MCDM and Various Prioritization Methods in AHP for CSS: A Comprehensive Review

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ABSTRACT Availability and diversity of cloud service providers (CSPs) had put the users into confusion for its selection of the appropriate service providers. Some cloud service providers are good at some services while others are good at offering other services. The selection of an appropriate cloud service is one of the multi-criteria decision analysis (MCDA) problems that became a critical issue of public concern in the uncertain cloud industry. Based on multiple criteria, various multi-criteria decision-making (MCDM) methods can be used for the selection of the best CSPs. Researchers considered MCDM techniques as the best methodology for deciding cloud rank. The paper presents a set of decision criteria and their sub-criteria required for evaluating CSPs. The main goal of this paper is to present a review of various MCDM methods for decision-making. Furthermore, the strengths and weaknesses of various MDCM techniques are discussed to help the researchers about the current trends in the field of decision making. An overview of MCDM techniques used for Cloud service selection (CSS) is presented. Several methods used for deriving priority vectors from a Pairwise Consistency Matrix (PCM) in Analytic Hierarchy Process (AHP) technique, used in recent years are discussed in this research paper.

INDEX TERMS Cloud service providers (CSPs), multi-criteria decision-making (MCDM), cloud service selection (CSS), pair-wise comparison matrix (PCM), analytic hierarchy process (AHP).

I. INTRODUCTION

In the last few years, due to the evolution of Information and Communication Technology (ICT), Cloud Computing is in great demand as this technology offers dynamically highly scalable resources. Cloud Computing has many advantages like 24 × 7 availability from any location, reduced cost, fast accessibility, better performance, retained standards, compatibility, effective and efficient management of resources. It is an internet-based emerging technology that reduced the cost of data storage, data processing, and hardware infrastructure as well as software tools. Computing resources collection and its management are done automatically using software in cloud computing [1]. The birth of Cloud Computing is originated from Service-Oriented Architecture (SOA). We can say Cloud Computing is a set of services that are provided from the Cloud service providers (CSPs) to different users on its demand. The cloud architecture has three different types of layers, a) SAAS – Software as a Service, b) PAAS – Platform

as a Service, c) IAAS – Infrastructure as a Service. Software as a Service (SAAS) provides on-demand availability of different software as a service to its users through a web browser. Google App. is an example of SAAS services. With Platform as a service (PAAS), the cloud provider delivers a complete solution for software development. Like SAAS, it also includes Operating Systems and the services required for a particular application [2]. Bungee Connect is a good example of PAAS that provides a complete set of software development life cycle management tools. Infrastructure as a Service (IAAS) refers to computing and storage infrastructure as a service. It includes servers, networking technology, and reserved bandwidth for storage. Amazon's Elastic Compute Cloud (EC2) is the best example of IAAS that delivers highly scalable computing power. All three services are typically charged on a user's usage basis. It reduces the user's stress of buying and setting up the data center for their organizations. In addition, to the three-layered architecture, the Cloud deployment models are of various types, namely, Public Cloud, Private Cloud, Community Cloud, Virtual Private Cloud, and Hybrid Cloud as shown in Figure 1. Public Cloud
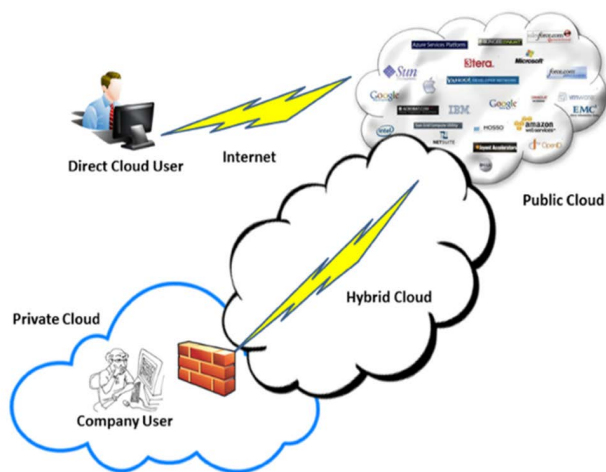
FIGURE 1. Cloud Architecture.

is set up outside the enterprise firewall and the user is allowed to access the cloud resources via available API. Security is a major issue that critic the usage of public cloud services. The applications deployed over public clouds need high security from their service providers. Private Cloud refers to setting up a virtualization environment on its private servers. This type of structure is adopted in those organizations that need full control over their data or infrastructure. A high level of security is achieved in private clouds as the access is provided only to the shareholders of the organization. But again, it needs more capital investment, so it's not truly a type of cloud service as it needs huge IT infrastructure. Also, it is difficult for an individual organization to have a team of security experts that can maintain the level of security and reliability. Community Cloud is adopted by enterprises having similar type of requirements. Being in an environment of public cloud, getting an isolated private cloud is achieved using the concept of Virtual Private Cloud. In Hybrid Cloud, the infrastructure resides partly within the internal enterprise data center and is partly consumed by third-party cloud vendors [3]. In the hybrid cloud model, there is synchronization of resources between the private and public cloud. Hybrid cloud can be used for both internal and external purposes depending on the user's need.

Decision-making is an aspect of life that we encounter every day. It becomes an important issue when confronting a complex decision-making situation. From a large variety of CSPs, it has become difficult for companies to adopt the best CSPs as per their needs. Multi-criteria decision-making (MCDM) offers a group of methods (shown in Table 2) for deciding the rank efficiently. Multiple domains have employed MCDM in the decision-making process. Based on multiple criteria, various MCDM methods can be used for selecting the best CSPs. Table 3 shows Yester year's work that makes use of various MCDM techniques for Cloud service selection (CSS).

This paper presents multiple decision criteria and their sub-criteria required for evaluating cloud services. The main goal

of this research paper is to review various MCDM methods available for decision-making. The pros and cons of MCDM methods are elaborated for the researchers working in the field of decision making. An overview of MCDM techniques used for CSS is presented. Various methods used for deriving priority vectors from Pairwise Consistency Matrix (PCM) in Analytic Hierarchy Process (AHP) technique, used in recent years are discussed in this study. This paper is divided into seven sections as follows: Section I gives the Introduction about Cloud Computing, the Cloud computing model, and decision making; Section II presents various decision-criteria and their sub-criteria for the evaluation of cloud services. Section III discusses various MCDM methods for decision-making. Table 2 presents the advantages and disadvantages/limitations of various MDCM techniques. Section IV presents various MCDM techniques used for CSS. Also, the MCDM techniques used for CSS are also tabulated in Table 3. Various methods that are used for deriving priority vectors from PCM in AHP are discussed in Section V along with a short description given in Table 4. Section VI provides results of this study. Section VII highlights future work and conclusion respectively.

