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FUZZY SYSTEMS AND THEIR MATHEMATICS

# Selection of cloud service providers using MCDM methodology under intuitionistic fuzzy uncertainty

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**Abstract**

Cloud computing concept has taken prodigious growth over the last decade. With the vast options of Cloud Service Providers available nowadays and a variety of services and facilities to choose from, it is of paramount necessity to opt for the best cloud service provider based on multiple criteria and requirements ascertained by any organization or an individual. This study selects the cloud service provider based on various conflicting criteria. In this paper, pentagonal intuitionistic fuzzy number (PIFN) with MCDM tool analytic hierarchy process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods have been used to rank the Cloud Service Providers (CSPs). Firstly, the criteria PIFN weights are calculated using comparison matrices with the help of decision-makers (DMs), and then, FTOPSIS is done to obtain the final ranking. Sensitivity and comparative analyses have been conducted to see the changes in ranking obtained. These analyses help analyze the most sensitive criteria and thus help the researchers mark and evaluate for future scope and further research.

**Keywords** Cloud Service Providers selection · Intuitionistic fuzzy number · Multi-criterion decision-making method · AHP-TOPSIS method

## 1 Introduction

We are living in the age of the digital era, where a massive amount of data is available online and offline. The requirement to store, analyze and access the necessary data securely and safely arises every day. We all need a tool that can help any individual or organization to store data online. This modern age requirement had thus necessitated the birth of "Cloud computing," which is basically storing the data on the web cloud, i.e., on shared data servers, and

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provides services like faster access to data, lower operating costs of managing and storing of data, security, and protection of data, etc.

Nowadays, cloud computing technology (CCT) is a well-liked subject matter among researchers and industries. CCT has become a possible preference for businesses and personal services to replace the on-premise IT infrastructure. This technology makes the information technology (IT)-based industries in a remarkable infrastructure and application-oriented services on an online subscription basis ideology. It has changed the understanding of how to acquire computing resources with much adaptability, accessibility, and less organizational effort (Zadeh 1965). These services are fully professional services offered to the subscribers who are interested in running their issues on remote servers when they are not able to execute the problem on local computers anymore. The remote servers are called a cloud. This technological expansion pushes service-given-based companies to acclimatize their services and put forward them to their valuable customers in the cloud. The services through online mode are very popular to the customer and make a huge interest to the online service provider platform. In that context, nowadays, there are many online services offered for the customer but the real challenge is to select the suitable one. Several IT-based companies are changing their business infrastructure and models by giving their products as CCT services. Renowned service providers like AWS, Microsoft, Google and IBM offer similar kinds of services at different levels and prices. The quality and features of such services also differentiate for different companies. The diversity presents a major challenge for clients to determine the most suitable technology that satisfies their main requirements.

Fuzzy set theory and its extension play an important role nowadays. The fuzzy system software has also been developed as the most effective and practical application of the theory and models with fuzzy sets (Chang and Zadeh 1972). These systems can deal with the representation of knowledge and reasoning subject to vagueness and uncertainties for the solution of various kinds of real-life problems. Fuzzy sets and systems are most effective in modelling complex systems and can integrate the human expert system and knowledge with uncertain information. In this regard, fuzzy systems have been implemented and applied in different types of domains of application, among many others, and make suitable decisions in an elegant manner. A fuzzy set consists of the collection of elements where every element has a graded membership value. That means for each and every member, it calculates the likelihood in the set and has degrees of membership values which vary from 0 to 1. The Linguistic variables are also be a representation in the fuzzy set ideology. It may be represented in words rather than numbers (e.g., very low, low, moderate, high, very high, etc.). According to suitable applicability, many studies need to apply the fuzzy logic methodology associated with cloud computing problem to address different types of research issues and challenges with proper solution.

The main objective of this study is to find the solution for selecting the best CCT provider selection (PS) associated with decision-makers fixed alternatives by the help of a proposed decision-making framework under uncertainty.

## 1.1 Literature review

### 1.1.1 Fuzzy and Intuitionistic fuzzy set

Uncertainty, indeterminacy, and vagueness are very important terms when associated with the real world conducting tests in terms of observations, measurements and decision-making.

In the classical set theory concept, the membership of elements in a set follows a simple binary logic. That is, either, $x$. belongs to $A$., i.e., $x \in A$. or $x$ not belong to $A$, i.e., $x \notin A$..The idea of corresponding membership grades can be implemented and the concept can be written with the help of characteristic function $\chi_A(x)$.. If $x \in A$., then $\chi_A(x) = 0$ and if $x \notin A$, then $\chi_A(x) = 1$. But in a practical sense, most of the physical phenomena cannot be described by the classical crisp sense since there is some uncertainty. From this point of view, one of the fashionable and efficient logical ideologies to capture the wisdom of uncertainty is "fuzzy set theory," customary by Zadeh(Zadeh 1965). By extending the binary scenarios of "belongs to" and "does not belong to," the fuzzy uncertainty theory provided the notion of the "degree of belongingness." Later, Chang and Zadeh (Chang and Zadeh 1972) constructed a well-structured mathematical version of the fuzzy logic. Then, many researchers (Dubois and Prade 1978; Dubois et al. 2000) contributed much of their effort to enhance the scrupulous domain of information. With the gradual development of the conventional fuzzy philosophy, later different types of fuzzy number ideology exist with different types of applications, such as triangular fuzzy number (Akyar et al. 2012), trapezoidal fuzzy number (Ponnialagan et al. 2018), pentagonal fuzzy number (Chakraborty et al. 2019), dense fuzzy number (Maity et al. 2020a), interval-valued fuzzy number (Mondal 2016), hesitant fuzzy number (Ghorui et al. 2021), lock fuzzy number (Maity et al. 2019), type 2 fuzzy number (Tudu et al. 2021), Hexagonal fuzzy number (Chakraborty et al. 2021), Gaussian fuzzy number (Rahaman et al. 2021), etc.

A major expansion of the fuzzy theory was carried out by the preface of the conception of intuitionistic fuzzy set by Atanassov (Atanassov 1986), which integrated the





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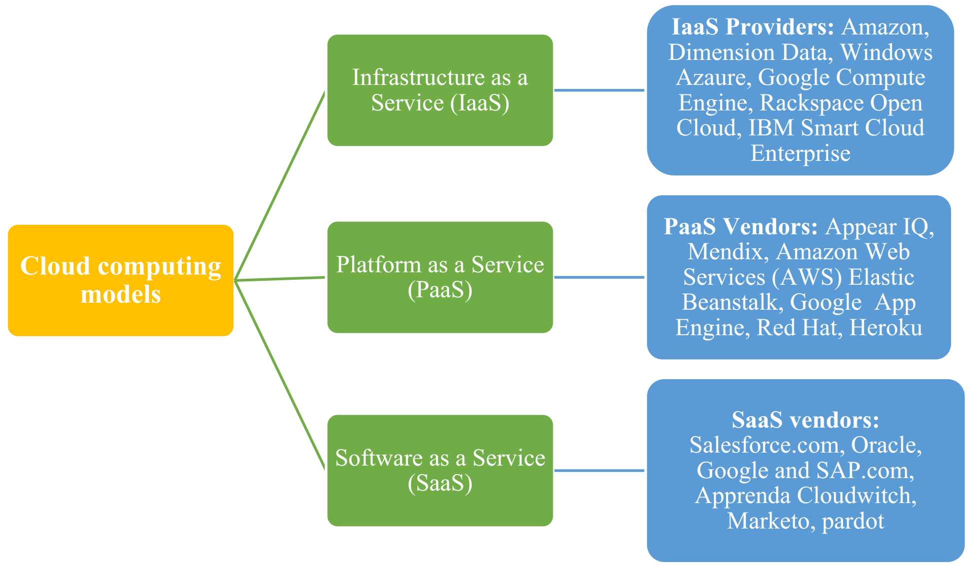
**Fig. 1** Model representing the types of Cloud computing services




design to count the "degree of belongingness" and "degree of non-belongingness" as well. For that reason, membership function is considered for degree of belongingness and non-membership function is for non-longingness. There exist different types of intuitionistic fuzzy numbers such as triangular IFS (Mondal and Roy 2014), generalized trapezoidal IFS (Mondal and Roy 2015), cloud-type intuitionistic dense fuzzy number (Maity et al. 2020b), interval-valued IFS (Mondal 2018), pentagonal IFS (Mondal et al. 2018), nonlinear IFS (Mondal et al. 2019), etc.

The application of fuzzy number (Ghorui et al. 2020) and its extension are also very impressive in scientific domain. The author of reference (Xu et al. 2018) applied Delphi method with intuitionistic fuzzy numbers for evaluating the comprehensive product quality for customer satisfaction. The author of reference (Wang et al. 2021) proposed interval 2-tuple linguistic intuitionistic fuzzy numbers and regret theory for scheme selection of design for disassembly (DFD) based on sustainability. The author of reference (Maiti and Roy 2021) used a triangular intuitionistic fuzzy number and proposed defuzzification technique. The introduced ranking method is applied to determine bi-level programming for Stackelberg game. The author of reference (Christi and Kasthuri 2016) and (Pathinathan and Minj 2018) used pentagonal intuitionistic fuzzy numbers, and the latter applied this fuzzy number with Russell's method in transportation problems. The author of reference (Giri et al. 2021) considered nonlinear intuitionistic fuzzy numbers and developed a possibilistic mean by the possibility measure. The implementation of the proposed arithmetic operations is explained by taking a case study of the inventory model. The author of reference (Zhang 2018) used interval-valued intuitionistic fuzzy numbers and introduced Schweizer-Sklar i-norm and Schweizer-Sklar i-conorm. An example was taken to check the validity and effectiveness of the approach. Moreover, we surely say that fuzzy sets and its extensions play an important role for solving several complex problems (Alshammari et al. 2020; Abu Arqub et al. 2021a, 2021b; Abu Arqub 2017; Alzahrani 2021; Ansari et al. 2020; Al-Zahrani 2020; Sahu et al. 2020).

## 1.2 Concept of cloud computing

Different types of companies nowadays give attention to their core functions by parting Cloud Service Providers (CSPs) to switch their computing belongings. CSPs are vendors who rent to their clients, diverse types of services that are enthusiastically provisioned based on customer's orders in a pay-as-you-go basis strategy.

In terms of applicability and adaptation, cloud computing services are structured (Fig. 1) as follows:

## 1.3 Infrastructures as a service (IaaS)

IaaS refers to services of cloud computing that offer storage, networking resources, servers, and virtual machines on-demand to the customers. These services are provided over the Internet on a pay-per-use basis. Using IaaS helps the business organization to reduce their expenditure on maintenance of onsite data centers and hardware costs and enables them to increase or decrease resources as per their organizational requirement. IaaS solutions aid the organization in gaining real-time insights into business and bypass the cost and complexity of managing huge data servers.

IaaS provides business solutions to migrate its applications over the cloud, which is scalable and reliable. It is a



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very useful tool for organizations where the demand for storage is not predictable, and it can increase or decrease the storage or backup and recovery as per the need. IaaS also provides all sorts of the web, networking, and application server support so that the IT team can focus only on the core business solutions of the organization and can easily deploy web apps quickly as and when required without worrying about the infrastructure.

### 1.4 Platform as a service (PaaS)

PaaS refers to using a platform or environment for software development through a web browser. It includes software development tools, database management systems, middleware, business intelligence services and web development applications. PaaS allows to build, deploy, test, maintain and update web applications. So, the consumer has to manage only the apps and their services and the cloud service provider takes care of the rest of the things.

