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Research Article

Implementing Fuzzy TOPSIS in Cloud Type and Service Provider Selection

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Cloud computing can be considered as one of the leading-edge technological advances in the current IT industry. Cloud computing or simply cloud is attributed to the Service Oriented Architecture. Every organization is trying to utilize the benefit of cloud not only to reduce the cost overhead in infrastructure, network, hardware, software, etc., but also to provide seamless service to end users with the benefit of scalability. The concept of multitenancy assists cloud service providers to leverage the costs by providing services to multiple users/companies at the same time via shared resource. There are several cloud service providers currently in the market and they are rapidly changing and reorienting themselves as per market demand. In order to gain market share, the cloud service providers are trying to provide the latest technology to end users/customers with the reduction of costs. In such scenario, it becomes extremely difficult for cloud customers to select the best service provider as per their requirement. It is also becoming difficult to decide upon the deployment model to choose among the existing ones. The deployment models are suitable for different companies. There exist divergent criteria for different deployment models which are not tailor made for an organization. As a cloud customer, it is difficult to decide on the model and determine the appropriate service provider. The multicriteria decision making method is applied to find out the best suitable service provider among the top existing four companies and choose the deployment model as per requirement.

1. Introduction

Cloud computing (CC) provides service to users adopting the distributed computing model. It provides computing resources and service to the users as per demand. Cloud computing enhances user's opportunity who can access infrastructure and software applications in a ubiquitous manner [1]. Hardware and licensing costs can be leveraged by utilizing cloud computing and customers can be served in an efficient manner with the aid of scalability attribute. Service offerings in cloud are complex and are constantly evolving. On-demand resource provisioning, broad network access, resource pooling, rapid elasticity, and measured services are some of the key characteristics in cloud computing. Various organizations are trying to adopt cloud from their existing IT infrastructure. The scalability and potential cost effectiveness are attracting various organizations to shift to cloud environment. Recent surveys have revealed that various organizations are willing to transfer their applications to cloud to avail the diverse advantages it offers. The cloud computing market has been growing over the years and the service providers are trying to gain foot hold in the market with various offers in terms of services [2]. There are several cloud service providers in current scenario who are providing services almost identical in nature but with variation in characteristics and offerings. The consumers often face difficulty in selecting the best cloud provider as per their requirement. Cloud providers including Amazon Web Services (AWS) and Microsoft give customers the choice to deploy their applications over a pool of virtual services with practically no upfront investment and with an operating cost proportional to their actual usage [3]. The cloud service providers help the companies to concentrate on their core business areas, but there are certain factors and parameters which customers need to consider during choice of service [4]. Cloud has different deployment models (Public, Private, and Hybrid) and different service models like SaaS, PaaS, and IaaS. Big IT organizations like Google, IBM, Microsoft, Amazon, etc., are offering various cloud services to users. It becomes an uphill task for a cloud customer or user to determine which company to choose [5, 6]. Also it becomes complex to decide on the deployment model. Customers are lacking relevant experience and information to assess the service providers capability in various occasions.

This paper analyzes the different criteria for choosing the suitable service provider along with the deployment model using the Multi Criteria Decision Making (MCDM concept). The evaluation will be done using the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method [7]. MCDM method helps decision makers (DMs) in integrating objective measurements with value judgments that are based on collective group ideas instead of individual opinions.

The best alternative is deduced based on the shortest distance from the fuzzy positive ideal solution (FPIS) and farthest distance from the fuzzy negative ideal solution (FNIS). FPIS refers to maximization of benefit criteria while minimizing cost criteria whereas FNIS will maximize cost criteria and minimize benefit criteria. Utilizing the concept of Fuzzy TOPSIS, FPIS, and FNIS was defined and distance from each alternative from FPIS and FNIS was calculated. In final stage the closeness coefficient will help in determining the ranking order of the alternatives [6].

The current research work deals with the application of TOPSIS in the two most critical areas of concern, viz., selection of the suitable cloud service provider from the top 3 in current fiercely competitive cloud industry and most suitable cloud based on its type. Section 2 deals with related works. Section 3 describes the different cloud service providers and cloud types. Section 4 describes the MCDA techniques. Section 5 deals with fuzzy TOPSIS. Section 6 has two parts dealing with cloud service provider selection and cloud type selection using TOPSIS. Section 7 concludes the paper.

MCDA technique has found its application in several research areas to determine the best alternative among numerous alternatives with different set of criteria. In the current scenario there are multiple cloud service providers offering numerous attractive benefits to customers. Similarly, it is very difficult to determine the suitable cloud type for an organization. Fuzzy TOPSIS has been applied in this paper to determine the most suitable service provider and also the cloud type for an organization.

2. Related Work

In recent years there had been numerous studies on cloud service provider selection and cloud type selection. There are top cloud service providers offering plethora of services at different rate and multiple features. It becomes extremely difficult for a company to decide the best service provider and also the type of cloud to choose [8]. Kumar and Rai (2016) have studied IaaS with 3 different sets of criteria and provided a framework on cloud simulation. Costa (2013) has worked on selection of cloud service providers using MACBETH MCDA technique. Park and Jeong (2013) proposed a new MCDM approach and applied the same on SaaS based ERP. Rad et al. have studied cloud service platforms and its salient features. Li et al. have worked on the issues related to cloud application performances. Peng et al. have done survey on cloud middleware.

Chen et al. applied constraint programming in cloud provider selection and provided inputs on enterprise policies and its conflicts with users expectations. Chung and Seo (2015) applied ANP technique while working on evaluation on cloud services. Lee and Seo (2013) applied AHP in their research on cloud IaaS.

Godse and Mulik (2009) applied MCDA technique on 3 companies for comparison.