II. CRITERIA AND SUB CRITERIA FOR EVALUATING CSPs

Cloud Computing has revolutionized every industry by allowing them to adopt cloud services at cheaper rates. Deciding to utilize the service for a specific cloud provider is a challenging task for the client stockholders. Customers get confused in determining the basis for selecting appropriate CSPs and their services. A careful analysis is required by cloud users for the proper selection of the best available CSP from a pool of CSPs.

Based on our literature study, the criteria and their sub-criteria that are considered as the main parameter for evaluating the Quality of service (QoS) of cloud providers are presented in Table 1. This literature review covers six main criteria for assessing CSPs.

A. SECURITY

Security plays an important role in adopting cloud infrastructure, many organization institutions would love to switch to the cloud, but they are mainly concerned about the security models provided by various CSPs in the market today. On the other hand, all the vendors guarantee that their cloud infrastructure is highly secured and covers all aspects of protection from various malware and vulnerabilities, but the end-users are not convinced about pushing their critical data to the cloud. Security of data and services must be taken into consideration seriously to attain the confidence of customers. There are six sub-criteria (Access Management, Privacy, Integrity, Confidentiality, Incidence Reporting, and Physical Access) under this security criteria.

B. PERFORMANCE

Every cloud has performance issues that mainly stem from overall cloud service accuracy, network latency, delay in

TABLE 1. Decision criteria and their sub-criteria for evaluating CSPs.

S. No.	Criteria	Explanation
1	**Security**	
	Access Management	It ensures that only authentic users can have access to services. The authorized users can access the resources depending on their status of authorization.
	Privacy	The ability of the system to seclude individual information.
	Integrity	Protection of data from being modified by an unauthorized user.
	Confidentiality	Confidentiality assures that the information is shared among authorized users only.
	Incidence Reporting	The CSPs should provide monitoring, notifications for unexpected errors, and incidence reporting tool to their clients.
	Physical Access	Physical access for the cloud is related to the protection of computing resources i.e., hardware, software, networks, and data from a human being or from the act of God that could cause serious destruction to an organization.
2	**Performance**	
	Speed	It refers to the amount of time taken by CSP to respond to a service requested by a user.
	Accuracy	Accuracy criteria is a measure that shows how close the stated value to the actual value is.
	Network Latency	It refers to the delay in communication between users and CSPs.
	Efficiency	An ability to use and produce the cloud computing services by CSPs without wasting time and money
	Resiliency	The ability of a cloud platform to recover from disaster and provide services continuously. The incompetency of cloud platforms to recover within a time frame from a failure reveals its low resiliency.
	Reliability	It is measured as the quality of performing consistently as expected by the client.
	Interoperability	The capability of the cloud service to operate on all platforms/environments.
3	**Migration**	
	Scalability	Ability to increase or decrease the services by the CSPs.
	Elasticity	The ability of CSPs to control an unexpected surge or decline of cloud services as per demand.
	Exit Provision	This criterion refers to the ability of a user to leave the services of CSPs.
	Portability	The capability of the cloud service to migrate to any platform/environment
	Continuity	Ability to manage the technical evolution and to address any business/legal issues that arise during the process of migration.
4	**Availability**	
	Uptime	Time for which the cloud services are available
	Downtime	Time for which the cloud services are unavailable
	Outage Frequency	Temporary suspension of services due to power failure or any other reason
5	**Cost**	
	Storage Cost	It refers to the cost for storage depending on the capacity of data/application
	Processing Cost	Processing cost is the cost to run any cloud service as per need.
	Network Cost	It is the cost charged by the CSPs to maintain hardware and network setup depending on the request from vendors.
	Data Transfer Cost	Cost for moving data within or outside the cloud from/to new technology.
	Possession Cost	It is the cost to acquire the right to use any services of a cloud.
6	**Accountability**	
	Compliance	Compliance means the implementation of the rules, policies, and standards specified in the agreement document.
	Possession	It refers to the rights of the consumer for its belonging.
	Acceptability	It is the quality certification of CSPs to offer the services
	Reputation	It refers to the trustworthiness of the CSPs

application processing. All these factors are the root cause of data loss or delay. Therefore, Cloud providers must offer a tool for performance monitoring that can help in avoiding potential problems. Also, CSPs must have protocols to mitigate the issues that arise in real-time. Performance benchmark must be followed by CSPs to easily identify QoS issues as they arise. There are seven sub-criteria (Speed, Accuracy, Network Latency, Efficiency, Resiliency, Reliability, and Interoperability) under the performance criteria.

C. MIGRATION

Migration refers to the shifting of resources from one technology to another environment. Leading organizations around the world are migrating their applications to the cloud but it is a challenging task, especially with the old applications that do not support cloud environment. Migration of company resources to a cloud environment may result in security challenges, application downtime, slow application, or data accessibility, and sometimes even need extensive troubleshooting to solve the migration issues. Five sub-criteria (Scalability, Elasticity, Exit Provision, Portability, and Continuity) come under this criterion.

D. AVAILABILITY

It is a degree of accessibility of the services delivered by service providers. To achieve a good reputation for availability, the services provider must operate 24×7. The cloud providers must adhere to the timeline of the reply mentioned in the SLA. There are three sub-criteria (Uptime, Downtime, and Outage Frequency) under this criterion.

E. COST

Cost is an important factor that causes the consumer to adopt a particular cloud service. A service consumer always likes to avail the services at a cheaper price. The amount paid by a user to CSPs for using a service is not the total final payment. Some additional costs are to be paid to get services ready to use in a business process. Five sub-criteria (Storage Cost, Processing Cost, Network Cost, Data Transfer Cost, and Possession Cost) come under this criterion.