Developers use PaaS to create applications or cloud-based customized apps which can be created using built-in components of the software. PaaS also helps the analysts in data mining, business predictions, making business decisions based on market insights, data warehousing, etc. Along with all software-related services, it also offers security, storage, workflow, and scheduling.

### 1.5 Software as a service (SaaS)

SaaS refers to connecting consumers with cloud-based apps using the Internet. It offers facilities such as emails, help desk applications, Microsoft office suite, Customer Relationship Management applications, and online calendars. SaaS is software that is deployed on the server of the Cloud service provider. It enables the consumer to take the app on rent and use it as per his requirement. All the data collected through the app are stored in the data center of the cloud service provider. In turn, the cloud service provider manages the data and also takes care of its security.

Some common form of SaaS which is used by individuals is Outlook, Yahoo Mail, Gmail, Hotmail, etc. This service is provided to individuals free of cost by creating an account with the provider. All the emails that the individual sends or receives are stored in the server of the cloud service provider, which can be accessed anytime, anywhere via the Internet.

Business organizations can use SaaS services to rent apps like ERP or CRM. It needs to subscribe to these apps by paying a subscription amount based on usage. Rest all the factors like software updates, maintenance, and bug fixing are done by the cloud service provider.

### 1.6 Motivation or objectives of this research

Cloud computing refers to storing data over the Internet or cloud so that it can be accessed anytime, anywhere as per the need if Internet access is available. For MCDM together with cloud computing research any one follow the following Table 1. In today's era of New Normal, all type of business organizations depend largely on the Internet. They are moving their data over the cloud, which gives them more flexibility and data security as well as large storage space without spending huge amounts on infrastructure. Business organizations aim to achieve flexible and scalable platforms with reduced cost and improved quality, and better customer support. The motivation behind this study is to select a good cloud service provider that has a top performance matrix.

There are many competitors in the market of Cloud Service Providers, and each provider comes up with a variety of services and features, which makes them somewhat better than their competitors. Selecting the best provider among so many available providers is an enormous task for any business house. Evaluating the various available options and analyzing their services is the objective of this study. This paper aims at the following:

(1) Selecting different alternatives for Cloud Service Providers and comparing them based on multiple criteria or services provided by them
(2) Selecting different criteria and creating a comparison matrix using PIFN to analyze its result.
(3) Using AHP method to make decisions based on multiple criteria (MCDM Technique).
(4) To compare and analyze which is the best alternative to choose from using numerical applications.

### 1.7 Novelties of the study

The novelties of the paper are as follows:

(1) Distance measure between two PIFN has been defined and used for the numerical illustration in this research.
(2) Formulae have been developed to determine the pentagonal intuitionistic fuzzy weight of criteria.
(3) Technique has been developed to aggregate the decision-maker's opinions into a single comprehensive significance in terms of PIFN.
(4) The ranking methodology, Fuzzy AHP- TOPSIS and also Fuzzy AHP-COPRAS have been used in this research. Fuzzy AHP-COPRAS is used for the comparative study. A comparative analysis has been conducted with two different fuzzy numbers to understand the difference of PIFN used in this study.





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**Table 1** Review of MCDM and cloud computing paper

| Authors information | The topic of the research | Number of criterion and sub-criterion | Uncertain environment types | MCDM methods used |
|---|---|---|---|---|
| Büyüközkan et al. (Büyüközkan et al. 2018) | Cloud computing technology selection | 6 main criteria and each criterion has 3–6 sub-criteria | Interval-valued Intuitionistic Fuzzy Logic | IVIF AHP, IVIF COPRAS, IVIF MULTIMOORA, IVIF VIKOR |
| Wibowo et al. Wibowo et al. 2016) | Evaluation of cloud services | 5 criteria | Intuitionistic fuzzy numbers | Fuzzy TOPSIS, Choquet integral operator |
| Jatoth et al. (Jatoth et al. 2019) | Selection of cloud services | 7 criteria | Gray Theory | AHP, Gray TOPSIS |
| Boutkhoum et al. (Boutkhoum et al. 2016) | Selection problem of cloud solution | 3 criteria and 10 sub-criteria | Triangular Fuzzy Number (TFN) | Fuzzy AHP, PROMETHEE |
| Kumar et al. (Kumar et al. 2017) | Cloud service selection | 10 criteria | Triangular Fuzzy Number (TFN) | AHP and Fuzzy TOPSIS |
| Le et al. (Le et al. 2014) | Cloud service selection | 9 criteria | Triangular Fuzzy Number (TFN) | ISM and Fuzzy Analytic Network Process (FANP) |
| Lee & Seo (Lee and Seo 2016) | Cloud service selection | 4 criteria | Triangular Fuzzy Number (TFN) | Balanced Scoreboard (BSC) Fuzzy Delphi method, FAHP, |
| Subramanian & Savarimuthu (Subramanian and Savarimuthu 2016) | Cloud service evaluation and selection in the marketplace | 6 criteria and 13 sub-criteria | Triangular Fuzzy Number (TFN) | Fuzzy ANP, Fuzzy TOPSIS, Fuzzy ELECTRE |
| Ali et al. (Ali et al. 2020) | Measuring the possibility of cloud adoption for software testing | 10 criteria and70 sub-criteria | Triangular Fuzzy Number (TFN) | FMCDM |
| Tanoumand et al. (Tanoumand et al. 2017) | Selecting cloud computing service provider | 6 criteria | Triangular Fuzzy Number (TFN) | Fuzzy AHP |
| Alam et al. (Alam et al. 2018) | Evaluate public cloud computing services | 9 main criteria and 30 sub-criteria | Triangular Fuzzy Number (TFN) | FAHP, WASPAS |
| This paper | Evaluation and selection of CSPs | 9 criteria | Pentagonal Intuitionistic Fuzzy Number (PIFN) | FAHP, FTOPSIS |

(5) Comparative and sensitivity analyses are conducted to check the robustness and steadiness of the techniques used.

(6) The remainder of the paper is organized in the following way: Sect. 2 briefly describes the concept of fuzzy numbers, PFN, PIFN, and respective arithmetic operations. Distance measure and defuzzification formulae are also represented in this section. It also includes the MCDM technique AHP and Fuzzy TOPSIS. Description of criteria, alternatives, and numerical application are covered in Sect. 3. Sections 4 and 5 represent the sensitivity and comparison analyses, respectively. Section 6 discusses the results and discussion. Finally, the conclusion and future scope are covered in Sect. 7.

## 2 Pentagonal Intuitionistic Fuzzy Number

Fuzzy set logic was introduced by the author Zadeh (1965) to deal with the impreciseness of real-life situations.

A set $\hat{T}$ is defined as $\hat{T} = \{(\tau, \mu_{\hat{T}}(\tau) : \tau \in \hat{T}, \mu_{\hat{T}}(\tau) \in (0,1)\}$ , where $\mu_{\hat{T}}(\tau)$ represents the membership function of $\hat{T}$, which takes value from zero to one. In real-life situations, where the information is vague and uncertain, fuzzy logic can be efficiently used to deal with these problems.

### 2.1 Pentagonal Fuzzy Number

(Chakraborty et al. 2019) A pentagonal fuzzy number (PFN) of a fuzzy set is represented as $I = (l_1, m_1, n_1, o_1, p_1); w$, where $l_1, m_1, n_1, o_1, p_1 \in \Re$, the set of real numbers such that $l_1 \le m_1 \le n_1 \le o_1 \le p_1$. The membership of PFN is denoted as





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$$U = f(x) = \begin{cases} 0, \quad \text{for } x \le l_1 \\ w\dfrac{(x-l_1)}{m_1-l_1}, \quad \text{for } l_1 \le x \le m_1 \\ w-(1-w)\dfrac{(x-m_1)}{n_1-m_1}, \quad \text{for } m_1 \le x \le n_1 \\ 1 \quad \text{for } x = n_1 \\ 1-(1-w)\dfrac{(o_1-x)}{o_1-n_1}, \quad \text{for } n_1 \le x \le o_1 \\ w\dfrac{(p_1-x)}{p_1-o_1}, \quad \text{for } o_1 \le x \le p_1 \\ 0 \quad \text{for } x \ge p_1 \end{cases} \tag{1}$$

***Remark 1*** If $\mu_{\hat{U}}(x) = 1$, in the closed interval $[m_1, o_1]$, then the pentagonal fuzzy number (PFN) is said to be reduced to the trapezoidal fuzzy number (TrFN).

***Remark 2*** If $m_1 = n_1 = o_1$, then the PFN is reduced to a triangular fuzzy number (TFN).

*Note 1* Fig. 2 denotes PFN, where $l_1 \le m_1 \le n_1 \le o_1 \le p_1$. The variable $'n_1'$ possesses the maximum degree of membership, i.e.,$\mu_{\hat{U}}(x)$ = 1. The variables $'m_1' and 'o_1'$ attain equal membership $\mu_{\hat{U}}(x) = 0.5$, whereas the variables $'l_1'$ and $'p_1'$ have 0 membership value. In other words, membership increases from $'l_1'$, reaches the maximum value at $'n_1'$ and then starts diminishing till $'p_1'$.

### 2.1.1 Arithmetic operation on PFN

**Definition 1** Let us assume two PFN $I = (l_1, m_1, n_1, o_1, p_1)$ and $J = (l_2, m_2, n_2, o_2, p_2)$, then the arithmetic properties between them are defined as follows:

$$1.\ \text{Addition} : (I+J) = (l_1+l_2, m_1+m_2, n_1+n_2, o_1+o_2, p_1+p_2) \tag{2}$$

$$\mathbf{2}.\ \text{Subtraction} : (I-J) = (l_1-p_2, m_1-o_2, n_1-n_2, o_1-m_2, p_1-l_2) \tag{3}$$

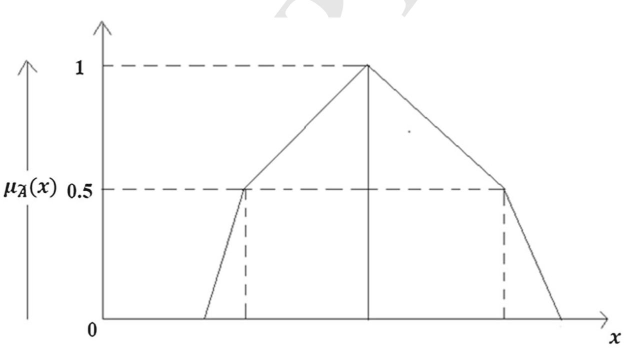


**Fig. 2** Graphical representation of PFN

$$\mathbf{3}.\ \text{Multiplication} : (I \times J) = (l_1 l_2, m_1 m_2, n_1 n_2, o_1 o_2, p_1 p_2) \tag{4}$$

$$\mathbf{4}.\ \text{Scalar Multiplication} : aI = (al_1, am_1, an_1, ao_1, ap_1) \tag{5}$$

$$\mathbf{5}.\ \text{Division} : \left(\frac{I}{J}\right) = \left(\frac{l_1}{p_2}, \frac{m_1}{o_2}, \frac{n_1}{n_2}, \frac{o_1}{m_2}, \frac{p_1}{l_2}\right) \tag{6}$$

$$\mathbf{6}.\ \text{Inverse} : I^- = \left(\frac{1}{p_1}, \frac{1}{o_1}, \frac{1}{n_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \tag{7}$$

Tables 2 and 3 describe the linguistic variables in terms of PFN, the latter provides the rating on 1–9 scale. In Table 2, linguistic terms are generally used for rating the alternatives w.r.t. criteria, whereas in Table 3, linguistic ratings are used for the comparison of conflicting criteria.