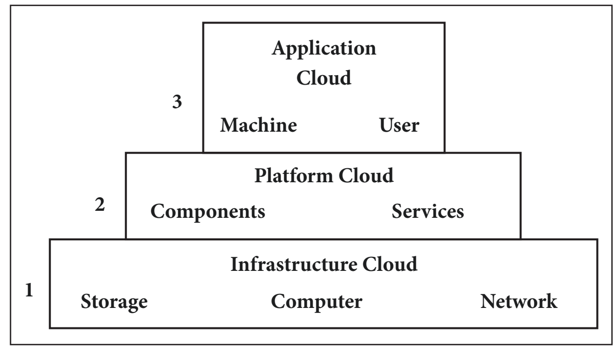

Figure 1: Cloud computing models.

3. Cloud Computing and Cloud Service Providers

3.1. Cloud Computing Overview. Cloud computing refers to storing of data in a remote place and accessing it via Internet instead of doing it in the local machine. So, the greatest advantage is that we need not require a hard drive or dedicated network for data storage and access. One well-known application is Office 365 by which user can store, access, and edit their MS Office documents online without the installation of software in their local machine. The architecture of cloud computing mainly comprises front-end device, back-end platform, cloud-based delivery, and network. The storage in cloud includes three options like public, private, and hybrid. In case of public cloud, it is available to the general public whereas infrastructure is owned and operated by service providers like Google and Microsoft. For private cloud, it is dedicated to a specific organization which can use it for storing organization's data, hosting business application, etc. Other organizations are not able to access the same. Advantages of both public and private cloud are present in hybrid cloud. Organizations can utilize private clouds for sensitive application, while public clouds are meant for nonsensitive applications.

3.2. Cloud Computing Models. Cloud computing models can be mapped against the layers of business value pyramid. Figure 1 depicts the same.

(i) SaaS. The top most layer of the above pyramid is SaaS or functional layer. This specific cloud type is responsible for delivering a single application with the help of a browser to various users through multitenant architecture. It is basically a "pay-as-you-go" model where provider sells an application based on license. The users need not have to take the hazards of maintaining servers or any software which basically reduces the cost. Service providers can also handle it easily as one application needs to be maintained here. Thus, it is cost effective for both sides, users and providers. Few well-known applications are Salesforce.com, SRM, ERP, etc. Few major characteristics of SaaS are listed in the following:

(I) Centralized web-based access to company and commercial software

(II) Providing superior services to client

(III) No software maintenance required from user's perspective

(IV) Integration with different applications possible through Application Programming

(V) Interfaces (APIs)

(ii) PaaS. PaaS or Platform as a service delivers development or operating environments as a service. It is a combination of tools and services designed for coding and deploying the applications in an effective and efficient manner. The major difference with SaaS model is that PaaS is a platform for development/deployment of the software instead of readymade software delivered over the Internet. Few major examples include Salesforce.com's Force.com, Azure from Microsoft, and Google App Engine. The major characteristics are the following:

(a) A one stop solution for developing, testing, deploying, hosting, and maintaining applications

(b) Web-based UI designing tools to create, modify, test, and deploy different UI scenarios

(c) Multitenant architecture facilitating concurrent users

(d) Load balancing, security, and failover capabilities for application to be deployed

(e) OS and cloud programming APIs to create new apps for cloud or to cloudify the current apps

(f) Tools to handle billing and subscription

(iii) IaaS. The infrastructure cloud is responsible for storage and compute resources as a service which is basically used by various IT organizations for providing business solutions. Complete flexibility is provided in this approach to the user; users can choose among desktops, servers, and network resources. The entire infrastructure package can be customized by choosing anything from the list of CPU hours, storage space, bandwidth, etc. This cloud type has different categories like private, public, and hybrid. Public cloud consists of shared resources whereas private cloud is responsible for providing secure access to the resources and is managed by the organization it serves [9]. This type of cloud is maintained by both internal and external providers. Some notable characteristics are the following:

(a) Resources distributed as a service

(b) Dynamic, on-demand scaling of resources

(c) Utility based pricing model

(d) Concurrent users on a single piece of hardware

3.3. Cloud Computing Benefits. Cloud computing provides different benefits. Cloud services offer scalability. Dynamic allocation and deallocation of resources happen based on demand. Cost savings are another major advantage which happens due to cost reduction in capital infrastructure. Applications can be accessed across the globe and without the hardware configuration in the local machine also. Network is simplified, and client can access the application without buying license for individual machine. Storing data on cloud is more reliable as it is not lost easily.

3.4. Challenges behind Cloud Services. Cloud services cover various issues along with its advantages. Few such concerns are listed in the following:

(a) Security and Privacy

(b) Interoperability and Portability

(c) Reliability and Availability

(d) Performance and Bandwidth Cost

3.5. Cloud Service Providers. Cloud service providers refers to different organizations that offer infrastructure, network services, software, hardware components, etc. to different customers and business entities. Cisco, Citrix, IBM, Google, Microsoft, Rackspace, etc. are examples of cloud service providers. In the paper we have considered currently, the top cloud service providers in market are like Amazon Web Services, IBM Bluemix, and Google Cloud Compute. Evaluating the cloud service provider is not an easy activity, but it requires thorough analysis. This has been dealt with in this research article in detail. Cost cannot be the single criteria for selecting a service provider, but different offerings should also be considered in detail. The different fine prints in the agreement need to be analyzed by customers before selecting the provider.

3.6. Public Cloud. In a public cloud a service provider manages resources such as infrastructure, application, and storage and makes it available to cloud consumers via Internet. The service providers like Microsoft, Amazon, Google, etc. own and operate their infrastructure from their own data centers [10]. With the increase in demand of service, users do not need to purchase hard ware as public cloud providers manage the infrastructure. Public clouds are owned by third party organizations and are made available to organizations. Google, Amazon, and Microsoft are notable examples of public cloud vendors.