F. ACCOUNTABILITY

It refers to the responsibility to use and protect the information beyond mere legal requirements. Cloud consumers expect privacy and security of their data from CSPs. Additionally, the data flow is expected to be global and dynamic. It is not only applied to CSPs, both service providers and customers are equally involved in this. If any of the parties is not following the policy rules, it may ruin the company's reputation or may get huge fines. There are four sub-criteria (Compliance, Possession, Acceptability, and Reputation) under this criterion.

III. MCDM METHODS FOR DECISION MAKING

MCDM is a sub-discipline of operations research that is concerned with structuring and solving decision problems.

Various MCDM techniques have been used extensively for solving decision-making problems in numerous fields of science and technology. Most of the MCDM methods require explicit weightage of the alternatives. Using these weights of alternatives, the ranking and sorting for the problems are done. MCDM approach reduces the incidence of biasing for any specific problem. This section highlights few techniques used for evaluating the problems based on decision making.

In Mohammed *et al.* [4] recommended a model based on eight important identified parameters (i.e., cloud certifications, security issues, polic's reliability, SLA, Cloud performance, etc.) for evaluating cloud services. Optimization non-linear technique known as cosine maximization (CM) technique was used to extract priority vectors for selecting cloud services. The current research study was based on the information received using a survey from IT experts and faculty members. Although, the CM method indicates consistency for the pairwise comparison matrix and is more efficient than Euclidean distance and other priority calculating methods. But this method does not support an incomplete and inaccurate pairwise comparison matrix. Technique based on QoS selection can be more helpful and accurate for analyzing cloud services. A. Hussain *et al.* [5] introduced an integrated technique known as Methodology for Optimal Service Selection (MOSS) for CSS. MOSS method enables decision-makers to choose the best cloud service with consensus considering both Quality of Service (QoS) and Quality of Experience (QoE). The best worst method (BWM) is used to obtain weights of two criteria (QoS and QoE). The ranks of various CSPs based on QoS and QoE are evaluated using existing MCDM methods. The final consolidated ranks of CSPs are obtained by Copeland' method.

A Trust entity is considered as a type of cloud service that helps in increasing the transaction rate in a cloud environment. This trust-based mechanism constructs some security strategies to safeguard its users. The stakeholders of the cloud, i.e., customers can trust different cloud suppliers, and similarly, the suppliers can also trust their customers [6]. The trust-based model in this paper is based on some attributes like domain name, trust degree, service type, etc. The reputation of cloud customers is completely based on these attribute' values. The cloud providers completely rely on the parameters like domain name, trust value and generation time, etc. Wrong/fraudulent values of these parameters can give a false reputation for the cloud stack holders and hence cannot be considered as a reliable method for adopting the cloud services in terms of security. Regarding cloud service trustworthiness, Sheikh in 2013, introduced a framework for verifying the security controls and capabilities claimed by the cloud providers. The security controls published by the providers are expressed as trust properties that are validated by some trustable authorities. The proposed hybrid model is a mixture of hard and soft trust. Trust properties are validated through digital certificates to measure the level of hard trust. The former experience and business behavior of the entity are used for assessing the soft trust [7]. The cloud providers

can cheat the system by flooding fake values that result in the wrong reputation and increase the acceptance of unsecured cloud services by their customers. This can be avoided by eliminating such parameters.

M. A. Alsalem *et al.* [8], made a comprehensive review for MADM approaches to assist different applications during COVID-19. Several issues and challenges were analyzed and discussed for multi-attribute, inconsistency, time consumption, unnatural comparison, vagueness, normalization, distance measurement, outranking, trade-off, conflict criteria, the importance of criteria, and data variation. Smarandache [73], presents an alternative approach of AHP called α-Discounting method for MCDM in short α-D MCDM. A set of preferences are transformed into a system of linear/non-linear, homogeneous /non-homogeneous and equality/inequality. AHP works only for preferences that are represented by PCM. On the other hand, α-D MCDM can be applied to any number of preferences [74]. As the name implies discount, this method discounts the coefficient of an inconsistent problem to some percentage so that the problem can be transformed into a consistent problem. Three examples of α-D MCDM method were presented [75] for the solution of non-linear decision-making problems. In [76], the α-D MCDM method was used for intervals as a preference instead of crisp numbers. Two consistent and one inconsistent example were constructed for solving decision-making problems and finally, more complicated results were returned.

In the field of decision making, the popular approach for obtaining a final ranking solution is based on distance. TOPSIS, VIKOR, CODAS, etc., are some of the techniques that use a distance-based approach for evaluating rank. In the case of the TOPSIS technique, it ranks the alternatives with two reference points which sometimes are often insufficient in case of non-linear problems. Additionally, it creates a problem of rank reversals. In [77], Wojciech, proposed a new distance based MCDM method known as the characteristic objects method (COMET). COMET is an intuitionistic approach that uses more reference points and does not require weighting factors. The preferences of each alternative are achieved based on the distance from the nearest characteristic objects and their values are obtained by using the tournament method and the principle of indifference. A fuzzy model is being constructed that yields the preference values of the alternatives, making it a multi-criteria model free of the rank reversal phenomenon [78].

A new variant of the COMET method based on hesitant fuzzy sets (HFS) was proposed by Wojciech [80]. The approach solves the problem of experts to determine unambiguous membership value for attributes. A case study for the selection of electric city buses was presented. HFS COMET is resistant to the phenomenon of rank reversal and produces more reliable decisions by aggregating the uncertain data. For solving uncertainty problems, in [81], the COMET approach was extended using HFS theory. A membership degree is established as a set of values that helps in facilitating a correct decision for uncertain data. Similarly, in [82],

the COMET approach was extended to solve Multi-criteria Group Decision Making (MCDGM) problems in a hesitant fuzzy environment. L-R-type Generalized Fuzzy Numbers (GFNs) were used to get the degree of hesitancy for an alternative under a certain criterion. This method provides decision-making that is resistant to the phenomenon of rank reversal. S. Faizi *et al.* [83], proposed a combined approach of Intuitionistic Fuzzy Sets (IFS) and COMET for solving MCGDM problems. When compared to HFS, the uncertainty can be expressed by IFS more accurately. The Triangular Intuitionistic Fuzzy Numbers (TFINs) can be used to handle uncertain data. The methodology requires an adaption of the matrix of expert judgment (MEJ). The good consistency level of MEJ, produces a good solution for MCDGM problems. The decision from experts may have a margin of error. The degree of membership can be represented in terms of intervals and not in crisp numbers. To solve this problem, the COMET, and Normalized Interval-Valued Triangular Fuzzy Numbers (NIVTFNs) can be combined to generate a precise solution in an uncertain environment [84].

