternative, AI = Ideal solution is the best alternative depending on the nature of the criteria, n number of alternatives.

$$\text{AAI} = \min x_{ij} \; if \; j \in benefit \;\; and \; \max x_{ij} \; if \; j \in cost \tag{10}$$

$$\text{AI} = \max x_{ij} \; if \; j \in benefit \;\; and \; \min x_{ij} \; if \; j \in cost \tag{11}$$

Definition 11. Normalization of the initial matrix X . The normalized matrix's elements N = $[n_{ij}]_{n*m}$ obtained by applying Eqs. (12) and (13).

$$n_{ij} = \frac{x_{aj}}{x_{ij}} \qquad if \qquad j \in cost \tag{12}$$

$$n_{ij} = \frac{x_{ij}}{x_{aj}} \qquad if \qquad j \in benefit \tag{13}$$

Definition 12. Construct the weighted normalized decision matrix V $= [v_{ij}]_{n*m}$ Eq. (14).

$$v_{ij} = n_{ij} \times W_j \tag{14}$$

Definition 13. Calculate the utility degree of alternatives K_i by applying Eqs. (15), (16).

$$k_i^- = \frac{S_i}{S_{aai}} \tag{15}$$

$$k_i^+ = \frac{S_i}{S_{ai}} \tag{16}$$

Where S_i is the summation of elements in matrix V applied by Eq. (17).

$$S_i = \sum_{i=1}^{n} v_{ij} \quad (17)$$

Definition 14. Determine if the utility function of alternatives $f(k_i)$ by the following Equation:

$$f(k_i) = \frac{k_i^+ + k_i^-}{1 + \frac{1-f(k_i^+)}{f(k_i^+)} + \frac{1-f(k_i^-)}{f(k_i^-)}} \quad (18)$$

Where $f(k_i^+)$ is the utility function to the ideal solution, $f(k_i^-)$is the utility function of the anti-ideal solution.

Definition 15. Calculate the utility function to the ideal solution and anti-ideal solution by Eqs. (19), and (20).

$$f(k_i^+) = \frac{k_i^-}{k_i^+ + k_i^-} \quad (19)$$

$$f(k_i^-) = \frac{k_i^+}{k_i^+ + k_i^-} \quad (20)$$

Definition 16. Ranking of the optimal alternatives which depend on the final values of utility functions $f(k_i)$ in Eq. (18).

4. Case Study

A case study is performed on seven CSPs and five criteria shown in Table, according to five experts' CSPs judgments based on a scale shown in Table. After identifying CSPs and making the decision matrix a T2NN-MARCOS method is applied to rank the CSPs in descending order the $F(k_i)$ values. The following descriptions of steps are shown below as in Figure 2:

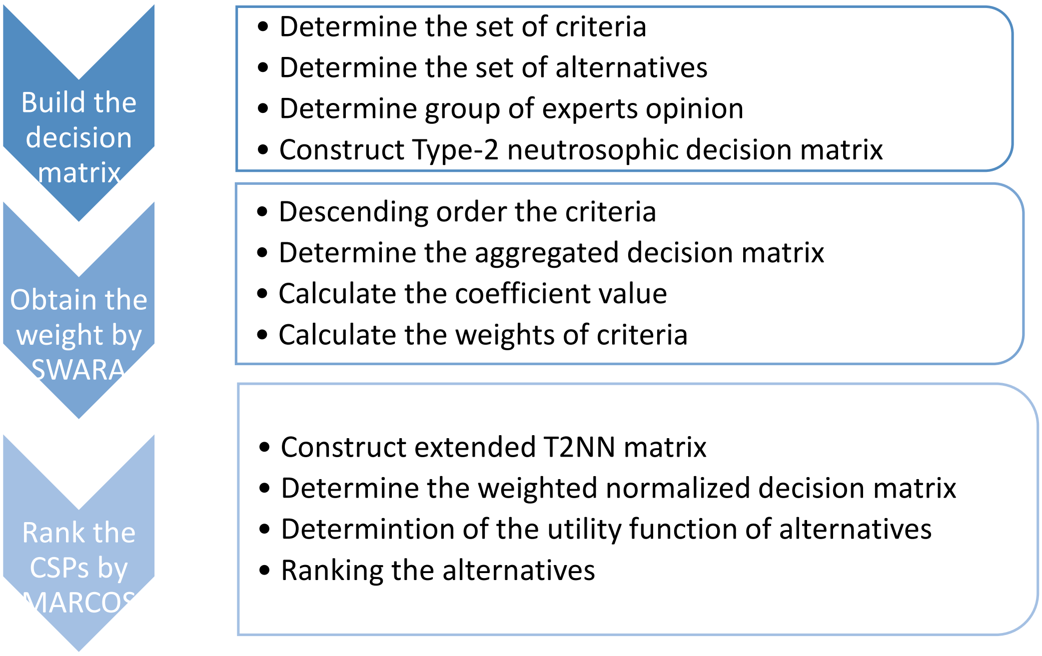

Figure 2. Framework of T2NN-SWARA-MARCOS.

Step 1. Identify the decision matrix.

The goal is to order the cloud service providers, first must determine the evaluation criteria. Suppose that the selected set of criteria is $C = (C1, C2, C3, C4, C5)$. As well as identifying the alternatives. Suppose that the selected set of CSPs is $A = (A1, A2, \ldots Am)$ where m number of CSPs, and Ex = (Ex_1, Ex_2, Ex_3, Ex_4, Ex5) be a set of experts.

Step 2. Construct the models by converting linguistic variables into crisp values. Transform the decision matrix into type-2 neutrosophic set values which are displayed in Table 1 [27].

Table 1. T2NN scale [27].

Linguistic variables	Type 2 neutrosophic number scale [(T_T, T_I, T_F), (I_T, I_I, I_F), (F_T, F_I, F_F)]	Score
Weakly important (WI)	⟨ (0.20, 0.30, 0.20), (0.60, 0.70, 0.80), (0.45, 0.75, 0.75) ⟩	0.291667
Equal important (EI)	⟨ (0.40, 0.30, 0.25), (0.45, 0.55, 0.40), (0.45, 0.60, 0.55) ⟩	0.425
Strong important (SI)	⟨ (0.65, 0.55, 0.55), (0.40, 0.45, 0.55), (0.35, 0.40, 0.35) ⟩	0.579167
Very strongly important (VSI)	⟨ (0.80, 0.75, 0.70), (0.20, 0.15, 0.30), (0.15, 0.10, 0.20) ⟩	0.804167
Absolutely important (AI)	⟨ (0.90, 0.85, 0.95), (0.10, 0.15, 0.10), (0.05, 0.05, 0.10) ⟩	0.9

Step 3. Based on the expected opinions of the expert's judgment, suppose that five experts start to judge the criteria in the scale of Table 2. Applying the score function equation and the scale that is shown in Table 1 to convert EXs' linguistic variables into crisp values by using Eq. (4).

Table 2. The crisp value of the expert's judgment.

EX1					
	C1	C2	C3	C4	C5
A1	0.292	0.9	0.804	0.579	0.579
A2	0.425	0.804	0.579	0.425	0.425
A3	0.579	0.292	0.425	0.9	0.579
A4	0.804	0.9	0.804	0.292	0.9
A5	0.579	0.425	0.579	0.292	0.292
A6	0.9	0.579	0.292	0.804	0.425
A7	0.579	0.425	0.9	0.579	0.804
EX2					
A1	0.425	0.804	0.9	0.292	0.292
A2	0.579	0.579	0.804	0.9	0.804
A3	0.804	0.9	0.292	0.579	0.292
A4	0.292	0.425	0.9	0.9	0.804
A5	0.579	0.579	0.425	0.804	0.579
A6	0.425	0.9	0.579	0.425	0.9
A7	0.9	0.579	0.425	0.804	0.579
EX3					
A1	0.425	0.9	0.804	0.292	0.9
A2	0.804	0.579	0.292	0.9	0.292
A3	0.579	0.579	0.9	0.425	0.804
A4	0.9	0.425	0.579	0.579	0.425
A5	0.425	0.9	0.804	0.292	0.579
A6	0.292	0.292	0.579	0.804	0.425
A7	0.579	0.579	0.9	0.425	0.804
EX4					
A1	0.804	0.425	0.579	0.9	0.579
A2	0.579	0.579	0.9	0.425	0.425
A3	0.425	0.9	0.579	0.579	0.9
A4	0.9	0.804	0.292	0.579	0.579
A5	0.292	0.425	0.425	0.425	0.292
A6	0.579	0.579	0.579	0.9	0.9
A7	0.804	0.425	0.579	0.9	0.579
EX5					
A1	0.9	0.292	0.579	0.425	0.425
A2	0.292	0.425	0.425	0.579	0.579
A3	0.804	0.579	0.579	0.425	0.425
A4	0.9	0.9	0.579	0.9	0.9
A5	0.425	0.804	0.292	0.425	0.804
A6	0.579	0.292	0.9	0.579	0.292
A7	0.9	0.292	0.579	0.425	0.425