Some advantages of public cloud are

(i) seamless data availability,

(ii) all round technical support,

(iii) scalability on demand,

(iv) limited investment,

(v) proper resource utilization.

Limitations of public cloud are

(i) data security and privacy.

3.7. Private Cloud. Private cloud as the name suggests refers to infrastructure which is linked to a concern either managed by an organization or third party. It may be present on premise or off site. In private cloud the service is offered to a specific organization and is not meant for public use. In terms of security private clouds are providing highest amount of security service. Private clouds can be built and managed by companies own infrastructure or by cloud service provider.

Some advantages of public cloud are

(i) control over data and information assets,

(ii) high level security,

(iii) superior performance due to intranet and network performance,

(iv) easier to achieve compliance.

Limitations of private cloud are

(i) underutilization of resources

(ii) costliness

3.8. Hybrid Cloud. Hybrid cloud deployment model involves composition of two or more clouds like private, public, etc. The combination of public cloud provider and private cloud platform can also be referred to as a hybrid cloud where they operate independently. Organizations can store sensitive data on private cloud environment and leverage the computational services from public cloud. The hybrid environment ensures minimum data exposure while taking advantage of public cloud platform. Some advantages of public cloud are

(i) private infrastructure to ensure easy accessibility,

(ii) reduction of access time and efficient resource utilization,

(iii) advantage of using computational infrastructure.

Limitations of hybrid cloud are

(i) higher cost,

(ii) security aspects,

(iii) compatibility issues.

4. Multicriteria Decision Analysis (MCDA)

4.1. Background of MCDA. Multicriteria Decision Analysis (MCDA) or Multi Criteria Decision Making is a subbranch of operational research which helps in decision making where several decision making criteria exist. Finding out the best option from the available alternatives is known as decision making. In real world scenario decision making is difficult where there are conflicting goals, different constraints, and unpredictable end results [11]. Here the fuzzy set theory can be used where we are unable to conclude precisely. In 1951 the vector maximum problem was first introduced by Harold William Kuhn and Albert William Tucker. This can be considered as the basics of MCDA. Later in 1972 "Multiple Criteria Decision Making" conference was held in Columbia University. MCDA has been growing in rapid space in the following decades since then.

The MCDA uses the mathematical and computational tools in selection of the best alternative among different choices which may have conflicting criteria. MCDA helps in finding the best alternative among different available choices with respect to specific criteria by decision maker.

We human beings face difficulty in finding the best alternative if there exists multiple criteria and in such situation MCDA can guide in proper decision making. As an example we may consider our current scenario where we have different cloud providers. All the cloud providers are competing against each other to gain the top position and have been trying to draw customers by providing different attractive and cost competitive features. There are distinctive features like control interface features, support services availability, and server OS types which are being offered by the cloud service providers. A customer needs to take decision on the distinctive features being offered by the cloud providers and select the one which is the best alternative among them. MCDA is developed based on the human thinking and their approach in decision making. There are several MCDA methods and techniques available, but the basic methodology is similar based on existing diverse set of criteria and decision making. MCDA consists of methodologies, application of theories, and techniques aiding and dealing with decision making problems. Decision making theory has been applied to solve various real-life problems where multiple conflicting criteria can exist.

4.2. MCDA Methods. MCDA is part of operational research which aims to select the suitable or best alternative among several options with the aid of mathematical and computational tools. It consists of two main categories: Multiattribute Decision Making (MADM) and Multiobjective Decision Making (MODM). MCDA can also be categorized into 2 types, viz., (a) Multiattribute Utility Theory (MAUT) and (b) outranking methods. Using MAUT we try to find a function which determines the utility or usefulness of an alternative. Every action is linked with a marginal utility and a real number will represent the preference in the considered action. The resultant utility represents the addition of the marginal utilities. Outranking method helps