Jean [85] proposed the Stable Preference Ordering Towards Ideal Solution (SPOTIS) method for MCDM based problems. In comparison to COMET, the approach is easy, needs very less information and has low complexity, and is resistant to the phenomenon of rank reversal, as the ranking is recognized based on the MCDM problems matrix score. It is based on the computation of the normalized distance of each alternative with respect to the best solution chosen for each criterion, and their weighted average distance. Nolberto [86], demonstrates a sequential interactive model for urban sustainability (SIMUS) that was based on Linear Programming and is resistant to the phenomenon of rank reversal. The phenomenon of rank reversal was examined by considering a situation of two or more projects that have identical values. This new concept was proved by analyzing the algorithm used to solve the decision-making problem. In [87], AHP and SIMUS methods were discussed that uses subjective weighting for ranking the alternatives. SIMUS relies on the elicitation of experts' opinions in an objective ranking procedure and is based on linear programming (LP). The methods were used to rank renewable energy sources (RESs) projects and were proved to be more effective in facilitating MCDGM in transparent procedures by enabling communities to make use of their initiative.

In case of uncertainty, the level of reliability in MCDM can be increased by reducing the subjectivity and increasing the reality of the obtained results. In [88], Sveta, proposed a fuzzy SIMUS approach that is based on the Fuzzy LP method and the SIMUS method. Without using the weights, the approach yields optimal results. Fuzzy SIMUS uses three stages. In the case of uncertainty, the formation of the parameters of a multi-criteria model is done in the first stage. The Fuzzy LP method is used to form the fuzzy SIMUS model for each objective in its second stage. The final stage is used to rank the alternatives. This methodology was employed in the planning of railway intercity passenger transport in Bulgarian's railway

network. Nine alternative transport plans and eight criteria were studied. Verification of the outcomes was accomplished successfully as the stability of the choice offered a suitable alternative.

Assigning weights to respondents makes the records more comprehensible as closely as possible. In this regard, Ping Zhou [9], presents a reliability model to measure the reliability of cloud services based on hierarchy variable weights and statistical classification. The model efficiently evaluates the reliability of cloud service by hierarchical division of four main characteristics and their sub-characteristic respectively. The research was done in continuation of the earlier work done by P. Zhou *et al.* [10]. In his old research, a quality model for evaluating cloud services was proposed based on six main characteristics. The new research done by the author is based on four main characteristics. Two characteristics: Completeness and Correctness are removed in the new model and few characteristics like Recoverability and Data backup are added. Availability and Continuity are added in place of Stability. Reliability is removed from the main characteristics and added as a sub characteristic in a new model for evaluating cloud reliability more comprehensively. Exclusion and replacement of the characteristics were done based on the evaluation activity which may deviate from reality. In addition, there is no clear weight assigning strategy for CSPs.

L. Coppolino *et al.* [11], states that multiple factors must be taken into consideration by a company for performing technology selection. A methodology based on the fuzzy logic approach is proposed to evaluate cloud offering selection for a group of companies that have a common supply chain. A challenging real case study is presented for the manufacturing domain of agro-based companies. To obtain the consistency of choices, three triangular fuzzy number systems are used by the author. Result obtained for the group of companies and the result found for most companies were not similar as this approach selects the most suitable solution for the entire supply chain without considering the characteristics of individual companies. In R. R. Kumar [12], [13] introduced a hybrid service selection technique by integrating AHP weighting methods with TOPSIS (MCSD method). A complex problem of cloud services selection is defined by using AHP. With the help of AHP, criteria weights are computed by pairwise comparison. Final cloud ranking is obtained using the TOPSIS method for overall performance. In comparison to other MCDM techniques, this hybrid technique is effective in evaluating cloud services by providing an accurate result based on the requirement of users presented only in quantified metrics. There is a need for a technique that could evaluate the cloud services represented by non-quantified metrics.

Before adopting cloud services, a user is always concerned about the trustworthiness of service providers. Measuring the trustworthiness of CSPs is again a key problem. In this regard, Z. Ma [14], introduces six factors (Controllability, cloud service's visibility, level of user's satisfaction, viability of service provider, safety, and reliability of service provider)

that impact the trustworthiness of cloud services. Based on these size factors an attribute model is proposed for the trustworthiness of cloud services. A method based on the Information Entropy and Markov chain was proposed to measure the degree of uncertainty of each factor used in the proposed attribute model and measure the level of trustworthiness of cloud services. To promote the standards of credibility and to increase the level of trustworthiness more factors can be explained and added to the existing trustworthy attribute model. Almost, all cloud services evaluation methods assume that the various selection criteria used for evaluating cloud services are independent of each other. However, these criteria have some interactions with each other that show an impact on the performance of the selection of cloud services. Le Sun [15] proposes a CSSCI framework for the appropriate selection of the best cloud services. Based on various interactions criteria, the non-linear preferences of users were modeled. This technique can be used to select cloud services based on the use's criteria priority order (weights) and the interaction types (interaction indices) between these priority criteria. The non-linear constraint optimization technique is used to evaluate the Shapley significance and to identify the interaction indices of priority criteria. The method is more efficient in comparison to other MCDM service selection methods. The main issue with this technique is that it is validated only for crisp data and does not support the preferences of users and QoS performance for real data. Based on the concept of Neutrosophic AHP, Mohamed Abdel-Baset [16], developed the Neutrosophic MCDM methodology for selecting the best cloud services. Incompatible and ambiguous information that exists during the process of performance analysis, is handled by triangular neutrosophic numbers symbolized by linguistic variables. The newly induced bias matrix when used in a neutrosophic environment reflects an improvement in the consistency rate. This method is novel but needs more involvement of companies for its verification. The method also faces challenges to express complex determinate parts.