Step 4. Obtaining the aggregate matrix by taking the average of the expert opinions by applying Eq. (5).

Step 5. Applying the SWARA method to calculate the weight of criteria ($C1$, $C2$, $C3$, $C4$, $C5$) as shown in Table 3. Ordering the criteria in a descending order from most important to least significant.

Table 3. Ranking criteria.

Criteria	Order
C3	1
C2	2
C4	3
C1	4
C5	5

Step 6. Evaluating the relative importanceS_j.

Table 4. Comparative importance of the criterion.

Questionnaire			
1	Security	15%	More important than Speed
2	Speed	30%	More important than Flexibility
3	Flexibility	10%	More important than Downtime
4	Downtime	25%	More important than Cost

Table 5. The relative importance

Order	Criteria	S_j
1	Security	----
2	Speed	0.15
3	Flexibility	0.3
4	Downtime	0.1
5	Cost	0.25

Step 7. Calculating the coefficient K_j by applying Eq. (6).

Table 6. The coefficient.

Criteria	K_j
Security	1
Speed	1.15
Flexibility	1.3
Downtime	1.1
Cost	1.25

Step 8. Finding the recalculated weight Q_j by applying Eq. (7), and the relative weights of the criteria W_j by applying Eq. (8) shown in Figure 3 and presented in Table 7.

Table 7. The weights of criteria.

Criteria	Q_j	W_j
Security	1	0.275253
Speed	0.869565217	0.239351
Flexibility	0.668896321	0.184116
Downtime	0.608087565	0.167378
Cost	0.486470052	0.133902

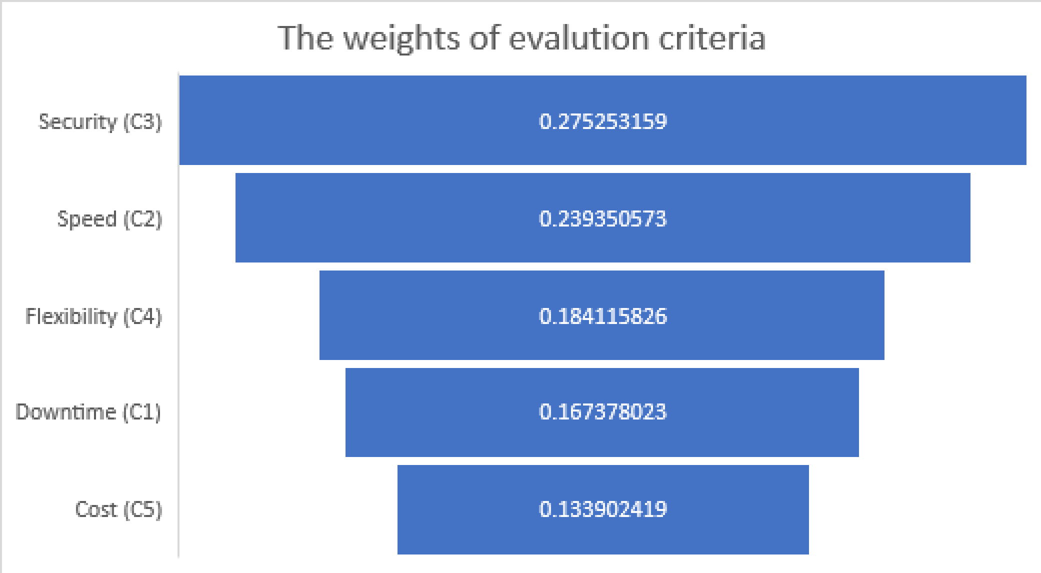

Figure 3. The final weights.