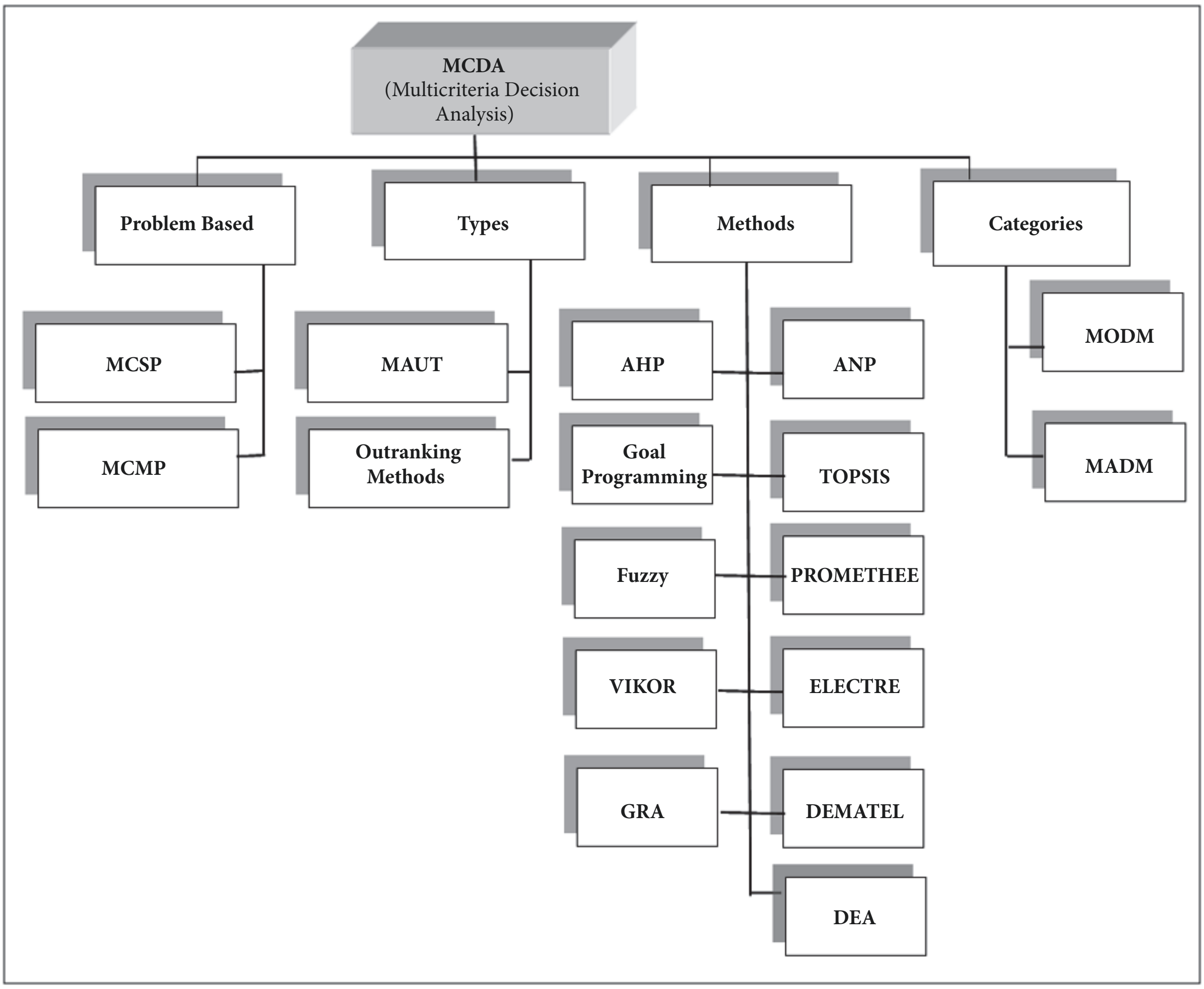

Figure 2: Different branches of MCDA.

in finding the alternative which is ranked higher when compared pairwise. Figure 2 shows the different branches of MCDA.

4.2.1. Analytic Hierarchical Process (AHP). Analytic Hierarchical Process (AHP) was introduced by Thomas L Satty in 1980. This is a popular and widely used method for MCDA. Complex MCDM problems are divided into system of hierarchies. In final stage AHP deals with an M X N matrix where M refers to number of alternatives and N represents number of criteria. The matrix is formed considering the relative importance of alternatives against each criterion. Both qualitative and quantitative criteria are used in AHP to find the alternatives and attributes are not entirely independent of each other [12]. Pair wise comparison is used in AHP and the attributes are structured into a hierarchical relationship. Hierarchy starts from top level and then proceeds towards the goal. Criteria, subcriteria, etc., represent the lower levels. The process execution in hierarchy tree initiates from the leaf nodes and it proceeds to the top level. Output level represents hierarchy related to the weight or the influence of different branches which originated at that level. In final stage the comparison is done and best alternative against each attribute is selected.

4.2.2. Analytic Network Process (ANP). Analytic Network Process (ANP) can be referred to as an extension or generalization of Analytic Hierarchy Process (AHP). ANP decision making technique is designed using unidirectional hierarchical relationships between different levels and taking upon the problem of dependence and feedback on different criteria. ANP considers interrelationships within decision levels and attributes using unidirectional hierarchical relationships. It models the decision problem by implementing ratio scale measurements based upon pair wise compare. The interdependence between elements is effectively handled by ANP using composite weights and "super matrix". In many real world scenarios of decision making, ANP has been successfully applied. It has been observed that many decision making problems cannot be hierarchically structured as there is involvement of interaction and dependence between higher and lower level elements [13]. Thus ANP is represented as a network instead of hierarchy. The feedback structure is devoid of the top-to-bottom form in hierarchy. It rather looks like a network with cycles connecting its component of elements which cannot be referred as levels and it loops to connect a component to itself. ANP has sources and sinks. Source node is the origin of paths of influence and is not the destination of paths. Sink node is a destination of paths of influence and is not an origin of paths. A full network may consist of source nodes, intermediate nodes which appear on the paths from source nodes and lie or fall on path to sink nodes and finally sink nodes.

4.2.3. Technique for Order of Preferences by Similarity to Ideal Solutions (TOPSIS). In multicriteria decision making (MCDM) methods we know the ratings and weights of the criteria. TOPSIS was first developed by Hwang and Yoon for solving issues where multicriteria exist and decision making becomes a complex affair. In TOPSIS the performance ratings and weights of the criteria are provided with crisp values. C.T. Chen developed TOPSIS methodology further in solving multiperson and multicriteria decision issues in real world environment where fuzzy exists. Linguistic variables are used to determine weights of all existing criteria and ratings given on each alternative linked to each criterion as there exists fuzziness in decision data and group decision.

In Fuzzy TOPSIS we define the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS). Then calculation is done on distance of each alternative from FPIS and FNIS. Finally ranking order of alternatives is determined using closeness coefficient.

4.2.4. Elimination and Choice Expressing Reality (ELECTRE). Elimination and Choice Expressing Reality (ELECTRE) was introduced initially in 1966. This deals with "outranking relations" by performing pairwise comparison among alternatives under each criterion separately. Later several versions were developed like ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV, and so on. ELECTRE belongs to the class of outranking methods and it involves up to 10 steps. Pairwise comparison is done between alternatives to find out the outranking relationships. The relationships in turn help in identifying and removing the alternatives which are dominated by others, resulting in a smaller set of alternatives.