*Note 2* PFNs selected in Tables 2 and 3 are assigned keeping in mind the graphical representation of PFN discussed in Fig. 2. Considering the PFN for the linguistic term 'very high/extremely good,' i.e., $4.3 \le 4.5 \le 4.6 \le 4.8 \le 5$. The maximum degree of belongingness, i.e., $\mu_{\hat{U}}(x)$ = 1 is at point 4.6. The membership function remains at the equal value of 0.5 at the points 4.5 and 4.8, however, considering the variables 4.3 and 5 whose membership value is 0. To summarize, membership value increases from 4.3, attains its pick value at 4.6 and then starts declining to 5. A generalized description of PFN is explained in Note 1.

*Note 3* Table 2 denotes the linguistic term used for rating the alternatives w.r.t. the criteria, whereas the linguistic terms used in Table 3 are used for the comparison matrix of criteria.

## 2.2 Pentagonal Intuitionistic Fuzzy Number (PIFN)

In this section, the definition and pictorial representation (see Fig. 3) of PIFN and its arithmetic operations are defined Nasir and Beenu (2021).

**Definition 2** A PIFN $\tilde{I} = \left\{\left(\tilde{l_1}, \widetilde{m_1}, \tilde{n_1}, \tilde{o_1}, \tilde{p_1}\right), w_I, v_I\right\}$ is a distinct fuzzy number on the real set $\Re$. The membership and non-membership functions of PIFN are defined as follows :

**Table 2** Linguistic terms expressed in PFN

| Linguistic terms | Pentagonal fuzzy number |
|---|---|
| Very high/extremely good | (4.3, 4.5, 4.6, 4.8, 5) |
| Moderately high/ very good | (3.7, 3.9, 4, 4.2, 4.3) |
| Moderate/ good | (2.9, 3, 3.2, 3.4, 3.6) |
| Low/ poor | (2, 2.2, 2..5, 2.6, 2.8) |
| Very low/ very poor | (1, 1.5, 1.6, 1.6, 2) |





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**Table 3** Linguistic terms on PFN 1–9 scale

| Linguistic terms | 1–9 scale | Pentagonal fuzzy number |
|---|---|---|
| Equally important (EI) | 1 | (1,1.5,2,3,5) |
| Moderately important (MI) | 3 | (2,4,5,6,6.5) |
| Strongly important (SI) | 5 | (3,5,6,7,8) |
| Very strongly important (VSI) | 7 | (6,7,7,8,9) |
| Absolutely important (AI) | 9 | (7,8,9,9,10) |
| Moderately not important (MUI) | 1/3 | (1/6.5,1/6,1/5,1/4,1/2) |
| Strongly not important (SUI) | 1/5 | (1/8,1/7,1/6,1/5,1/3) |
| Very strongly not important (VSUI) | 1/7 | (1/9,1/8,1/7,1/7,1/6) |
| Absolutely not important (AUI) | 1/9 | (1/10,1/9,1/9,1/8,1/7) |

$$\mu_I(x) = \begin{cases} 0, & \text{for } x < l_1 \\ W\dfrac{(x-l_1)}{m_1-l_1}, & \text{for } l_1 \le x \le m_1 \\ W + \dfrac{(w_I - 0.5)(x-m_1)}{n_1-m_1}, & \text{for } m_1 \le x \le n_1 \\ w_I & \text{for } x = n_1 \\ W + \dfrac{(w_I - W)(o_1 - x)}{o_1 - n_1}, & \text{for } n_1 \le x \le o_1 \\ W\dfrac{(p_1 - x)}{p_1 - o_1}, & \text{for } o_1 \le x \le p_1 \\ 0 & \text{for } x > p_1 \end{cases} \tag{8}$$

and

$$\vartheta_I(x) = \begin{cases} 0, & \text{for } x < l_1 \\ 1 - \dfrac{W(x-l_1)}{m_1-l_1}, & \text{for } l_1 \le x \le m_1 \\ \dfrac{W - (W - v_I)(x-m_1)}{n_1-m_1}, & \text{for } m_1 \le x \le n_1 \\ v_I & \text{for } x = n_1 \\ \dfrac{W - (W - v_I)(o_1 - x)}{o_1 - n_1}, & \text{for } n_1 \le x \le o_1 \\ 1 - \dfrac{W(p_1 - x)}{p_1 - o_1}, & \text{for } o_1 \le x \le p_1 \\ 0 & \text{for } x > p_1 \end{cases} \tag{9}$$

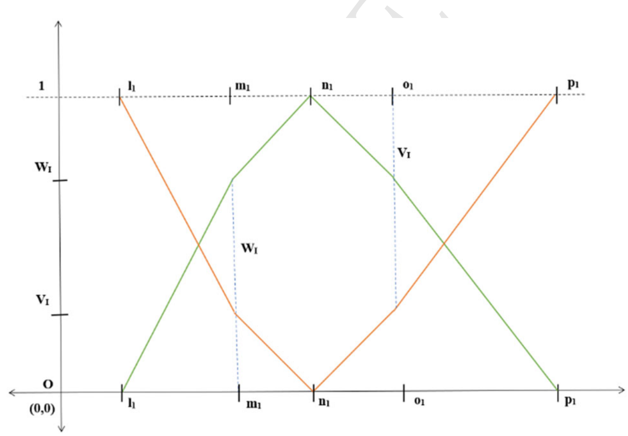


**Fig. 3** Graphical representation of PIFN

Throughout the paper, we take the value of $W = 0.5$, where the value of $W \in [0, 1]$. The DMs can assume the value depending on the particular research problems.

### 2.2.1 Arithmetic operations on PIFN

**Definition 3** Let us assume two PIFN $A = \left(\widetilde{l_1}, \widetilde{m_1}, \widetilde{n_1}, \widetilde{o_1}, \widetilde{p_1}\right), w_a, v_{a'}$ and $B = \left(\widetilde{l_2}, \widetilde{m_2}, \widetilde{n_2}, \widetilde{o_2}, \widetilde{p_2}\right), w_b, v_{b'}$, then the arithmetic properties between them are defined as follows:

Nasir and Beenu (2021)

$$\text{Addition}: (A+B) = (l_1 + l_2,\ m_1 + m_2,\ n_1 + n_2, o_1 + o_2, p_1 + p_2), \\ \min\{w_a, w_b\}, \max\{v_{a'}, v_{b'}\} \tag{10}$$

$$\text{Subtraction}: (A-B) = (l_1 - p_2,\ m_1 - o_2,\ n_1 - n_2, o_1 - m_2, p_1 - l_2), \\ \min\{w_a, w_b\}, \max\{v_{a'}, v_{b'}\} \tag{11}$$

$$\text{Multiplication}: (A \times B) = (l_1 l_2,\ m_1 m_2,\ n_1 n_2, o_1 o_2, p_1 p_2), \min\{w_a, w_b\}, \\ \max\{v_{a'}, v_{b'}\}, A > 0, B > 0 \tag{12}$$

$$\text{Scalar Multiplication: } aI = (al_1,\ am_1,\ an_1, ao_1, ap_1), \\ w_a, v_{a'},\ a \ge 0 \tag{13}$$

$$\text{Inverse}: A^{-} = \left(\frac{1}{p_1}, \frac{1}{o_1}, \frac{1}{n_1}, \frac{1}{m_1}, \frac{1}{l_1}\right), w_a, v_{a'} \tag{14}$$

### 2.2.2 Distance measure between two PIFN

Distance calculation between two fuzzy numbers is absolutely important in some of the MCDM methods. Distance measure gives an idea of ranking of the alternatives. In this research, TOPSIS approach is used for ranking the CSPs. TOPSIS methodology determines the distance of each





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alternative from the positive ideal solution (PIS) and negative ideal solution (NIS), respectively. Hence, the final ranking is based on the calculation of relative closeness (RC) which is a formula for distance. As this research incorporates PIFN, the following distance measures are defined to compute the distance between two PIFN.

**Definition 4** Let us take two PIFN, $A = \left(\widetilde{l_1}, \widetilde{m_1}, \widetilde{n_1}, \widetilde{o_1}, \widetilde{p_1}\right), w_a, v_{a'}$ and $B = \left(\widetilde{l_2}, \widetilde{m_2}, \widetilde{n_2}, \widetilde{o_2}, \widetilde{p_2}\right), w_b, v_{b'}$, then the distance between two PIFN can be determined by using the following distance methods:

#### 2.2.2.1 Hamming distance

$$d(A,B) = \begin{bmatrix} \left|(1+w_a-v_{a'})\widetilde{l_1} - (1+w_b-v_{b'})\widetilde{l_2}\right| \\ +\left|(1+w_a-v_{a'})\widetilde{m_1} - (1+w_b-v_{b'})\widetilde{m_2}\right| \\ +\left|(1+w_a-v_{a'})\widetilde{n_1} - (1+w_b-v_{b'})\widetilde{n_2}\right| \\ +\left|(1+w_a-v_{a'})\widetilde{o_1} - (1+w_b-v_{b'})\widetilde{o_2}\right| \\ +\left|(1+w_a-v_{a'})\widetilde{p_1} - (1+w_b-v_{b'})\widetilde{p_2}\right| \end{bmatrix} \tag{15}$$

***Example 1*** Let $a_1 = (1,3,5,7,10); 0.6, 0.2$ and $a_2 = (1,2,3,5,7); 0.7, 0.2$ be two PIFN; then, the distance between them is calculated as follows:

$$d(a_1,a_2) = \frac{1}{5}\begin{bmatrix} |(1+0.6-0.2)1-(1+0.7-\ 0.2)1| \\ +|(1+0.6-0.2)3-(1+0.7-\ 0.2)2| \\ +|(1+0.6-0.2)5-(1+0.7-\ 0.2)3| \\ +|(1+0.6-0.2)7-(1+0.7-\ 0.2)5| \\ +|(1+0.6-0.2)10-(1+0.7-\ 0.2)7| \end{bmatrix}$$

$$= 1.92$$

### 2.2.3 Reason for considering PIFN for the problem instead of other fuzzy numbers:

Ranking of CSPs under the influence of various conflicting criteria includes hesitancy, uncertainty, and vagueness of the problem. PFNs capture the ambiguity and uncertainty more compared to triangular fuzzy numbers (TFNs) and trapezoidal fuzzy numbers (TRFNs). Incorporation of PFNs with intuitionistic fuzzy numbers, i.e., PIFNs takes the degree of confidence to an enhanced level, as now, the experts or the DMs can express freely not only their degree of assurance but also the degree of non- assurance. In real-life situations, when an expert or group of experts have been given the platform to express their sureness and hesitancy, that indicates rational thinking, which leads to optimal decision-making. Thus, in this paper, PIFN has been integrated with MCDM methods AHP, TOPSIS, and COPRAS for obtaining the weight of the criteria and ranking of the CSPs.

## 2.3 PIFN- AHP method

AHP (analytic hierarchy process) is a famous mathematical tool which was first developed by the author of Wind and Saaty (1980), a scientific method used in multi-criteria decision-making (MCDM). This method helps decision-makers to resolve intricate problems with heuristic methods. Calculations of criteria's weights are the key points for ranking risk factors. AHP constructs the problem hierarchy with the creation of comparison matrices to give subjective findings about the factors which are considered vastly responsible for ranking. In this paper, FAHP is (see Fig. 4) used rather than AHP as Fuzzy takes under advisement the ambiguity and impreciseness of the decision experts. The steps for FAHP are described below.