Step 9. After constituting the T2NN decision matrix, then calculate the AAI, and AI by applying Eqs. (10), and (11) as exhibited in Table 8.

Table 8. The T2NN decision matrix.

	C1	**C2**	**C3**	**C4**	**C5**
	min	max	max	max	min
W_i	0.167378	0.239351	0.275253	0.18411583	0.133902
AAI	0.7592	0.3166	0.445	0.3616	0.7216
A1	0.5692	0.6642	0.7332	0.4976	0.555
A2	0.5358	0.5932	0.6	0.6458	0.505
A3	0.6382	0.65	0.555	0.5816	0.6
A4	0.7592	0.6908	0.6308	0.65	0.7216
A5	0.46	0.6266	0.505	0.4476	0.5092
A6	0.555	0.5284	0.5858	0.7024	0.5884
A7	0.4116	0.3166	0.445	0.3616	0.4374
AI	0.4116	0.6908	0.7332	0.7024	0.4374

Step 10. Constructing the normalized decision matrix N $= [n_{ij}]_{n*m}$ applying by Eqs. (12), and (13) as shown in Table 9.

Table 9. The normalized decision matrix.

	C1	C2	C3	C4	C5
	min	max	max	max	min
W_i	0.167378	0.239351	0.275253	0.18411583	0.133902
AAI	0.54215	0.458309	0.606929	0.51480638	0.606153
A1	0.72312	0.961494	0.606929	0.70842825	0.788108
A2	0.768197	0.858715	1	0.91941913	0.866139
A3	0.644939	0.940938	0.818331	0.82801822	0.729
A4	0.54215	1	0.756956	0.92539863	0.606153
A5	0.894783	0.907064	0.860338	0.63724374	0.858995
A6	0.741622	0.76491	0.688762	1	0.743372
A7	1	0.458309	0.798963	0.51480638	1
AI	1	1	1	1	1

Step 11. Determination of the weighted normalized decision matrix V $= [v_{ij}]_{n*m}$ applying by Eq. (14), as presented in Table 10.

Table 10. The weighted normalized decision matrix.

	C1	C2	C3	C4	C5
	min	max	max	max	min
W_i	0.167378	0.239351	0.275253	0.184116	0.133902
AAI	0.090744	0.109697	0.167059	0.094784	0.081165
A1	0.121034	0.230134	0.167059	0.130433	0.10553
A2	0.128579	0.205534	0.275253	0.16928	0.115978
A3	0.107949	0.225214	0.225248	0.152451	0.097615
A4	0.090744	0.239351	0.208354	0.170381	0.081165
A5	0.149767	0.217106	0.236811	0.117327	0.115021
A6	0.124131	0.183082	0.189584	0.184116	0.099539
A7	0.167378	0.109697	0.219917	0.094784	0.133902
AI	0.167378	0.239351	0.275253	0.184116	0.133902

Step 12. Collecting the utility degree of alternatives K_i by applying Eq. (15), and (16) as shown in Table 11.

Table 11. The utility degree of alternatives.

A	k_i^-	k_i^+
A1	1.38778464	0.754189975
A2	1.64619715	0.894623954
A3	1.48767792	0.808476863
A4	1.45366922	0.78999487
A5	1.53838252	0.836032215
A6	1.43610899	0.780451787
A7	1.33532019	0.725678228

Step 13. Calculating the utility function to the ideal solution and anti-ideal solution by Eqs. (19), and (20). Determination of the utility function of alternatives $f(k_i)$ by Eq. (18) as shown in Table 12.

Table 12. The utility function of alternatives.