ELECTRE method handles discrete criteria that are both qualitative and quantitative and provides ordering of alternatives. Ranking of alternatives is obtained by using graphs in an iterative procedure. This method starts comparing pair wise of alternatives under each criterion. The ELECTRE method finds a whole system of binary outranking relations among the alternatives. ELECTRE method at times is unable to identify the preferred alternative since the systems are not necessarily complete ones. It yields the core of leading alternatives. This method eliminates the less favorable ones thus giving a clear understanding of the alternatives. In cases where we need to deal with few criteria and large alternatives, this ELECTRE method will be useful.

4.2.5. Fuzzy. Fuzzy set theory has been initially proposed by Zadeh in 1965 and is applied in areas of uncertain data or there is lack of precise information. Fuzzy can help in multicriteria decision making where there exist several uncertainties in available information. The decision pools help in finding selected alternative criteria using the fuzzy MCDA model. Weights are assigned to criteria which are evaluated in terms of linguistic values. Linguistic values are then assigned fuzzy numbers. Inside fuzzy set, fuzzy terms are described by linguistic variables which in turn are used to map the linguistic variables to numeric variables [14].

4.2.6. Goal Programming. Goal Programming is a MODM tool proposed by Charnes in 1955. In areas of multiple conflicting objects the Goal Programming is applied. This is an extension of Linear Programming. Multiple conflicting objective measures can be handled by the Goal Programming optimization procedure. Mathematical programming is combined with the logic of optimization in order to take decisions involving several objectives in different multicriteria decision making problems.

4.3. Motivations in Selecting TOPSIS Method. TOPSIS is one of the most popular multicriteria decision making (MCDM) methods. It deals with the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution while determining the best alternative. TOPSIS is a well-known method due to the following reasons: (a) theoretical stringency, (b) effective usage of human thinking in selection process, (c) guides in decision making using rank alternatives in fuzzy environment, (d) proper implementation of subjective and objective criteria, (e) crisp values assigned to performance ratings and also to the weights of the criteria which helps in dealing with MCDM problems.

5. Brief Overview of TOPSIS Method

TOPSIS stands for Technique for Order Preference by Similarity to Ideal Solution. Here two artificial alternatives are hypothesized which are Ideal Alternative and Negative Ideal Alternative. Ideal Alternative is the one which has the best attribute values like maximum benefit attributes and minimum cost attributes. Similarly Negative Ideal Alternative includes the worst attribute values like minimum benefit attributes and maximum cost attributes. The TOPSIS method chooses the alternative which is nearest to the ideal solution and farthest from the negative ideal solution [15, 16]. The outline of the TOPSIS method is presented in the following.

Step 1. Evolution matrix is formed of m alternatives and n criteria, using the intersection of each alternative and criteria given as x_{ij}, and then we have a matrix $(x_{ij})_{\mathrm{m\ x\ n}}$

Step 2. The matrix $(x_{ij})_{mxn}$ is then normalized to form the matrix.

R = $(r_{ij})_{m\ x\ n}$ using the normalization method r_{ij} = $X_{ij}/\sqrt{\sum_{i=1}^{m} x_{ij}^2}$, i = 1, 2, ... m, j = 1, 2, ..., n

Step 3. Calculate the weighted normalized decision matrix

$t_{ij} = r_{ij}.\, w_j$, i = 1, 2, ..., m, j = 1, 2 . . . . . . , n where $w_j = W_j / \sum_{j=1}^{n} W_j$, j = 1, 2 . . . ...n so that $\sum_{j=1}^{n} w_j = 1$ and W_j is the original weight given to the indicator v_j, j = 1, 2 . . . ..n

Step 4. Determine the worst alternative (A_w) and the best alternative (A_b)

$A_w = \{(\max(t_{ij} \mid i = 1, 2 \ldots, m) \mid j \in J_-), (\min(t_{ij} \mid i = 1, 2 \ldots m) \; j \in J_+)\} \equiv \{t_{wj} \mid j = 1, 2 \ldots n\}$,

$A_b = \{(\min(t_{ij} \mid i = 1, 2 \ldots, m) \mid j \in J_-), (\max(t_{ij} \mid i = 1, 2 \ldots m) \; j \in J_+)\} \equiv \{t_{bj} \mid j = 1, 2 \ldots n\}$,

where

$J_+ = \{j = 1, 2, \ldots, n \mid$ j associated with the criteria having a positive impact and

$J_- = \{j = 1, 2, \ldots, n \mid$ j associated with the criteria having a negative impact

Step 5. Calculate the L2 – distance between the target alternative i and the worst condition A_w

$$d_{iw} = \sqrt{\sum_{j=1}^{n} \left(t_{ij} - t_{wj}\right)^2}, \quad i = 1, 2 \ldots \ldots, m \qquad (1)$$

and the distance between the alternative i and the best condition A_b

$$d_{ib} = \sqrt{\sum_{j=1}^{n} \left(t_{ij} - t_{bj}\right)^2}, \quad i = 1, 2 \ldots \ldots, m \qquad (2)$$

where d_{iw} and d_{ib} are L2 – norm distances from the target alternative i to the worst and the best conditions, respectively.

Step 6. Calculate the similarity to the worst condition:

$s_{iw} = d_{iw}/(d_{iw} + d_{ib})$, $0 \le s_{iw} \le 1$, i = 1, 2 . . . . . . m.

$s_{iw} = 1$ if and only if the alternative solution has the best condition.

$s_{iw} = 0$ if and only if the alternative solution has the worst condition.

Step 7. Rank the alternative according to s_{iw} (i = 1, 2 . . . ..m).