*Step 1* Construction of a comparison matrix in terms of PIFN by a decision expert or a group of decision experts using Table 3. The linguistic ratings assigned by DMs are transformed into PIFN. The aggregation of the opinions is done by using Eq. 22.

*Step 2* Defuzzification of PIFN.

Defuzzification or score value of PIFN can be calculated using the following formula:

$$S_p = \frac{l+m+3n+o+p}{6}(1+w_a-v_{a'}) \tag{16}$$

*Step 3* Normalization of each of the defuzzified matrix

$$N_{gh} = \frac{n_{gh}}{\sum_{g=1}^{m} n_{gh}}, \text{ where } g = 1,2,\ldots,m; g = 1,2,\ldots,n \tag{17}$$

*Step 4* Estimation of criteria priority weight (P.W)

$$P.W = \frac{p^{th}rootvalue}{\sum p^{th}root} \tag{18}$$

*Step 5* Determination of the consistency index ($C.I$) of the matrix

$$(C.I) = \frac{\delta_{max} - n}{n-1}$$

where $\boldsymbol{n}$ denotes the size of the matrix considered in the study.

*Step 6* Calculation of consistency ratio (C.R)

$$(C.R) = \frac{C.I}{R.I} \tag{19}$$

where random index (R.I) value changes with the size of the matrix "$\boldsymbol{n}$."

The value of C.R $\leq 0.1$ denotes the matrix to be consistent.





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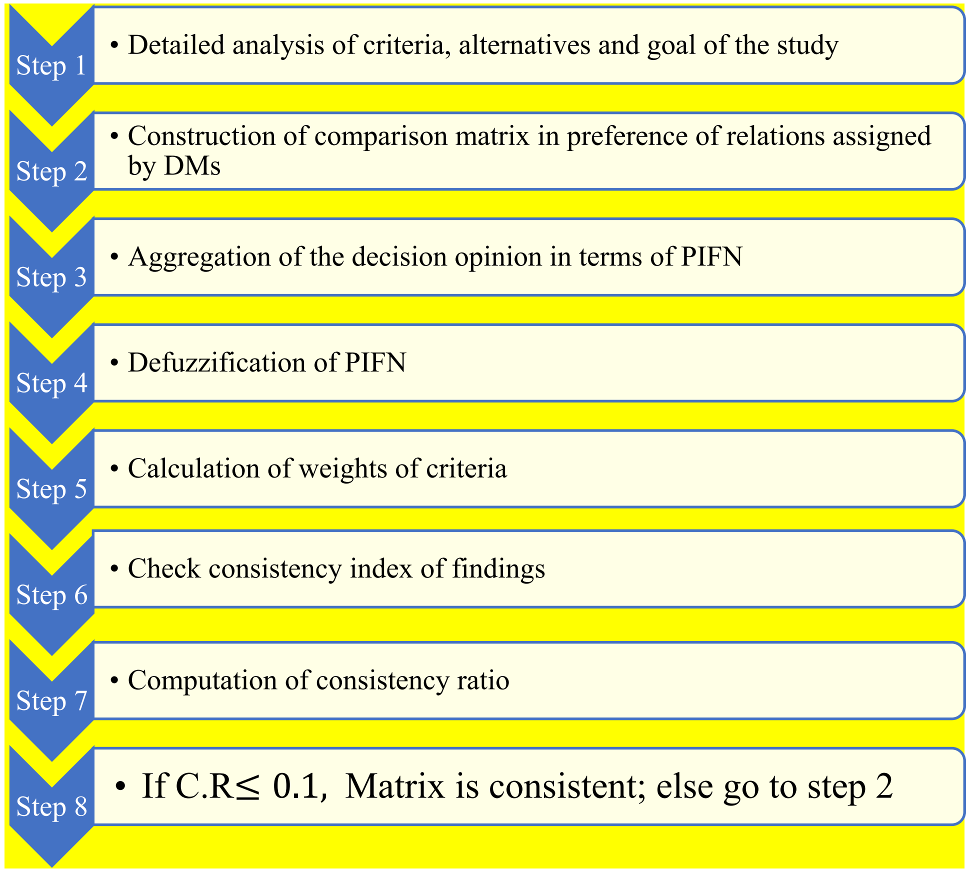


**Fig. 4** Schematic structure of AHP for strategy

## 2.4 Determination of pentagonal intuitionistic fuzzy weights of criteria

*Step 1* The geometric mean value of PIFN is obtained using

$$M_g = \left(\prod_{h=1}^{n} y_{gh}\right); \min_{h=1,2,..,n} w_{gh}, \max_{h=1,2,..,n} v_{gh}, g = 1, 2, \ldots, m \qquad (20)$$

*Step 2* Summation of each $M_g$ using Eq. 7.

*Step 3* Calculation of the inverse of each $M_g$ using Eq. 11 and thereby arranged in increasing order.

*Step 4*To determine the pentagonal intuitionistic fuzzy weight of criteria using the following equation:

$$W_g = M_g * (M_1 + M_2 + \cdots + M_i)^{-1} \qquad (21)$$

## 2.5 PIFN- TOPSIS approach

The TOPSIS MCDM technique is one of the extensively used methodologies, introduced by Hwang and Yoon (Hwang and Yoon 1981) to rank the alternatives, and thus, DMs have a clear idea about the most preferred alternative. The TOPSIS process is categorized as a distance measurement method in which the ideal alternative obtained is nearby to the positive ideal solution (PIS) and extreme from the negative ideal solution (NIS). The linguistic terms assigned by the DMs can be captured better with fuzzy TOPSIS (FTOPSIS). The fuzzy approach is useful in dealing with the hesitancy and uncertainty of the DMs and the conflicting criteria. In this research, for the ranking of CSPs, which is dependent on multiple conflicting criteria, the MCDM method fuzzy TOPSIS is used. The PIFN has been incorporated with the classical TOPSIS technique to obtain FTOPSIS (see Fig. 5) formulae. The fuzzy logic extends our goal to obtain more sensitive results in this regard.

For the ranking of Cloud Service Providers (CSPs), the MCDM technique TOPSIS introduced by the authors of Hwang and Yoon (1981) is applied. The PIFN-TOPSIS methodology is described in the following steps:

*Step 1* Determination of alternatives and their preferential linguistic ratings in terms of PIFN.

Let us assume a set of 'm' CSPs $p_1, p_2, \ldots, p_m$ and 'n' criteria $f_1, f_2, \ldots, f_n$. Let $D_1, D_2, \ldots, D_k$ be the number of decision-makers (DMs). Thus, the DMs assign PIFNs as their decision for the alternatives depending on different criteria.

*Step 2* Aggregation of decisions of DM assigned in PIFN using the following equation:





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$$\begin{cases} \tilde{l}_{gh} = \min\limits_{k=1,2,\ldots,K} \tilde{l}_{hik} \\ \tilde{m}_{gh} = \min\limits_{k=1,2,\ldots,K} \tilde{m}_{hik} \\ \tilde{n}_{gh} = \sqrt[K]{\prod\limits_{k=1}^{K} \tilde{n}_{hik}} \\ \tilde{o}_{gh} = \max\limits_{k=1,2,\ldots,K} \tilde{o}_{hik} \\ \tilde{p}_{gh} = \max\limits_{k=1,2,\ldots,k} \tilde{p}\ hik \\ w_{gh} = \min\limits_{k=1,2,\ldots,k} w_{hik} \\ v_{gh} = \max\limits_{k=1,2,\ldots,k} v_{hik} \end{cases} \tag{22}$$

*Step 3* Normalization of the PIFN, using the formula:

$$\breve{N} = [n_{gh}]_{mn}, g = 1, 2, \ldots, m; h = 1, 2, \ldots.., n$$

$$N^{B}_{gh} = \left(\frac{\tilde{l}_{gh}}{\tilde{p}^*}, \frac{\tilde{m}_{gh}}{\tilde{p}^*}, \frac{\tilde{n}_{gh}}{\tilde{p}^*}, \frac{\tilde{o}_{gh}}{\tilde{p}^*}, \frac{\tilde{p}_{gh}}{\tilde{p}^*}\right); w_{hi}, v_{hi} d \in B.C, \tilde{p}^* = \max p_{gh}$$

$$N^{NB}_{gh} = \left(\frac{\tilde{l}^*_h}{\tilde{p}_{gh}}, \frac{\tilde{l}^*_h}{\tilde{o}_{gh}}, \frac{\tilde{l}^*_h}{\tilde{n}_{gh}}, \frac{\tilde{l}^*_h}{\tilde{m}_{gh}}, \frac{\tilde{l}^*_h}{\tilde{l}_{gh}}\right); w_{hi}, v_{hi} d \in N.B.C, \tilde{l}^*_h = \min \tilde{l}_{gh} \tag{23}$$

where B.C and N.B.C signify the benefit criteria and non-benefit criteria, respectively.

*Step 4* To calculate the weighted fuzzy normalized matrix, the criteria's fuzzy weightage is multiplied by the normalized fuzzy value. For the product of two PIFN, Eq. 12 needs to be used.

$$W = [WN_{gh}]_{mn} g = 1, 2, \ldots, m; h = 1, 2, \ldots.., n$$

where

$$FW_{gh} = \breve{N}_{gh} \times \widehat{W_h}, \quad g = 1, 2, \ldots.., m; h = 1, 2, \ldots, n \tag{24}$$

*Step 5* Computation of the fuzzy positive ideal solution (FPIS) ($P^+$) and fuzzy negative ideal solution (FNIS)($N^-$), where $t_g^+$ denotes the maximum value of $t_{gh}$ and $t_g^-$ denotes the minimum value of $t_{gh}$:

$$\begin{aligned} P^+ = &\left(a_1^+; \min_g w_{g1}, \max_g v_{g1}\right), \left(a_2^+; \min_g w_{g2}, \max_g v_{g2}\right), \ldots, \\ &\left(a_n^+; \min_g w_{mn}, \max_g v_{mn}\right) = \left\{\begin{pmatrix} \max t_{gh} | h \in M_{BC}), \\ (\min t_{gh} | h \in M_{NBC} \end{pmatrix}\right\}, \\ N^- = &\left(a_1^-; \min_g w_{g1}, \max_g v_{g1}\right), \left(a_2^-; \min_g w_{g2}, \max_g v_{g2}\right), \ldots, \\ &\left(a_n^-; \min_g w_{mn}, \max_g v_{mn}\right) = \left\{\begin{pmatrix} \min t_{gh} | h \in M_{BC}), \\ (\max t_{gh} | h \in M_{NBC} \end{pmatrix}\right\} \end{aligned} \tag{25}$$

where $M_B$ denotes the benefit criteria, and $M_{NB}$ denotes the non-benefit criteria.