IV. VARIOUS MCDM TECHNIQUES USED FOR CSS

Cloud computing is transforming ICT industries by offering infrastructure, platforms, applications as a service on a subscription basis. IBM, Microsoft, Google, and Amazon are the leading enterprises that offer different Cloud services to their customers. The increase of the computing environment in every sector leads to an increase in its adoption of various cloud services. In the few past years, considerably many scholars suggested their idea for assessing the services of CSPs. This section highlights few recent techniques used for evaluating the services offered by cloud providers.

Multiple evaluation criteria are taken into consideration while selecting the optimal CSPs but several decisive factors were neglected. To overcome this problem, Khubaib [62], introduced a hybrid model using FAHP and WASPAS. A hierarchical model with 9 main evaluation factors and 30 secondary evaluation factors was prepared. FAHP is used to perform a Relative weight assessment of these main and

TABLE 2. Advantages and Disadvantages/Limitation of various MCDM techniques.

Technique	Class of Method	Advantage	Disadvantage/ Limitation	References
AHP	Pairwise comparison	A hierarchical structure that uses pairwise comparison to obtain goal, criteria, and alternatives weight.	Cannot handle the impact of cognitive limitations for rational values. Also, interconnections and inner dependencies among decision factors cannot handle by AHP.	[17]
ANP	Pairwise comparison	A network structure that handles interconnections and inner dependencies among the elements of a system.	Too complex to implement and consume more time for decision-makers who participate in the process of a decision of subjective questionnaires.	[18], 19]
BWM	Pairwise comparison	It requires fewer comparison data and produces more reliable results with more consistent comparisons.	Need to add uncertainty to the nominal problem for rational decision-making. A minor inaccuracy in data values will variate the assessment.	[20], [21]
MACBETH	Pairwise comparison	Require only qualitative judgments for criteria (weight) and alternatives scores. Also, useful in solving complex decision-making problems. The method provides a consistency checking for the judgments, and if any inconsistency is found, the method suggests expected variations to make them consistent	May produce an unreliable result for the usage of non-standard scale (standard scale is 0-9).	[22]
TOPSIS	Distance-based	Gives an ideal solution for situations with many conflicting criteria and alternatives. It is a programmable method that provides stable performance results for oscillating data.	It uses Euclidean Distance that does not consider the correlation of attributes. It is difficult to weigh elicitation and maintain the consistency of judgment.	[23]
COMET	Distance-based	It is a non-linear MCDM method that uses reference points instead of weighting factors. Also, the method is resistant to the phenomenon of rank reversal	A classical COMET method may cause a problem for decision experts in determining the unambiguous membership value for attributes.	[79], [80]
VIKOR	Distance-based	It solves decision problems with conflicting and non-commensurable criteria.	The methods require initial weights in advance. Hence, it cannot be applied in a situation when only the names of variables are available.	[24], [25]
CODAS	Distance-based	The overall performance of an alternative is calculated based on Euclidean & Hamming distance from the negative-ideal point.	Requires to subjectively provide weights of Decision-makers and experts.	[26], [27]
TODIM	Distance-based	It is more influential in dealing with the uncertainty and vagueness of subjective assessments produced by the decision-makers	High computation power and expertise is required to implement this approach.	[28]
COPRAS	Utility-based methods	It is an appropriate technique for quantitative multi-criteria evaluation of maximizing and minimizing the number of various variables.	In the data variation case, this method may be less stable when compared with other MCDM methods. With a minor variation of data, the results may vary.	[24]

TABLE 2. *(Continued.)* Advantages and Disadvantages/Limitation of various MCDM techniques.

WSM	Utility-based	Easy to understand and implement even without any knowledge of programming. It also works with a spreadsheet.	In the analysis process, benefit and cost criteria cannot be used together at the same. Before the normalization process, the cost criteria need to be converted into benefit criteria	[29]
WPM	Utility-based	Exclude an element to be measured and use relative values in place of actual values.	A decision matrix with equal weights is not produced. Only two performance values are taken into consideration and therefore normalized scores do not appear to be realistic.	[30]
WASPAS	Utility-based	Having the advantages of both WSM and WPM. Solutions with low values are avoided. Operate on uncertain data too.	Ambiguity and inaccuracy cannot be handled with crisp WASPAS	[31]
MAUT	Utility-based	Based on the measurement of preferences of decision-makers, it measures the preferences of an individual. Uncertainty is taken into consideration.	The methods need massive input data. Need involvement of the decision-maker to provide their preferences.	[32], [33]
ELECTRE	Outranking	Advance competence without affecting the outcome while considering fewer data. Even the unsatisfactory information about data is taken into consideration as this will help to explain the reason for good and bad ranking	Unable to obtain a score for each action. The problem of Intransitivity may also arise in this method.	[34], [35]
PROMETHEE	Outranking	It is an easier method for weighting criteria and ranking decision alternatives. It is an easy sequencing method, and no assumption is required for criteria proportionate.	The method assumes that the criteria are weighted appropriately by the decision-maker. No clear procedure for assigning the weights to criteria.	[36]
ORESTE	Outranking	This approach is used for the problems for which criteria weights and quantitative data are missing.	It can only address those MCDM problems where the estimation values are crisp numbers.	[37]
SAW	Scoring method	Can be implemented by simple easier computer programs. Ability to make decisions intuitively.	Values for all criteria must be positive and maximum. Not always discern the real situation	[38], [39]
Goal Programmin: GP	MODM Priori Method	Capable of producing infinite alternatives. Support concurrent solutions for large-scale problems.	Need extra time and thought for constructing the goal programming model. In the establishment of objective levels and weightings for criteria, the involvement of more decision-makers is required.	[40]

secondary evaluation factors. The rank of the cloud services is evaluated by WASPAS method. The cloud service environment is an uncertain environment that demands methods to handle fuzzy information while selecting an appropriate cloud service. L. Sun [63], presents a novel fuzzy framework for improving the existing techniques for CSS. The uncertain relationships between the database objects for service matching were modeled by building fuzzy ontology.