6. Applying MCDM Topsis in Cloud

6.1. Evaluation of Cloud Service Provider Using TOPSIS. Three experts evaluate three types of cloud service providers A, I, G and find their evaluations in linguistic variables with respect to objectives, i.e., criteria $C_1 \ldots\ldots C_9$.

The decision makers use seven point scale linguistic variables which are represented by triangular fuzzy numbers to express importance of weight/priority to *Nine* criteria given by Box 1

The criteria are assessed by decision makers which are represented in Table 1.

The three different decision makers are represented in Table 1 by D1, D2, and D3.

Very Low (VL)	(0,0,0.1)
Low (P)	(0,0.1,0.3)
Medium Low (ML)	(0.1,0.3,0.05)
Medium (M)	(0.3,0.5,0.7)
Medium High (MH)	(0.5,0.7,0.9)
High (H) (0.7,0.9,1.0)	
Very High (VH)	(0.9,1.0,1.0)

Box 1

Table 1: Criteria assessed by decision makers.

Feature Name	**D1**	**D2**	**D3**
Business Size Support	H	VH	VH
Support for Versatile Industries	VH	H	H
Control Interface Features	H	H	H
Availability of Support Services	VH	VH	VH
Server OS Types	H	H	VH
Preconfigured Operating Systems	MH	MH	MH
Available Runtimes	MH	H	MH
Middleware	H	MH	MH
Native Databases	VH	VH	H

As per above assessment and based on the values of linguistic variables, the fuzzy weight of each criteria j is found as

$$\widetilde{w_j} = \frac{1}{3}\left[w_j^{(1)} + w_j^{(2)} + w_j^{(3)}\right] \qquad (3)$$

Thus

$$\begin{aligned} \widetilde{w_1} &= \frac{1}{3}[G + VG + VG] \\ &= \frac{1}{3}[G + VG + VG] \\ &= \frac{1}{3}[(0.7, 0.9, 1.0) + (0.9, 1.0, 1.0) + (0.9, 1.0, 1.0)] \\ &= \frac{1}{3}[2.5, 2.9, 3] \\ &= (0.83, 0.97, 1) \end{aligned} \qquad (4)$$

Similarly we can obtain the values of $\widetilde{w_2}, \widetilde{w_3} \ldots\ldots \widetilde{w_9}$

In Table 2 features of different cloud service providers are given along with the reason for the different weightage and motivation behind the weightage.

The three cloud companies are evaluated by three decision makers on a seven point linguistic scale comprising the values in Box 2.

The decision makers' opinion is considered for each criterion in Table 3. The fuzzy decision matrix of 3 cloud service providers is given by the following.

For cloud provider AWS, under the feature F_1, the evaluation is

$$\widetilde{x}_{11} = \frac{1}{3}[G + VG + VG]$$

Table 2: Cloud service providers and feature compare.

Feature Name	Cloud Service Providers					
	Amazon Web Services(AWS)	Major Motivators for Weight Assignment	IBM Bluemix (IB)	Major Motivators for Weight Assignment	Google Compute Engine (GCE)	Major Motivators for Weight Assignment
Business Size Support	Good	Supporting Small-Medium Business	Very Good	Supporting Large - Small-Medium Business	Very Good	Supporting Large - Small-Medium Business
Support for Versatile Industries	Good	Supporting medium range of industries	Very Good	Supporting large set of industries	Poor	Supporting very few industries
Control Interface Features	Very Good	Supporting API, GUI, Web Based Application/Control Panel and Command Line	Poor	Supporting Web Based Application/Control Panel and Command Line	Good	Supporting API, Web Based Application/Control Panel and Command Line
Availability of Support Services	Very Good	Supporting Live Chat, Phone, 24/7, Forums, Online/Self-Serve Resources	Good	Supporting 24/7, Forums, Online/Self-Serve Resources	Good	Supporting 24/7, Forums, Online/Self-Serve Resources
Server OS Types	Very Good	Support Linux and Windows	Good	Supporting Windows	Very Good	Supporting Linux and Windows
Preconfigured Operating Systems	Very Good	Supporting Amazon Linux, Cent OS, Debian, Oracle Enterprise Linux, Red Hat Enterprise Linux, SUSE Enterprise Linux, Ubuntu, Windows Server	Poor	Supporting None	Good	Supporting Cent OS, Debian, Red Hat Enterprise Linux, Ubuntu, FreeBSD, openSUSE Linux
Available Runtimes	Good	Supporting NET, Java, PHP, Python and Ruby	Very Good	Supporting Go, Node, Java, PHP, Python and Ruby	Poor	Supporting None
Middleware	Good	Supports Tomcat	Very Good	Supports Jboss, Tomee	Poor	Supports None
Native Databases	Very Good	Supports CouchDB, Microsoft SQL, MongoDB, MySQL	Good	Supports MySQL and PostGreSQL	Poor	Supports None

Very Poor (VP)	(0,0,1)
Poor (P)	(0,1,3)
Medium Poor (MP)	(1,3,5)
Fair (F)	(3,5,7)
Medium Good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very Good (VG)	(9,10,10)

Box 2

$$= \frac{1}{3}\left[(7,9,10)+(9,10,10)+(9,10,10)\right]$$
$$= \frac{1}{3}(25,29,30) = (8.3,9.6,10) \tag{5}$$

Under Feature F_2,

$$\begin{aligned}\tilde{x}_{12} &= \frac{1}{3}\left[G+MG+MG\right] \\ &= \frac{1}{3}\left[(7,9,10)+(5,7,9)+(5,7,9)\right] \\ &= \frac{1}{3}(17,23,28) = (5.6,7.6,9.3)\end{aligned} \tag{6}$$

Likewise, evaluation is done for AWS for remaining features.