*Step 6* Determination of the distance measure of all alternatives from the PIS and NIS. The two Hamming distances for an individual alternative can be computed as follows:

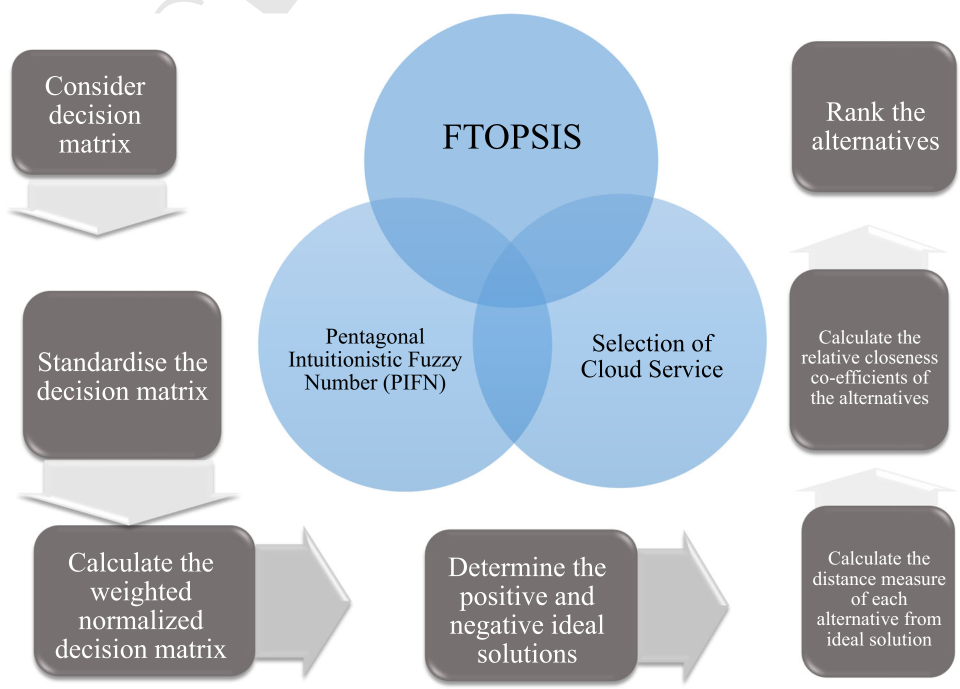


**Fig. 5** A schematic structure of FTOPSIS strategy



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$$\breve{M}_g^{+} = \sum_{h=1}^{n} d(t_{gh}, t_g^{+}),\ g = 1,2,\ldots...,m$$

$$\breve{M}_g^{-} = \sum_{h=1}^{n} d(t_{gh}, t_g^{-}),\ g = 1,2,\ldots...,m \tag{26}$$

where (.,.) denotes the Hamming distance between two fuzzy numbers. Using Eq. 15, the distance between two PIFN can be computed.

*Step 7* Determination of the relative closeness to the ideal alternatives:

$$RC_g = \frac{\breve{M}_g^{-}}{\breve{M}_g^{-} + \breve{M}_g^{+}},\ g = 1,2,\ldots.,m \tag{27}$$

*Step 8* Ranking of the alternatives:

The alternatives are ranked based on the value determined by $RC_g$.The larger value of $RC_g$ represents the better alternatives.

## 3 Pentagonal Intuitionistic Fuzzy MCDM methodology for the ranking of CSPs

### 3.1 Pseudocode depicting the empirical study application

The research model under consideration involving 'g' number of CSPs based on 'h' number of criteria is represented below. The input taken in our study is the preferential linguistic terms assigned by DMs. These variables are converted to PIFN for obtaining the output, i.e., the ranking of the treatment options.

g = Cloud Service Providers.

h = Number of criteria.

g*h = Size of the matrix.

*Input* The preferential rating matrix in terms of PIFN.

*Output* The ranking order of the CSPs in the TOPSIS approach.

1. **for**(g = 1 to m, h = 1 to n)**do.**

2. Generate PIFN by DMs.

For every given criterion, create a matrix and compare the given criteria with each other using linguistic terms on PIFN 1–9 scale.

3. Calculating criteria weight in PIFN by using FAHP.

4. Use PIFN AHP methodology to check whether the matrix is consistent or not.

5. If the matrix is consistent, calculate PIFN-TOPSIS for ranking of CSPs.

**Else**, Go back to step 4.

6. Construct normalized values $NZ_{ef}$

$$overset\ \underset{\smile}{N} = [n_{gh}]_{mn}\ , g = 1,2,\ldots,m; h = 1,2,\ldots...,n;$$

$$N_{gh}^{B} = \left(\frac{\tilde{l}_{gh}}{\tilde{p}^{*}}, \frac{\tilde{m}_{gh}}{\tilde{p}^{*}}, \frac{\tilde{n}_{gh}}{\tilde{p}^{*}}, \frac{\tilde{o}_{gh}}{\tilde{p}^{*}}, \frac{\tilde{p}_{gh}}{\tilde{p}^{*}}\right); w_{hi}, v_{hi} d \in B.C, \tilde{p}^{*} = \max p_{gh},$$

$$N_{gh}^{NB} = \left(\frac{\tilde{l}_h^{*}}{\tilde{p}_{gh}}, \frac{\tilde{l}_h^{*}}{\tilde{o}_{gh}}, \frac{\tilde{l}_h^{*}}{\tilde{n}_{gh}}, \frac{\tilde{l}_h^{*}}{\tilde{m}_{gh}}, \frac{\tilde{l}_h^{*}}{\tilde{l}_{gh}}\right); w_{hi}, v_{hi} d \in N.B.C, \tilde{l}_h^{*} = \min \tilde{l}_{gh};$$

7. Generate weighted normalized value $FW_{gh} = \breve{N}_{gh} \times \hat{W}_h$;

8. Calculate $(FPIS)$ and $(FPIS)$

$$P^{+} = \left(a_1^{+}; \min_g w_{g1}, \max_g v_{g1}\right), \left(a_2^{+}; \min_g w_{g2}, \max_g v_{g2}\right), \ldots., \left(a_n^{+}; \min_g w_{mn}, \max_g v_{mn}\right) = \left\{\left(\max t_{gh} | h \in M_{BC}\right), \left(\min t_{gh} | h \in M_{NBC}\right)\right\},$$

$$N^{-} = \left\langle \left(a_1^{-}; \min_g w_{g1}, \max_g v_{g1}\right), \left(a_2^{-}; \min_g w_{g2}, \max_g v_{g2}\right), \ldots, \left(a_n^{-}; \min_g w_{mn}, \max_g v_{mn}\right) \right\rangle \left\{\left(\min t_{gh} | h \in M_{BC}\right), \left(\max t_{gh} | h \in M_{NBC}\right)\right\};$$

9. Calculate the distance measure of each CSPS from $(FPIS)$ and $(FPIS)$

$$\breve{M}_g^{+} = \sum_{h=1}^{n} d(t_{gh}, t_g^{+}),$$

$$\breve{M}_g^{-} = \sum_{h=1}^{n} d(t_{gh}, t_g^{-}),$$

10. Compute relative closeness $RC_g = \frac{\breve{M}_g^{-}}{\breve{M}_g^{-} + \breve{M}_g^{+}}$;

11. **end for.**

*Note 3.1* The decision-makers are the people who are using cloud services in either the organization where they work or in their business establishment 3.2 Flowchart of the application taken in the proposed research. The methodology are taken for solving the addressed issues are graphically shown in the Fig. 6 as follows:

### 3.2 Description of the cloud service providers (CSPs) taken in this study

Cloud Space is networked storage, or disk space, available over a specific network—the Internet.

Cloud Service Providers are organizations who rent out the cloud space to other organizations or individuals and provide them with cloud-based platforms where data can be stored or accessed. The requirement of CSP arises when a business unit wants to reduce the cost of hardware, servers and storage space and transfer all the data online so that it can be accessed from anywhere and anytime.





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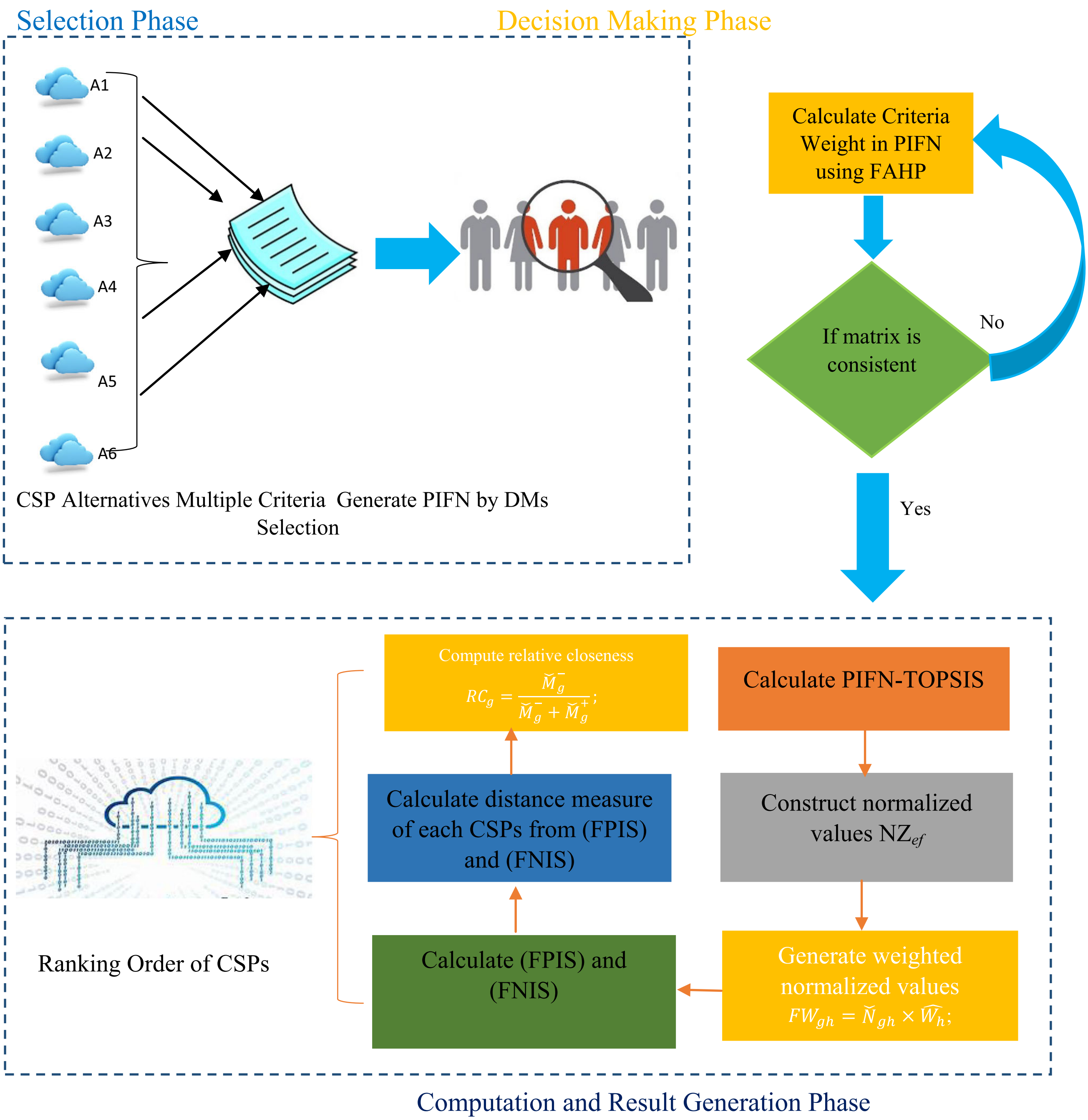


**Fig. 6** Flowchart depicting the methodology used in the study

Transferring data to the cloud gives the organization or an individual an option to reduce the storage cost, streamline work, and collaborate with other members remotely.

CSP helps in managing all the information technology-related activities like backup, security, support, and maintenance of data being saved in cloud space. These companies help in establishing and managing public and private clouds or on-demand computing services which can be customized as per the requirement of the customer. Cloud Service Technologies are required to ascertain the best suitable services for the consumers. It empowers individuals or organizations to develop computing solutions quickly at a reasonable cost. Among the pool of CSPs available which provides services globally, we are selecting six top alternatives for Cloud Service Providers and will compare them on various parameters. In this study, the alternatives selected are some renowned CSPs, the names have not been mentioned as they may have a problem ranking them without any authorization.