The system is based on three aspects: The composition of cloud service that matches with user-requested service(s). User preference weights are calculated by the fuzzy AHP method. Fuzzy TOPSIS is employed to judge cloud services based on the performance and weights of the non-functional properties. Considering the objective and subjective attributes for judging a cloud computing provider, Sen Lie [64], proposed a MAGDM based tool that helps client users to select

appropriate cloud providers to fulfill their requirements. The accurate and efficient result for ranking cloud vendors is achieved by considering the objective weights of the attributes and experts' decisions, in addition to the subjective preferences of the experts and their identity differences. The complete procedure involves three steps. In the first preparation stage, collection of decision opinions is done to prepare decision matrices, following the normalization process for these matrices. The second phase involves the aggregation of SV and SAW to determine the attribute weights and determine DM weights by aggregating newly improved TOPSIS and Delphi - AHP. Aggregate the weights of the attributes and preferences of experts by using the LWAA operator. In the final stage, the comprehensive evaluation values are calculated to decide the best computing vendor.

H. Ma *et al.* [65], introduced a time-aware trustworthy approach for CSS. The theory of interval neutrosophic set (INS) is adopted to measure three values: performance cost, potential risk, and level of uncertainty. The cloud service having high-performance cost, low-performance risk, and uncertainty level is considered as the best service. The study supports decision-making in a cloud environment. The SLA between cloud vendors and their clients ensures their commitment for QoS provided among them. It is difficult to evaluate the degree of risk in a virtual environment by the traditional QoS web service approach. In [66] based on cloud theory, Fan Lin proposed a risk assessment method for cloud computing. Risk values and indicators from virtual machines are used to generate five property clouds. According to the weight matrix, these five clouds are integrated into one cloud with the help of cloud backward generator, thus reducing the problem to determine the risk level of a cloud computing environment. A. Jaiswal [67], rank the best cloud services based on QoS using TOPSIS and fuzzy TOPSIS. The weights of multiple criteria yielded by AHP and ANP respectively were given as an input to TOPSIS and fuzzy TOPSIS to decide the best cloud service. Due to the capability of handling unlimited criteria and alternatives [68], Rakesh Ranjan Kumar designed a new model by integrating fuzzy TOPSIS with AHP. Weights obtained by AHP were utilized by the fuzzy TOPSIS technique for calculating the rank order for CSPs. The sensitivity analysis for the results obtained by this new model shows good robustness for its ranking decision and less dependency on criteria weights. To assess the trustworthiness of CSPs, S. Singh *et al.* [69], proposed a CMTE system that makes use of the TOPSIS technique to derive trustworthiness from compliance between CSPs and cloud clients. The system satisfies the cloud user(s) for their QoS requirement by selecting an appropriate CSP from a pool of CSPs.

C. Jatoth *et al.* [70], proposed an integrated MCDM model for assigning multiple ranks to cloud services based on the quantified QoS characteristics using an extended Grey Technique for Order of choice along with AHP. This approach reduces the uncertainty in data and ambiguity in the process of decision-making. Depending on the requirements of

the cloud clients for a cloud service, an integrated MCDM model was proposed by G. Ilieva *et al.* [71] that combines multi-criteria and fuzzy approaches. The study employed two classic MCDM methods (SAW and WASPAS) to obtain weight coefficients. Relative weights, crisp values, and linguistics terms were converted into triangular fuzzy numbers. Then MARCOS is employed to obtain the ranking of CSPs. R. K. Tiwari *et al.* [72] introduced a framework that identifies the best cloud service by using the MCDM method TOPSIS and single-valued neutrosophic sets (SVNS). The framework yields the result by the linguistic rating of cloud services. SVNN (Single-valued neutrosophic number) is an instance of a neutrosophic set that represents uncertain, imprecise, and incomplete real-world information. SVNN handles inaccurate knowledge for the degree of truth, indeterminacy, and falsehood. The newly developed N-TOPSIS method is efficient for the selection of the best cloud service as it is only based on SVNN and not applicable for an interval-valued neutrosophic set. Moreover, SVNN and MCDM methods other than TOPSIS can be combined to improve the consistent result and its efficiency for analyzing the best CSPs.

In [89], Ahmed, used relative preference of various criteria and alternatives to propose an efficient and feasible MCDM approach for CSS. It was an integrated approach that makes use of TOPSIS and BWM methods. Weights of criteria were acquired by the BWM method, which needs less computation as it requires fewer data comparisons and produces reliable results as it does not include second comparison. TOPSIS method uses weights and relative scores to evaluate the rank of CSPs. To prove its effectiveness and reliability against AHP standard method, the integrated approach was tested for use case scenarios by considering nine criteria for the selection of CSPs. Although, the integrated technique was proved an efficient and better approach to rank CSPs; the use of TOPSIS may lead to the problem of rank reversal. Interval-valued intuitionistic fuzzy (IVIF) numbers overcome the weaknesses of conventional crisp numbers by handling uncertain information in real-life applications. The IVIF sets are more acceptable to solve complex problems of decision-making [90]. An integrated framework was provided in [91] to evaluate appropriate CSP. AHP under IVIF environment was integrated to determine weights of criteria. Other MCDM methods like COPRAS, TOPSIS, MULTIMOORA, and VIKOR were integrated under IVIF environment to assess a set of choices that eventually analyze the best alternative with vague information. The use of MCDM under the IVIF environment is successful in dealing with ambiguous information. The framework can be used for solving decision-making complex problems with uncertainty. However, the methodology does not deal with numerous criteria/alternatives and may require complex calculations and lengthy time. There is a need to investigate this methodology for optimization. Changes in the weights of the criteria may also change the result and hence need to observe.

A hybrid methodology of BWM and TOPSIS methods was proposed by Rakesh [92] to rank the cloud services. It was a three-phase approach. In the first phase evaluating criteria and alternatives were determined. The second phase was used to find the weights of these criteria using BWM. The final phase used the TOPSIS method to yield the best rank for the services offered by CSPs. The method was robust and show good consistency against the sensitivity analysis. The drawback of this method was its inability to consider interrelationships among the various decision-making criteria. A trust relationship between cloud consumers and providers revealed the reputation level of CSPs. To evaluate the trustworthiness of CSPs and for the selection of the best CSP, a Context-Aware Multifaceted Trust Framework (CAMTF) was proposed by Alhanahnah [93]. CAMTF makes use of two MCDM methods: AHP was used to compute SLA trust factor while non-SLA trust factor was computed using Fuzzy Simple Additive Weighting (FSAW). It was a versatile system that works under diverse conditions. Few issues like automation of SLAs extraction process were not explored in detail. Also, the system does not discuss the result for the situation of uncertainty.