Similarly for other 2 cloud service providers, viz., IB & GCE under 9 Features ($F_1, F_2 \ldots F_9$) the evaluations are done.

Normalized decision matrix for each 9 features is determined against the 3 cloud service providers. Normalized fuzzy decision matrix $\tilde{v} = (\tilde{v}_{ij})$ where $\tilde{v}_{ij} = (\tilde{r}_{ij})(.)(\tilde{w}_j)$.

Table 3: Cloud service provider features and decision makers analysis.

Feature Name	Cloud Providers	Decision Makers D_1	D_2	D_3
Business Size Support (F_1)	AWS	G	VG	VG
	IB	VG	G	G
	GCE	VG	VG	BG
Support for Versatile Industries (F_2)	AWS	G	MG	MG
	IB	VG	G	VG
	GCE	P	F	MP
Control Interface Features (F_3)	AWS	VG	VG	G
	IB	P	F	MP
	GCE	G	G	MG
Availability of Support Services (F_4)	AWS	VG	G	VG
	IB	G	G	MG
	GCE	G	G	G
Server OS Types (F_5)	AWS	VG	VG	VG
	IB	G	MG	G
	GCE	VG	VG	VG
Preconfigured Operating Systems (F_6)	AWS	VG	G	G
	IB	P	MG	MP
	GCE	G	G	G
Available Run Times (F_7)	AWS	G	G	VG
	IB	VG	G	G
	GCE	P	F	P
Middleware (F_8)	AWS	G	MG	MG
	IB	VG	G	VG
	GCE	P	MP	F
Native Databases (F_9)	AWS	VG	VG	VG
	IB	G	G	G
	GCE	P	F	F

Weighted normalized fuzzy decision matrix is determined next.

The fuzzy positive and fuzzy negative ideal solutions are

$$P^* = (\widetilde{V}_1^{\,*}, \widetilde{V}_2^{\,*} \ldots .. \widetilde{V}_9^{\,*})$$

$$\overline{N} = (\overline{\overline{V}}_1, \overline{\overline{V}}_2 \ldots\ldots \overline{\overline{V}}_9) \text{ respectively such that}$$

$$\widetilde{V}_j^{\,*} = (1,1,1) \text{ and } \overline{\overline{V}}_j = (0,0,0)$$

The distance of the alternatives from B_i from positive solution is calculated by

$$d_i^+ = \sum_{j=1}^{n} d\left(V_{ij}, V_j^*\right) \tag{7}$$

This is done for all the 3 cloud service providers.

Similarly, the distance from the alternatives from (0,0,0) is calculated.

The separation measures from positive ideal solution and negative ideal solution are calculated [17]. Table 4 depicts the same.

Table 4: Separation measures.

Cloud Providers	d_1^+	d_1^-
AWS	3.6759	6.0917
IB	4.285	5.56645
GCE	3.78625	6.0728

In Table 4 the separation measures are provided. The closeness coefficient will be calculated based on the separation measures obtained in Table 4.

The closeness coefficient CC_i is given by $d_i^-/(d_i^+ + d_i^-)$

$$CC_1 = \frac{6.0917}{(3.6759 + 6.0917)} = 0.6237$$
$$CC_2 = \frac{5.56645}{(4.285 + 5.56645)} = 0.5650 \tag{8}$$
$$CC_3 = \frac{6.0728}{(3.78625 + 6.0728)} = 0.6159$$

Very Low (VL)	(0,0,0.1)
Low (P)	(0,0.1,0.3)
Medium Low (ML)	(0.1,0.3,0.05)
Medium (M) (0.3,0.5,0.7)	
Medium High (MH)	(0.5,0.7,0.9)
High (H)	(0.7,0.9,1.0)
Very High (VH)	(0.9,1.0,1.0)

Box 3

Very Poor (VP)	(0,0,1)
Poor (P)	(0,1,3)
Medium Poor (MP)	(1,3,5)
Fair (F)	(3,5,7)
Medium Good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very Good (VG)	(9,10,10)

Box 4

Table 5: Assessment criteria by decision makers.

Feature Name	**D1**	**D2**	**D3**
Cloud environment	H	VH	H
Data center location	VH	H	H
Resource sharing	H	H	H
Cloud storage	VH	VH	VH
Scalability	H	H	VH
Pricing structure	MH	MH	MH
Cloud security	MH	H	MH
Performance	H	MH	MH

The ranking order is now determined based on the closeness coefficient and its found AWS>GCE>IB. Hence the best alternative cloud service provider is AWS, i.e., Amazon Web Services.

6.2. Evaluation of Suitable Cloud Types Based on Notable Features. Evaluations are done in linguistic variables by cloud experts to evaluate suitable cloud platforms with respect to the different features like cloud environment, data center location, resource sharing, cloud storage, scalability, pricing structure, cloud security, and performance [18, 19].

Cloud experts use seven points linguistic variable scale based on the triangular fuzzy numbers and express the weightage/priority to 8 unique features (Box 3).

A committee is formed with decision makers to identify the evaluation criteria, which is shown in following Table 5. The committee of decision makers is represented by D1, D2, and D3 and assessment of criteria importance is shown in Table 5.