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### 3.3 Cloud service provider selection criteria

Cloud Service Provider selection criteria are taken into consideration after a detailed evaluation by a group of decision expert. All the criteria have been taken keeping in mind the general requirement of cloud users by doing a survey with few decision-makers and industry colleagues. We also did secondary research in order to validate our findings through case paper studies and Internet research. In this segment, we have briefly explained the criteria taken in this study.

1. Cloud Security/Privacy—Protection of data against data loss, theft or leakage. Cloud security consists of policies, procedures and technologies that work to protect the data and customers' privacy.

   Data privacy and data security are considered to be the top priority for any organization. CSP also needs to abide by the industry and regulatory requirements so that any kind of data breach can be avoided. So, any organization needs to clearly understand the security measures offered by the CSP and also the mechanism that is being used to protect the organization's data and applications. In case the organization deals in sensitive data like finance or national security, then it is imperative to have data privacy and data security at the highest level.
2. Pricing—Cost of cloud services and discounts if any are based on business models and their framework. While it may not be a big factor for any small usage organization, it plays a significant role if cloud usage is significant or a big organization.

   One needs to look into the pricing structure and its various components charged by CSP. Some CSPs determine the price on an hourly usage basis, some charges on a minutes basis or some charges on a pay-as-per-go basis. So, the pricing component is one of the important factors for any customer.
3. Downtime—It is the total time period in which services are not available due to unexpected circumstances such as outages, maintenance activities or maintenance or updates of the providers. Many natural disasters also lead to the downtime of cloud solutions.

   The unavailability of services being provided by the CSP may increase the cost to the client. It may affect their normal working routines and they might incur heavy losses due to it. It also impacts the reputation of the provider, as well as the customer.
4. Support Services—These are the activities which provide QoS and high-performing networks and also ensure a high-quality end-user experience. Support services are important in the deployment of CSP in any organization. One has to check whether CSP's cloud architecture and support services offered are suitable for the organization's workload and roadmap. Customization or any recoding is required by CSP to fit into the organization's requirements. Additionally, one has to enquire about the extra or any hidden charges and response time for any additional support services or not?
5. Portability—It is the ability to be easily deployed or migrated to a new user or location without any integration issues. It ensures smooth change from one environment to another with minimum disruption. (Büyüközkan et al. 2018).

   There may be chances that the data of customers might be lost due to moving the data from one platform to another. To avoid this, CSP should provide an environment or an API (Application Program Interface) which helps to retrieve the data from the old platform/source to a new platform (Cloud Standards Customer Council 2017).
6. Scalability—It is the ability to increase or decrease resources or services to meet the changing demands. In cloud computing, scalability refers to the ability to increase workload with existing hardware resources. This is important to evaluate in order to determine whether a system can handle a large number of application requests. (Jeong 2013; Almishal and Youssef 2014).
7. Disaster recovery—Any organization going for CSP implementation needs to understand the disaster recovery and data recovery options and CSPs ability to support data preservations. Does CSP have any backup plan, data restoration plan, integrity checks, and the additional cost associated with data recovery, if any?
8. Deployment and upgrades—For deployment, there are mainly three basic variants that can be distinguished as Public Cloud (offering of services from a freely accessible provider), Private Cloud (services which can only be accessed by one company) and Hybrid Cloud (i.e., getting best from the former two and combining it). Also, one needs to see whether CSP is giving regular updates or not and are they included or charged separately.
9. Service Level Agreements (SLAs) —It is the agreement between the provider and customer about the quality and reliability of service. It describes all the negotiations and terms and conditions of the contract (Ashraf 2014). SLAs could be very complex as there are no standards available in the cloud industry on how to construct SLAs and define it. Anyone take the different alternative as different service providers and give inputs with respect to the alternatives. Using the proposed methodology any one can rank the alternative





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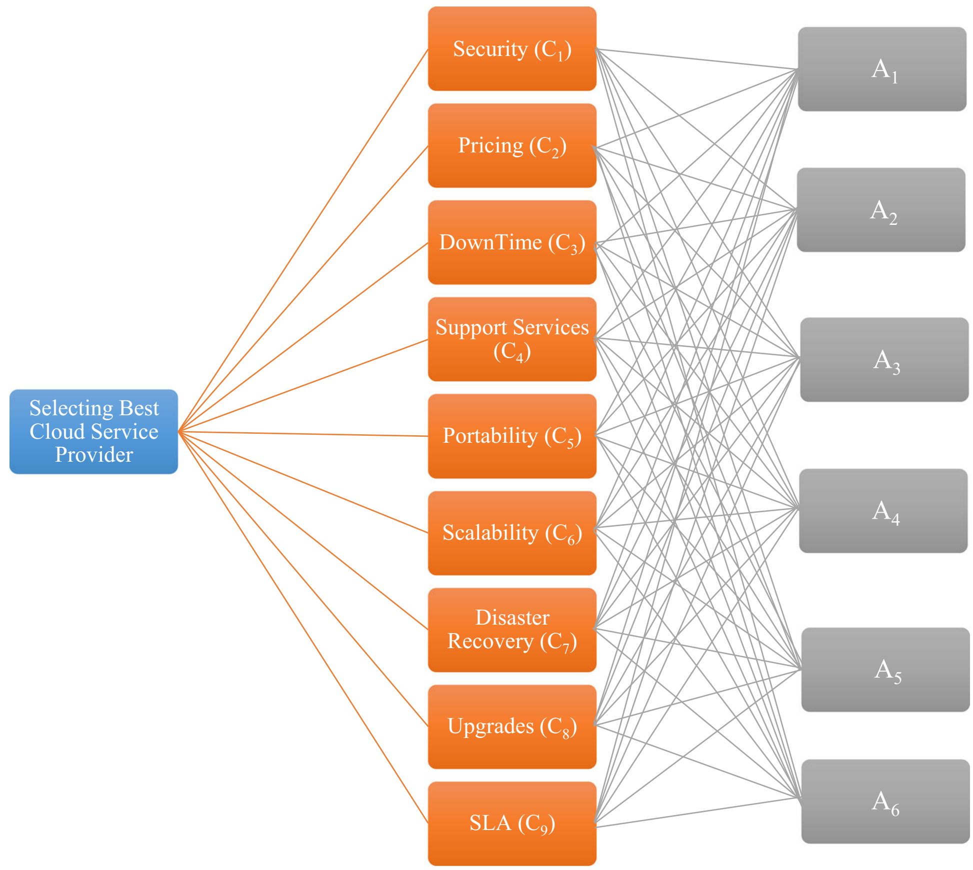


**Fig. 7** Hierarchical framework representing the criteria and alternatives taken in this research

**Table 4** Linguistic variables rating in terms of PIFN

| Linguistic terms | 1–9 Scale | Pentagonal intuitionistic fuzzy number |
|---|---|---|
| Equally important (EI) | 1 | $\langle(1,1,1,1,1); w_a, v_{a'}\rangle$ |
| Moderately important (MI) | 3 | $\langle(2,4,5,6,6.5); w_a, v_{a'}\rangle$ |
| Strongly important (SI) | 5 | $\langle(3,5,6,7,8); w_a, v_{a'}\rangle$ |
| Very strongly important (VSI) | 7 | $\langle(6,7,7,8,9); w_a, v_{a'}\rangle$ |
| Absolutely important (AI) | 9 | $\langle(7,8,9,9,10); w_a, v_{a'}\rangle$ |
| Moderately not important (MUI) | 1/3 | $\langle(1/6.5, 1/6, 1/5, 1/4, 1/2), w_a, v_{a'}\rangle$ |
| Strongly not important (SUI) | 1/5 | $\langle(1/8, 1/7, 1/6, 1/5, 1/3) w_a, v_{a'}\rangle$ |
| Very strongly not important (VSUI) | 1/7 | |
| Absolutely not important (AUI) | 1/9 | $\langle(1/10, 1/9, 1/9, 1/8, 1/7) w_a, v_{a'}\rangle$ |



easily. In the Fig. 7 hierarchical framework of the criteria and alternatives taken in the paper are shown.

*Note 4.1* In the criteria given above, pricing and downtime are non-benefit criteria, while security/privacy, support services, portability, scalability, upgrades, disaster recovery, and SLA are benefit criteria.

Table 4 illustrates the PIFN linguistic terms taken in this study for the calculation of criteria's weight. Since the membership degree and non-membership value may vary for each DMs, the generalized value $(w_a, v_{a'})$ is represented in Table 4.

*Note 3* The transpose of the matrix is represented in Table 5.

The linguistic data collected by the DMs in Table 5 are transformed to PIFN. The individual PIFN assigned by the DMS is integrated into a single PIFN by using Eq. 22. The PIFN weights are calculated using the steps described in sub-Sect. 3.4 of this paper. Table 6 depicts the final PIFN weights which will be used further for ranking the alternatives using the FTOPSIS approach.

Table 7 represents the weights of the criteria calculated by using the MCDM tool FAHP. For the calculation of criteria's crisp weights, firstly, the PIFN is defuzzified



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**Table 5** Criteria to criteria comparison were conducted by three DMs

| Criteria | Decision-makers (DMs) | Security ($c^1$) | Pricing ($c^2$) | Downtime ($c^3$) | Support Services ($c^4$) | Portability ($c^5$) | Scalability ($c^6$) | Disaster Recovery ($c^7$) | Upgrades ($c^8$) | SLA ($c^9$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Security ($c^1$) | DM1 | EI | 1/AI | EI | 1/AI | EI | 1/AI | EI | 1/AI | 1/AI |
| | DM2 | EI | 1/AI | 1/AI | 1/AI | 1/AI | 1/AI | EI | 1/AI | 1/AI |
| | DM3 | EI | 1/AI | 1/AI | 1/AI | 1/AI | EI | EI | EI | 1/AI |
| Pricing ($c^2$) | DM1 | AI | EI | EI | VSI | VSI | 1/SI | AI | VSI | EI |
| | DM2 | AI | EI | VSI | VSI | SI | 1/SI | AI | VSI | VSI |
| | DM3 | AI | EI | VSI | SI | VSI | VSI | AI | AI | VSI |
| Down Time ($c^3$) | DM1 | AI | EI | EI | EI | EI | 1/VSI | AI | EI | EI |
| | DM2 | AI | 1/VSI | EI | 1/VSI | VSI | 1/VSI | EI | EI | EI |
| | DM3 | AI | 1/VSI | EI | SI | EI | VSI | AI | AI | EI |
| Support Services ($c^4$) | DM1 | AI | EI | EI | EI | EI | 1/VSI | AI | EI | EI |
| | DM2 | AI | 1/VSI | VSI | EI | EI | EI | AI | VSI | EI |
| | DM3 | AI | 1/SI | EI | EI | EI | VSI | AI | AI | EI |
| Portability ($c^5$) | DM1 | AI | 1/VSI | EI | EI | EI | 1/VSI | EI | EI | 1/VSI |
| | DM2 | AI | 1/SI | EI | EI | EI | 1/SI | AI | VSI | 1/VSI |
| | DM3 | AI | 1/VSI | EI | EI | EI | AI | AI | AI | EI |
| Scalability ($c^6$) | DM1 | AI | SI | VSI | VSI | VSI | EI | AI | VSI | VSI |
| | DM2 | AI | SI | VSI | EI | SI | EI | AI | VSI | SI |
| | DM3 | AI | 1/VSI | 1/VSI | 1/VSI | 1/AI | EI | EI | EI | VSI |
| Disaster Recovery ($c^7$) | DM1 | EI | 1/AI | 1/AI | 1/AI | EI | I/AI | EI | 1/AI | 1/AI |
| | DM2 | EI | 1/AI | EI | 1/AI | 1/AI | 1/AI | EI | 1/AI | 1/AI |
| | DM3 | EI | 1/AI | 1/AI | 1/AI | 1/AI | EI | EI | EI | 1/AI |
| Upgrades ($c^8$) | DM1 | AI | 1/VSI | VSI | EI | EI | 1/VSI | AI | EI | EI |
| | DM2 | AI | 1/VSI | EI | 1/VSI | 1/VSI | 1/VSI | AI | EI | EI |
| | DM3 | EI | 1/AI | 1/AI | 1/AI | 1/AI | EI | EI | EI | 1/AI |
| SLA ($c^9$) | DM1 | AI | EI | EI | EI | VSI | 1/VSI | AI | EI | EI |
| | DM2 | AI | 1/VSI | EI | EI | VSI | 1/SI | AI | EI | EI |
| | DM3 | AI | 1/VSI | EI | EI | EI | 1/VSI | AI | AI | EI |