In the process of pairwise comparison, the classical AHP ca't deal with imprecision and subjectivity. To handle this problem, Sehra *et al.* proposed a Fuzzy Analytic Hierarchy Process (FAHP) which deals with uncertain values given by the decision-makers. FAHP was used to select the best model for estimating the effort for a given problem. The work included the comparison of AHP and Fuzzy AHP, and a case study was presented to select an effort estimation model [94]. Other MCDM methods can also be experimented with the fuzzy approach. A hybrid approach of three fuzzy techniques (Fuzzy ANP, Fuzzy TOPSIS, and Fuzzy ELEC-TRE) was proposed by Subramanian [95] to solve complex decision-making problems involving qualitative and quantitative criteria. Fuzzy set theory handles uncertainty in CSS in an efficient way. The approach involves three phases. Phase one calculates the relative criteria weights using Fuzzy ANP (FANP). In phase two, these weights were used by Fuzzy TOPSIS to produce a weighted normalized matrix that eventually calculates the rank of the alternatives. The final rank of the alternatives were achieved in phase three which apply Fuzzy ELECTRE to the three top-ranked results produced by phase two. A real case study was done to evaluate the proposed approach. Criteria weights were interchanged to perform sensitivity analysis of the proposed model. The successful result of the sensitivity analysis was a proof of the robustness of the proposed approach. This approach produces the rank by considering uncertain values but was only limited to triangular fuzzy values.

More alike Subramanian, an approach based on Fuzzy AHP was discussed by Kumar [96]. Quantitative and qualitative evaluating criteria were identified and PCM was constructed using triangular fuzzy numbers. The criteria were compared, and the final rank was produced and evaluated using a case study. Again, this approach also ranks the alternatives using triangular fuzzy values only. The approach can

be extended for other fuzzy numbers. In [97], an integrated MDCM model was proposed for CSS based on balanced scorecard (BSC), fuzzy delphi method (FDM), and FAHP. Four main criteria were identified as BSC perspectives. FDM was used to identify decision-making factors under each BSC perspective. A decision-making hierarchical model was constructed. FAHP was employed to calculate the weights for decision-making criteria. Comparison between criteria was done by FAHP to yield the ranking result for the CSS problem. This study considers only fourteen decision-making criteria for CSS which is the main limitation for this research work. The numbers of criteria are less and need to consider more criteria for evaluating CSS problems. Additionally, a sensitivity approach must be performed to validate the proposed model. Four parameters were analyzed using AHP for evaluating the rank of the CSPs. The data was provided by a cloud Storage Company called Nasuni. This work was implemented for evaluating five CSPs based on four criteria which was a limitation of this research work [98]. A benchmarking tool was presented by Piotr [99], which analyzed five criteria using the AHP method to support inexperienced users for taking correct decisions while choosing the best solution from five available CSPs. The study was done for a country with limited CSPs and limited criteria. However, smaller companies using few resources like email, ftp may be benefited from this proposed strategy in making decisions in the absence of any experts.

A hybrid MDCM method for CSS was proposed by Al-Faifi [100]. It considers the inter-relationship between the performance criteria. K-means algorithm was used to cluster the CSPs with similar features. The process of clustering various CSPs reduces the number of matrices to be evaluated by DEMATEL and ANP methods Furthermore, one representative is obtained from each cluster using DEMATEL and ANP techniques. ANP method calculates the weights of criteria and finally, the best alternative is obtained. The DEMATEL method requires the inter-relationship between the alternatives, and this can be the limitation of this hybrid model. Also, the selection of CSPs was based on four criteria. More criteria must be taken into consideration for selecting the best CSPs. Two processes (FAHP and PROMETHEE) approach were proposed by Boutkhoum [101]. At first, FAHP was used to structure the criteria and convert the decision of experts to an appropriate value. Secondly, using the precise weights of the alternatives, the PROMETHEE method was used to order the alternatives. Results investigated using sensitivity analysis prove the combined technique as a suitable tool for evaluating CSPs but consider a narrow focus on only five cloud computing solutions.

V. VARIOUS PRIORITIZATION METHODS IN AHP

Analytic Hierarchy Process (AHP) is the oldest and most extensively used technique for decision-making based on the MCDA approach. Based on common characteristics, the decision problems are decomposed into elements. Further, these elements are represented in a hierarchical model with

TABLE 3. Various MCDM techniques used for CSS.

Reference(s)	Technique(s)	Description	Validation
[62]	FAHP-WASPAS	A hybrid MCDM model based on FAHP and WASPAS method that incorporates the uncertainty at various levels. Multiple cloud service models: IaaS, SaaS, and PaaS can adopt this model for decision evaluation.	CS, SA
[63]	Fuzzy ontology FAHP, and Fuzzy TOPSIS	A system (Cloud-FuSeR) that selects the best CSPs based on indeterminate and fuzzy expressions of the users.	EV, CS
[64]	SV, TOPSIS, SAW, Delphi-AHP	A MAGDM methodology that aggregates weights of the experts and objective/subjective attributes for ranking cloud vendors. It is three steps procedure: Step 1: Preparation of decision matrices and normalizing them. Step 2: Aggregating the weights of the attributes and DMs preferences using the LWAA operator. Step 3: Calculate the final evaluation values to identify the best cloud computing provider.	Example
[65]	MCDM using CINS	A time-aware trustworthy CSS approach.	CS
[66]	Cloud Theory	Risk assessment method to choose the best cloud service by adopting cloud theory	EV
[67]	TOPSIS & Fuzzy TOPSIS both with AHP and ANP	Selection of best-ranked cloud service based on QoS	CS
[68]	AHP and Fuzzy TOPSIS	A new robust model for ranking cloud services using AHP and fuzzy TOPSIS technique	EV, SA
[69]	AHP and TOPSIS	Compliance-based system for trust evaluation of CSPs.	CS
[70]	AHP and Grey TOPSIS	Integrated MCDM model for the selection of best cloud services based on QoS characteristics	CS, SA
[71]	SAW, WASPAS, CODAS, MABAC and MARCOS	A fuzzy method (MARCOS) for evaluating the performance of cloud platforms.	Example
[72]	SVNS and TOPSIS	A framework to identify the best cloud service by using TOPSIS and SVNC. Generates the result by the linguistic rating of cloud services. In addition to representing uncertain, imprecise, and incomplete real-world information, SVNN also handles inaccurate knowledge for the degree of truth, indeterminacy, and falsehood.	CS, SA
[89]	TOPSIS and BWM	Weights of criteria were acquired by the BWM method, which needs less computation as it requires fewer comparison data and produces reliable results as it does not include a second comparison. TOPSIS method uses weights and relatives scores to evaluate the rank of the CSPs. The use of TOPSIS may lead to the problem of rank reversal.	CS
[91]	AHP, COPRAS, TOPSIS, MULTIMOORA, and VIKOR in IVIF environment	MCDM methods like AHP, COPRAS, TOPSIS, MULTIMOORA, and VIKOR were integrated under IVIF environment to assess a set of choices that eventually analyze the best alternative with vague information. The methodology does not deal with numerous criteria/alternatives and may require complex calculations and lengthy time.	CS
[92]	BWM and TOPSIS	The result yielded by using an integrated approach of BWM and TOPSIS method was robust and show good consistency against the sensitivity analysis. The drawback of this method was an inability to consider interrelationships among the various decision-making criteria.	CS, SA