$f(k_i^-)$	$1-f(k_i^-)$	$f(k_i^+)$	$1-f(k_i^+)$	$f(k_i)$
0.3521	0.6479	0.6479	0.35210033	0.633056
0.417663	0.582337	0.768542	0.23145814	0.942637
0.377445	0.622555	0.694536	0.30546426	0.743283
0.368816	0.631184	0.678658	0.32134153	0.704475
0.390309	0.609691	0.718208	0.28179237	0.80368
0.364361	0.635639	0.67046	0.32953968	0.68496
0.338789	0.661211	0.623406	0.37659383	0.57962

Step 13. Ranking of the optimal alternatives which depend on the final values of utility functions $f(k_i)$ in Eq. (18), as presented in Table 13.

Table 13. Rank of alternatives based on T2NN-MARCOS.

A	Rank
A1	6
A2	1
A3	3
A4	4
A5	2
A6	5
A7	7

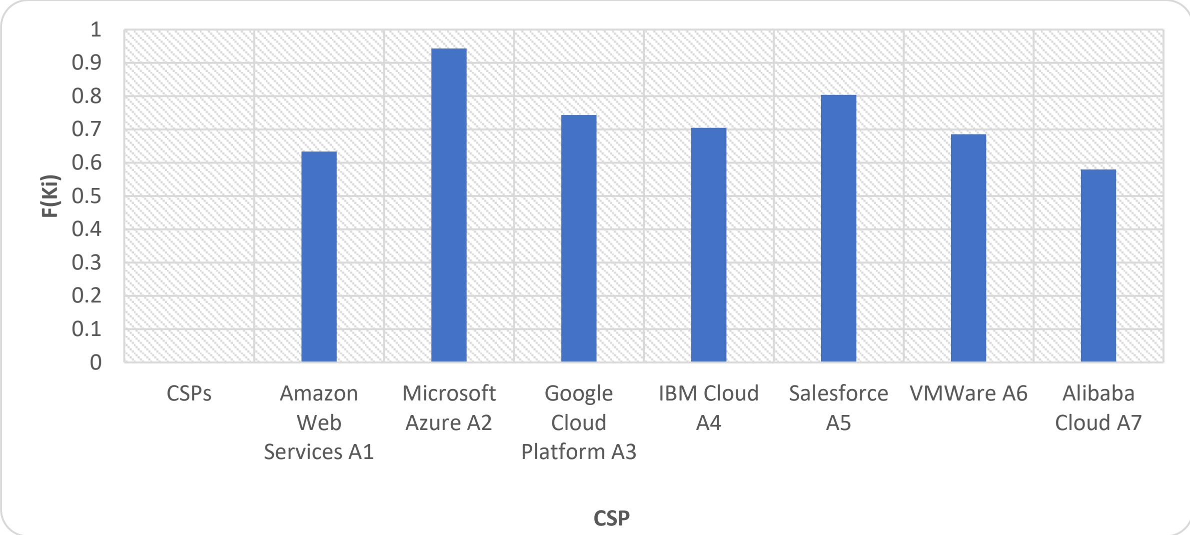

Figure 4. Rank of alternatives based on T2NN MARCOS.

The final rank of alternatives shown in Figure 4 using the T2NNs-MARCOS shows that Microsoft Azure which donated as A2 is the best CSP and A7 is the worst. The ranking of all alternatives is A2>A5>A3>A4>A6>A1>A7.

5. Sensitivity Analysis

In this part, a sensitivity analysis was performed on the alternative rank. As a result, we will show how different criterion weights will affect the final ranking of alternatives. A change has been made to the weight measurement values to indicate whether the alternative order will change, which suggests weights based on different criteria to rank the alternatives in different situations and show the stability of the rank. Table 14 shows the rank of alternatives after changing the weights. As shown in Figure 5, in case 1 if the weight of C1 is bigger than the weight of C3, alternative 2 is the best, and alternative 7 is the worst, A2>A5>A3>A6>A4>A1>A7.

Case 2 if the weight C1 is bigger than the weight C2, alternative 2 is the best, and alternative 1 is the worst, A2>A5>A3>A6>A7>A4>A1.

Case 3 if the weight C2 is bigger than the weight C3, alternative 2 is the best, and alternative 7 is the worst, A2>A5>A3>A4>A6>A1>A7.