**Table 6** The PIFN weights of criteria taken in this research

| Criteria | PIFN weights of Criteria |
|---|---|
| Security ($c^1$) | $\langle(0.182, 0.217, 0.376, 0.574, 0.677); 0.5, 0.4\rangle$ |
| Pricing ($c^2$) | $\langle(0.005, 0.006, 0.017, 0.046, 0.059); 0.5, 0.4\rangle$ |
| Down time ($c^3$) | $\langle(0.009, 0.010, 0.042, 0.165, 0.189); 0.5, 0.4\rangle$ |
| Support services ($c^4$) | $\langle(0.013, 0.016, 0.044, 0.129, 0.151); 0.5, 0.4\rangle$ |
| Portability ($c^5$) | $\langle(0.016, 0.019, 0.063, 0.208, 0.242); 0.5, 0.4\rangle$ |
| Scalability ($c^6$) | $\langle(0.006, 0.007, 0.030, 0.176, 0.214); 0.5, 0.4\rangle$ |
| Disaster recovery ($c^7$) | $\langle(0.077, 0.086, 0.261, 0.560, 0.662); 0.5, 0.4\rangle$ |
| Upgrades ($c^8$) | $\langle(0.029, 0.033, 0.114, 0.444, 0.518); 0.5, 0.4\rangle$ |
| SLA ($c^9$) | $\langle(0.016, 0.020, 0.047, 0.104, 0.120); 0.5, 0.4\rangle$ |

using Eq. 16, and then, the AHP tool is applied to get the priority weights. The AHP technique is discussed in sub-Sect. 3.3 of this research paper.

Table 7 and Fig. 8 represent the crispified weights of criteria calculated by using FAHP.

*Note 3* The scores and chart represent the criteria 'security ($c^1$)' with the highest score followed by 'disaster recovery ($c^7$),' 'upgrades ($c^8$),' 'portability ($c^5$),' 'downtime ($c^3$),' 'scalability ($c^6$),' 'support services ($c^4$),' 'SLA )' and 'pricing ($c^2$).'

According to the score value shown in above Table 5, it is evident that 'Security' is the most vital attribute for selecting a Cloud service provider with the crisp weight of '0.294.' Protection of data against data loss, theft or

**Table 7** Criteria weights were obtained by using FAHP

| Security ($c^1$) | Pricing ($c^2$) | Down time ($c^3$) | Support services ($c^4$) | Portability ($c^5$) | Scalability ($c^6$) | Disaster recovery ($c^7$) | Upgrades ($c^8$) | SLA ($c^9$) |
|---|---|---|---|---|---|---|---|---|
| 0.294 | 0.013 | 0.055 | 0.049 | 0.073 | 0.053 | 0.278 | 0.141 | 0.043 |

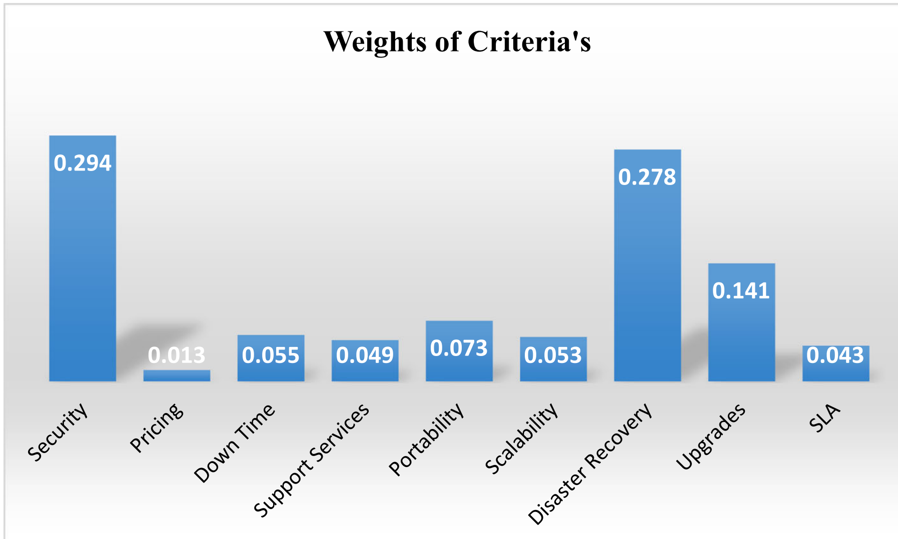


**Fig. 8** Clustered column chart depicting the weights of criteria obtained using FAHP

**Table 8** Linguistic variables rating in terms of PIFN for alternative rating w.r.t criteria

| Linguistic terms | Pentagonal intuitionistic fuzzy number |
|---|---|
| Extremely good (EG)/ extremely high (EH) | $\langle(5, 5.4, 5.5, 5.6, 6); w_a, v_{a'}\rangle$ |
| Very good (VG)very high (VH) | $\langle(4.2, 4.5, 4.7, 4.9, 5); w_a, v_{a'}\rangle$ |
| Good (G)/ high (H) | $\langle(3, 3.3, 3.6, 3.8, 4); w_a, v_{a'}\rangle$ |
| Poor (P)/ low (L) | $\langle(2.2, 2.3, 2.5, 2.9, 3); w_a, v_{a'}\rangle$ |
| Very poor (VP)/ very low (VL) | $\langle(1, 1.2, 1.5, 1.7, 2); w_a, v_{a'}\rangle$ |

**Table 9** Alternatives linguistic ratings assigned by DMs w.r.t criteria

| Alternatives | $A_1$ | | $A_2$ | | $A_3$ | | $A_4$ | | $A_5$ | | $A_6$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Decision-makers (DMs) | DM1 | DM2 | DM1 | DM2 | DM1 | DM2 | DM1 | DM2 | DM1 | DM2 | DM1 | DM2 |
| Security | EG | EG | EG | EG | EG | EG | EG | EG | VG | VG | VG | VG |
| Pricing | L | H | H | H | H | H | H | H | L | H | L | L |
| Down time | VL | VL | L | L | L | L | H | L | L | L | H | H |
| Support Services | EG | EG | EG | EG | EG | EG | VG | VG | VG | VG | EG | VG |
| Portability | EG | EG | VG | VG | EG | EG | EG | EG | VG | VG | VG | VG |
| Scalability | EG | EG | G | G | VG | VG | EG | VG | VG | VG | VG | VG |
| Disaster Recovery | EG | EG | EG | EG | VG | VG | G | VG | G | VG | VG | G |
| Upgrades | EG | EG | EG | EG | EG | EG | VG | VG | VG | VG | G | G |
| SLA | EG | EG | EG | EG | EG | EG | EG | EG | VG | VG | G | G |

leakage is a topmost priority so that any kind of data breach can be avoided. This is followed by Disaster recovery with the weight of '0.278.' For any organization; data recovery options, data preservation and a backup plan for data restoration, and integrity checks are crucial. Next comes upgrades which are also important and need to be done in regular intervals so that it complies with the ongoing market trends along with the dynamism of the macro-



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**Table 10** Representation of distance measure from PIS and NIS, relative closeness and ranks of the alternatives

| Alternative | D + | D- | Relative closeness | Rank |
|---|---|---|---|---|
| $A_1$ | 0.059 | 0.293 | 0.833 | 1 |
| $A_2$ | 0.063 | 0.288 | 0.820 | 2 |
| $A_3$ | 0.080 | 0.272 | 0.773 | 3 |
| $A_4$ | 0.123 | 0.228 | 0.649 | 4 |
| $A_5$ | 0.232 | 0.119 | 0.339 | 5 |
| $A_6$ | 0.269 | 0.083 | 0.235 | 6 |

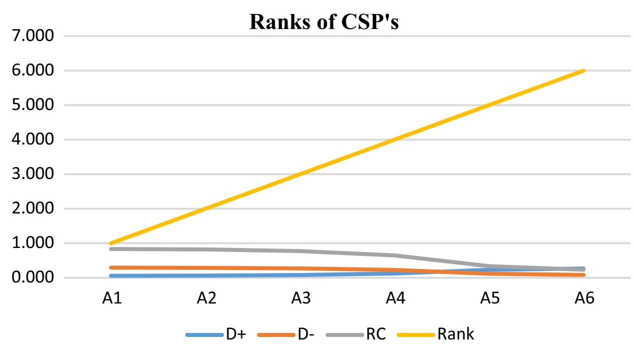


**Fig. 9** Line chart representing the distance measure, relative closeness and rankings of the CSPs

**Table 11** Rankings obtained under sensitivity analysis

| Alternatives | Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| $A_1$ | 2 | 4 | 1 |
| $A_2$ | 1 | 1 | 2 |
| $A_3$ | 3 | 2 | 3 |
| $A_4$ | 4 | 3 | 4 |
| $A_5$ | 5 | 6 | 5 |
| $A_6$ | 6 | 5 | 6 |

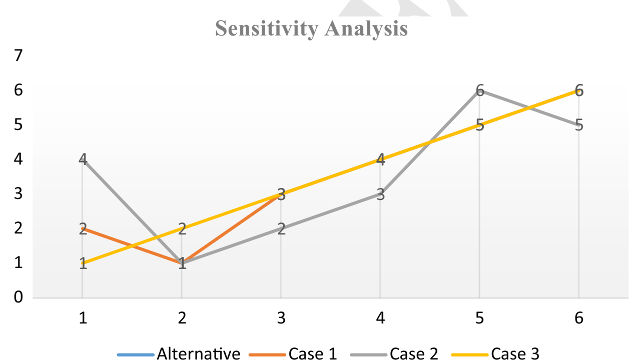


**Fig. 10** Line chart illustration of rankings obtained under sensitivity analysis

environment. We use the linguistic variable rating in terms of PIFN for the alternative with respect to criterion in Table 8. DMs rating for alternative are mention in Table 9.

### 3.4 TOPSIS for final ranking of the CSPs (Numerical study)

*Step 1*. Formation of integrated PIFN using Eq. 22.

*Step 2* Calculation of normalized matrix using equation 23.

*Step 3* Computation of weighted normalized matrix using equation 24.

*Note 4* The weighted normalized matrix is constructed using the product of PIFN weights of criteria obtained and the normalized matrix.