The fuzzy weight of each criterion j is determined with the help of given values of linguistic variables. These are provided below.

$$\widetilde{w_j} = \frac{1}{3}\left[w_j^{(1)} + w_j^{(2)} + w_j^{(3)}\right] \tag{9}$$

Thus

$$\begin{aligned}\widetilde{w_1} &= \frac{1}{3}[\mathrm{H} + \mathrm{VH} + \mathrm{H}] \\ &= \frac{1}{3}[\mathrm{H} + \mathrm{VH} + \mathrm{H}] \\ &= \frac{1}{3}[(0.7, 0.9, 1.0) + (0.9, 1.0, 1.0) + (0.7, 0.9, 1.0)] \\ &= \frac{1}{3}[2.3, 2.8, 3] \\ &= (0.77, 0.93, 1)\end{aligned} \tag{10}$$

Similarly, we can obtain the values of $\widetilde{w_2}, \widetilde{w_3} \ldots\ldots \widetilde{w_9}$

The three cloud platforms are evaluated by three decision makers on a seven point linguistic scale comprising the values in Box 4

The decision makers' opinion is combined for each criterion in Table 6. The fuzzy decision matrix of 3 cloud platforms is given by

For Cloud Platform Public, under the feature CE, the evaluation is

$$\begin{aligned}\widetilde{x}_{11} &= \frac{1}{3}[\mathrm{G} + \mathrm{VG} + \mathrm{G}] \\ &= \frac{1}{3}[(7, 9, 10) + (9, 10, 10) + (7, 9, 10)] \\ &= \frac{1}{3}(23, 28, 30) = (7.6, 9.6, 10)\end{aligned} \tag{11}$$

Under feature DC,

$$\begin{aligned}\widetilde{x}_{12} &= \frac{1}{3}[\mathrm{G} + \mathrm{G} + \mathrm{MG}] \\ &= \frac{1}{3}[(7, 9, 10) + (7, 9, 10) + (5, 7, 9)] \\ &= \frac{1}{3}(19, 25, 29) = (6.3, 8.3, 9.6)\end{aligned} \tag{12}$$

Likewise, evaluation is done for public cloud for remaining features.

Similarly for the other 2 cloud platforms, viz., Private and Hybrid under 8 features (CE, DC…PR) the evaluations are done.

Normalized decision matrix for each 8 features is determined against the 3 cloud platforms.

Normalized fuzzy decision matrix $\widetilde{v} = (\widetilde{v}_{ij})$ where $\widetilde{v}_{ij} = (\widetilde{r}_{ij})(.)(\widetilde{w}_j)$.

Weighted normalized fuzzy decision matrix is determined next.

The fuzzy positive and fuzzy negative ideal solutions are $\mathrm{P}^* = (\widetilde{V}_1{}^*, \widetilde{V}_2{}^* \ldots\ldots \widetilde{V}_9{}^*)$

Table 6: Assessment on different platforms by decision makers.

Feature Name	Cloud Platforms	Decision Makers D_1	D_2	D_3
Cloud Environment CE	Public	G	VG	G
	Private	MG	F	MG
	Hybrid	VG	VG	VG
Data Center Location DC	Public	G	G	MG
	Private	MG	MG	F
	Hybrid	G	VG	G
Resource Sharing RS	Public	VG	G	VG
	Private	MG	MG	F
	Hybrid	G	G	G
Cloud Storage CS	Public	G	VG	VG
	Private	MG	G	G
	Hybrid	MG	G	G
Scalability SC	Public	VG	VG	VG
	Private	F	G	G
	Hybrid	G	VG	VG
Pricing Structure PS	Public	VG	G	VG
	Private	F	MG	F
	Hybrid	G	MG	G
Cloud Security SE	Public	MG	F	F
	Private	VG	VG	VG
	Hybrid	G	G	G
Performance PR	Public	F	F	MG
	Private	VG	G	VG
	Hybrid	G	VG	G

Table 7: Separation measures.

Cloud Types	d_1^+	d_1^-
Public	1.413	3.378
Private	1.645	2.914
Hybrid	2.78625	4.56

$\overline{N} = (\overline{\widetilde{V}}_1, \overline{\widetilde{V}}_2 \ldots\ldots \overline{\widetilde{V}}_9)$ respectively such that
$\widetilde{V}_j^{\,*} = (1,1,1)$ and $\overline{\overline{V}}_j = (0,0,0)$

The distance of the alternatives from B_i from positive solution is calculated by

$$d_i^{\,+} = \sum_{j=1}^{n} d\left(V_{ij}, V_j^{\,*}\right) \qquad (13)$$

This is done for all the 3 cloud platforms.

Similarly, the distance from the alternatives from (0,0,0) is calculated.

The separation measures from positive ideal solution and negative ideal solution are calculated [20]. This is given in Table 7.

The closeness coefficient CC_i is given by $d_i^{\,-} / (d_i^{\,+} + d_i^{\,-})$ based on the separation measures obtained in Table 7. The separation measure in Table 7 is determined based upon the FPIS and FNIS.

The ranking order is determined from the closeness coefficient matrix and it was found Hybrid>Public>Private. The best alternative cloud type is Hybrid.

7. Conclusion

In today's smart era, competition is gradually increasing among the Cloud service providers in the market. It is getting steeper day by day as new entrants are joining in the service provider pool. Top cloud service providers are changing their strategies to retain their position in this volatile market. Hence they are very keen on selection of features which they are providing to the customers. So every provider offers a set of specific features which differ from those of the others. Now it is the client's responsibility to choose the appropriate vendor from the available ones based on their need. This vendor selection requires understanding and analyzing the features in deep, which is quite tedious if done manually. So there is a crying need of some technique which can perform this analysis automatically. This paper deals with TOPSIS methodology which helps us to select the most suitable service provider by analyzing its available offerings and features. It also studied in detail the different MCDA methods available along with the TOPSIS methodology. The TOPSIS technique is applied in selecting the suitable cloud for an organization which is embracing cloud from on-premise architecture. However, the detailed study will help cloud consumers in selecting the best service provider and cloud service from a set of different offerings and cloud features.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Aveek Basu carried out the research work. Sanchita Ghosh participated as the reviewer and research guide. All authors read and approved the final manuscript.

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