Case 4 if the weight C3 is bigger than the weight C4, alternative 2 is the best, and alternative 7 is the worst, A2>A5>A3>A6>A4>A1>A7.

Case 5 if the weight C4 is bigger than the weight C5, alternative 2 is the best, and alternative 7 is the worst, A2>A5>A3>A4>A6>A1>A7.

Case 6 if the weight C5 is bigger than the weight C2, alternative 2 is the best, and alternative 7 is the worst, A2>A5>A3>A7>A6>A4>A1.

Case 7 if the weight C5 is bigger than the weight C3, alternative 2 is the best, and alternative 7 is the worst, A2>A5>A3>A6>A1>A4>A7.

Case 8 if the weight C4 is bigger than the weight C3, alternative 2 is the best, and alternative 7 is the worst, A2>A5>A3>A6>A4>A1>A7.

Case 9 if the weight C1 is bigger than the weight C4, alternative 2 is the best, and alternative 7 is the worst, A2>A5>A3>A4>A6>A1>A7.

Table 14. The rank of alternatives under sensitivity analysis.

	Original	Case 1 c1>c3	Case 2 c1>c2	Case 3 c2>c3	Case4 c3>c4	Case5 c4>c5	Case 6 c5>c2	Case 7 c5>c3	Case 8 c4>c3	Case 9 c1>c4
A1	6	6	7	6	6	6	7	5	6	6
A2	1	1	1	1	1	1	1	1	1	1
A3	3	3	3	3	3	3	3	3	3	3
A4	4	5	6	4	5	4	6	6	5	4
A5	2	2	2	2	2	2	2	2	2	2
A6	5	4	4	5	4	5	5	4	4	5
A7	7	7	5	7	7	7	4	7	7	7

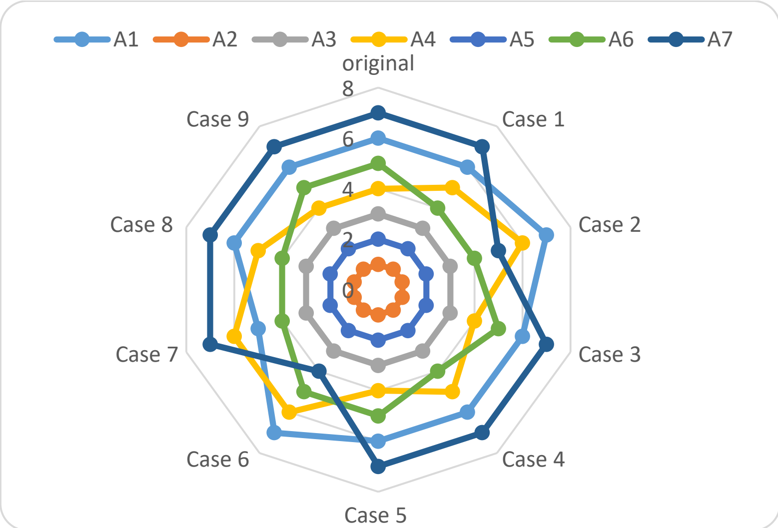

Figure 5. Cases in criteria weights changing.

6. Conclusion

Leading enterprise companies like Amazon, Microsoft, and Google now offer a wide range of cloud services in the form of specialized, dependable, and reasonably priced web apps. Individuals and organizations in various fields find these services attractive, such as healthcare, business, and education. So, we rank the popular Cloud Service Providers (CSPs) among potential cloud customers according to specific criteria or attributes related to the services they offer. This study shows that the proposed approach is an effective multi-criteria decision-making (MCDM) tool for the difficult analysis of selection among information sets. We provided a numerical example showing our suggested method of selecting Cloud Service Providers (CSPs) in cloud service management to select the optimal one. The proposed method was evaluated using type-2 neutrosophic (T2NN) based on two popular MCDM methods, SWARA and MARCOS. In the future, we plan to use different multi-criteria decision-making methods with more complex criteria.

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Author Contributions

All authors contributed equally to this research.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

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Conflict of interest
The authors declare that there is no conflict of interest in the research.

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