*Step 4* PIS and NIS are calculated using equation 25.

*Step 5* Distance measures of each CSPs are calculated from the PIS and NIS using Eq. 15.

*Step 6* Lastly, the relative closeness is determined for each alternative using Eq. 27 as mention in Table 10. The higher value of *RC* represents the optimal CSPs (see the Table 10 and Fig. 9).

## 4 Sensitivity Analysis

Sensitivity analysis is carried out by interchanging the PIFN weights of the most sensitive criterion. Three different cases have been undertaken, and thus, the rankings obtained under these cases are represented in Table 11. Graphically, these rankings are illustrated with the help of a line chart in Fig. 10.

*Case 1* Interchange of PIFN weights of support services and pricing—On interchanging the given values by decision-makers for support services and pricing, we found that the ranking of Alternative 1 has changed, while the rest others are not showing any change. This shows that pricing is one of the factors which is responsible to change the selection of cloud service providers A1 and A2.

**Table 12** Ranks of the alternatives using FCOPRAS and FTOPSIS

| Alternatives | Rank (FCOPRAS) | Rank (FTOPSIS) |
|---|---|---|
| $A_1$ | 1 | 1 |
| $A_2$ | 2 | 2 |
| $A_3$ | 3 | 3 |
| $A_4$ | 4 | 4 |
| | 5 | 5 |
| | 6 | 6 |





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*Case 2* Interchange of PIFN weights of upgrades and Downtime—This case shows a drastic change in the ranking of all the alternatives except A2. Minimal downtime and regular updates should be the main criteria of cloud service provider but according to the decision-makers, these two criteria have different values if we consider different CSP alternatives. As, downtime is considered a vital factor for selecting CSP, interchanging its value with other criteria shows a substantial change.

*Case 3* Interchange of PIFN weights of portability and scalability—As both the criteria portability and scalability are at par, the changes in the ranking of alternatives are very negligible.

The ranking obtained under the first two cases depicts that the alternative $A_1$ ranking order is changed from the first position to 2nd and 4th place in the two cases, respectively. This change in ranking under the change of two sensitive criterion represents the importance of these criteria. Considering the case 3, it is easy to understand from Table 11 and Fig. 10 that the same ranking is obtained as the methodology used in this paper. The interchange of weight of criteria's portability and scalability shows no alteration in ranking of the alternatives. This indicates the equivalency of these two criteria. Thus, these three cases in sensitivity study deliver an overall thought to the CSPs about the significance of individual criteria. Moreover, in future, CSPs can efficiently utilize this idea to obtain maximum benefit.

**Remark** *The three cases are considered as per the opinion of the decision expert. The most sensitive criteria are taken into account, and accordingly, their weights are interchanged to obtain the ranking. This mechanism is utilized to analyze the change in the pattern of ranking and to get a clear and deeper concept of the most important criteria.*

## 5 Comparative Analysis

The comparative study has been divided into two segments. In the first analysis, our methodology, i.e., FTOPSIS ranking, has been compared with the FCOPRAS MCDM ranking tool. In the second segment, the fuzzy number, i.e., PIFN, which has been applied in this study, has been compared with the trapezoidal intuitionistic fuzzy number (TRIFN), triangular intuitionistic fuzzy number (TIFN). Thus, the ranking obtained under these two different concepts has been discussed in the following subsections.

### 5.1 Comparative study with FCOPRAS technique

The complex proportional assessment (COPRAS) methodology was first developed by the authors of reference (Zavadskas et al. 1994). Fuzzy COPRAS is a comprehensive method of COPRAS technique, widely applicable to decision-making problems. It is a stepwise ranking and evaluation technique for the alternatives with reference to significance and utility degree. Table 12, Figs. 11, 12 and 13 demonstrate the ranking obtained using the existing MCDM tool FTOPSIS with FCOPRAS. The latter approach has been used for comparing with the existing one, and the observation or the ranking obtained is the same.

### 5.2 Comparative study with different fuzzy numbers

This section depicts Table 13 and Fig. 12, which are obtained under the ranking of CSPs under trapezoidal intuitionistic fuzzy numbers (TrIFN), (Parvathi and Malathi 2012) and (Rezvani 2013) and triangular intuitionistic fuzzy numbers (TIFN), (Wang et al. 2013) and (Li 2010) and the ranking is compared with PIFN which is used in this research. The author of reference (Vashishtha and Susan 2022) developed multi-lexicons adaptive neuro fuzzy inference system (MultiLexANIFS), which integrates inputs from different lexicons to carry out the sentiment analysis of social media posts. The existing method, i.e., by use of PIFN, the alternative $A_1$ ranks the highest, followed by $A_2 > A_3 > A_4 > A_5 > A_6$. The rank obtained under TrIFN shows that the rank of the alternative $A_1 \& A_2$ remains the consistent position of 1st and 2nd followed by $A_3 > A_4 > A_6 > A_5$. In TIFN, the ranks of the alternatives are interchanged, $A_2$ being the first followed by $A_1 > A_3 > A_4 > A_6 > A_5$.

**Remark** *The ranking obtained under comparative analysis in this section depicts same ranking when FTOPSIS is compared with FCOPRAS. This indicates the equivalency of the two methods. Thus FTOPSIS technique is used for ranking and FCOPRAS technique isfor comparative study. In numerical we get consistent results for both techniques. The comparative analysiswas also done with respect to different types of intuitionistic fuzzy numbers i.e., TrIFN and TIFN insubsection 5.2* $A_1, A_2, A_3 and A_4$ *but interchange of ranking for the* $A_5 and A_6$ *alternatives. In comparison of PIFN with TFN, it is seen that the alternative* $A_2$ *scored first rank followed by* $A_1$ *scoring second rank. The other alternatives ranking obtained under TFN hold consistent rank with TrFN. The ranking obtained under PIFN with MCDM tool TOPSIS can be said as the best technique because PIFN incorporates the degree of hesitancy and vagueness of the DMs in an optimal way compared to other type of Intuitionistic fuzzy number.*





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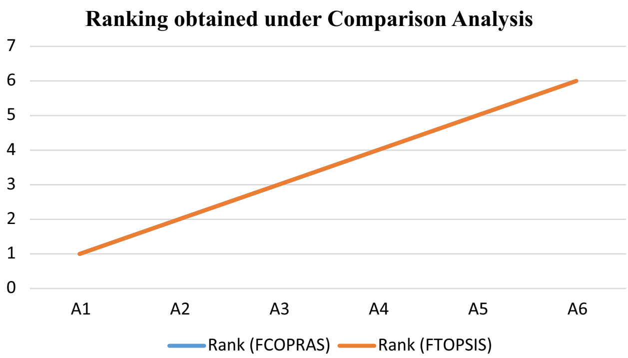


**Fig. 11** Line chart representation of rankings obtained under comparative analysis

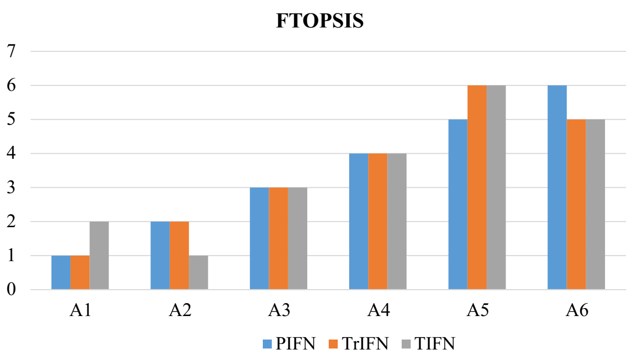


**Fig. 12** Bar graph representation of rankings obtained under the comparative analysis of different types of intuitionistic fuzzy number

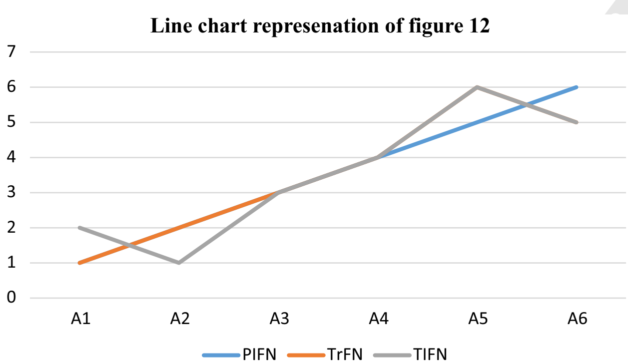


**Fig. 13** Line chart representation of rankings obtained under the comparative analysis of different types of intuitionistic fuzzy number

## 6 Main findings

This paper reveals the rankings of the Cloud Service Provider alternative using fuzzy AHP and fuzzy TOPSIS methods. The ranking technique FTOPSIS is further compared with the other MCDM technique FCOPRAS. The comparative study is presented in Sect. 5. The comparative study has been integrated into two sections. The first sub-Sect. 5.1 depicts the comparison of MCDM FTOPSIS used in this paper with FCOPRAS. The ranking obtained under

**Table 13** Ranks of the alternatives using different types of intuitionistic fuzzy numbers

| Alternatives | PIFN | TrIFN | TIFN |
|---|---|---|---|
| $A_1$ | 1 | 1 | 2 |
| $A_2$ | 2 | 2 | 1 |
| $A_3$ | 3 | 3 | 3 |
| $A_4$ | 4 | 4 | 4 |
| $A_5$ | 5 | 6 | 6 |
| $A_6$ | 6 | 5 | 5 |

these two MCDM shows that the alternatives $A_1$ and $A_2$ obtain the rankings 1 and 2, respectively. Thus, the FTOPSIS technique for ranking used in this study and the FCOPRAS for comparison yields consistent rankings of the CSPs. In the second segment, the intuitionistic fuzzy number, i.e., TrIFN and TIFN.

Using TOPSIS, the final ranking has been done, which shows that Alternatives 1 and 2, i.e., are the best Cloud Service Providers taking into consideration all the factors responsible for selecting the best alternative. The sensitivity analysis shown in Sect. 4 shows that in case 1 and 3, where the most sensitive criteria's fuzzy weights are interchanged, also alternative 1 and 2 obtain consistent ranks of 1 and 2, which implies that they are the top giants of the market due to the fact that it provides excellent services along with customer satisfaction and any business house can consider it reliable to store and access their important data.

## 7 Conclusion and future research scope

This paper primarily focuses on the use of intuitionistic fuzzy numbers with fuzzy AHP-fuzzy TOPSIS tool for obtaining the weights of criteria and ranking of CSPs. Formulae are developed using PIFN for determine the weight of criteria and also aggregate the decision-maker's estimation into a single comprehensive value. Further, Fuzzy AHP- TOPSIS and Fuzzy AHP- COPRAS have been used to determine the final ranking of the alternatives. The requirement to move the business to the cloud has increased manifold due to the fact that it reduces the operational cost and provides flexibility to the business to grow its functional areas. So, the opinions of different decision-makers have been considered to determine the best alternative. Although the views of decision-makers are highly influenced by their working environment and the size and severity of business, the attempt to determine the alternative ranking is done. Comparative and sensitivity



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analyses have been conducted to check the robustness and steadiness of the techniques used.

In the future study, the researchers can use different types of fuzzy numbers depending on the problem and availability of the data. The different number of criteria and alternatives can be added or eliminated. Diverse MCDM tools such as WASPAS, ELECTRE, PROMETHEE, VIKOR methodology can be used in future.

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**Data availability** All data supporting the results reported in the article are present in the paper.

## Declarations

**Conflict of interest** The authors declare that there is no conflict of interest in this study.

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