TABLE 3. *(Continued.)* **Various MCDM techniques used for CSS.**

[93]	AHP and FSAW	AHP technique was used to compute the SLA trust factor and the non-SLA trust factor was computed using FSAW. Although the system was versatile but still has a few issues like automation of SLAs extraction process were not explored in detail. Also, the system does not discuss the result for the situation of uncertainty.	CS
[95]	Fuzzy ANP, Fuzzy TOPSIS, and Fuzzy ELECTRE	This fuzzy integrated approach involves three phases. Phase one calculates the relative criteria weights using Fuzzy ANP (FANP). In phase two, Fuzzy TOPSIS was used to produce a weighted normalized matrix. The final rank of the alternatives is achieved in phase three which applies Fuzzy ELECTRE to the three top-ranked results produced by phase two. This approach produces the rank by considering uncertain values but was only limited to triangular fuzzy values.	CS
[96]	Fuzzy AHP	Quantitative and qualitative evaluating criteria were identified and PCM was constructed using Triangular fuzzy numbers. The criteria were compared, and the final rank was produced. The approach ranks the alternatives only by using triangular fuzzy values and needs to be extended for other fuzzy numbers.	CS
[97]	BSC, FDM, and FAHP	Four main criteria were identified as BSC perspectives. FDM was used to identify decision-making factors under each BSC perspective. FAHP compare the criteria to yield the ranking result for the CSS problem. This study considers only fourteen decision-making criteria for CSS which is the main limitation for this research work.	CS
[98]	AHP	Based on the AHP technique, five CSPs were evaluated using four criteria. The drawback of this research work is its limitation for using four criteria only. More criteria can be used to rank more CSPs.	EV
[99]	AHP	A benchmarking tool that analyzes five criteria using the AHP method to support inexperienced users for taking correct decisions while choosing the best solution from five available CSPs. The study was done for a country with limited CSPs and limited criteria.	EV
[100]	K-means, DEMATEL, and ANP	K-means algorithm was used to cluster the CSPs with similar features. ANP method evaluates the weights of criteria and finally, the best alternative is obtained. The DEMATEL method requires the inter-relationship between the alternatives, and this can be the limitation of this hybrid model.	EV
[101]	FAHP and PROMETHEE	FAHP convert the decision of experts to an appropriate value. Using the precise weights of the alternatives, the PROMETHEE was used to order the alternatives. Results investigated using sensitivity analysis prove the combined technique as a suitable tool for evaluating CSPs but consider a narrow focus on only five cloud computing solutions.	Example, SA

CS: Case Study; ELECTRE: Elimination and Choice Expressing Reality; EV: Experimental Validation; INS: Interval Neutrosophic Set; SA: Sensitivity Analysis; MAGDM: Multi-attribute group decision-making; SV: Statistical Variance; SVNS: Single-valued neutrosophic set.

different levels. Levels can be further subdivided into sub-levels depending on the requirement. Comparing the elements of a level with a specific element of its upper level, a pair-wise comparison matrix (PCM) is prepared by receiving the rating (scale 1-9) from experts. Generating PCM from the judgments of experts is one of the difficult tasks in the AHP technique. Diagonal elements of PCM are equal to 1. As per Saaty's definition [42], a PCM is said to be consistent if all the elements of a matrix hold

$$a_{ij} = a_{ik}{}^*a_{kj}$$

AHP makes use of priority vector, $\omega = (\omega_1, \omega_2, \omega_3, \ldots, \omega_n)$, derived from the Pairwise Comparison Matrix (PCM). The various methods used for deriving priority vectors from a PCM in AHP are as follows:

A. EIGENVECTOR (EV)
Priority vector ω of a square matrix A is achieved by solving a linear problem as [41]

$$Aw = \lambda w$$

Such that $\omega \sum_{i=1}^{n} \omega_i = 1$ where $\omega_i \geq 0$ and $i = 1, 2, 3, \ldots, n$.

If λ is an eigenvalue for A then the solution obtained will be nonzero always. If A with positive values is perfectly consistent, if and only if $\lambda = n$; otherwise $\lambda > n$ for inconsistency. The consistency ratio value less than 0.1 for a comparison matrix indicates its acceptance for consistency. The procedure to estimate the vector by using the EV method is achieved by consecutive squaring the comparison matrix and each time normalizing the row sums. Stop the procedure once the difference between normalized sums in two consecutive calculations is smaller than a prescribed value. For small deviations of consistent ratios ω_i/ω_j, the EV method produces the desired output priority vector ω, but this method gives unreliable results if the matrix is of a high order.

B. ADDITIVE NORMALIZATION (AN)

It is one of the simplest methods used to obtain the approximate priorities vector. Priority vector w is derived by dividing the elements of each column of matrix A by the sums of columns in the comparison matrix. The resulting vector is obtained by dividing the summation of the elements in each row by the number of elements in the respective given row [42], [43]. The procedure is as follows:

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, \quad where\ i, j = 1, 2, 3, \ldots .n.$$

$$w_i = \frac{\sum_{j=1}^{n} a'_{ij}}{n}, \quad where\ i = 1, 2, 3, \ldots .n.$$

The resultant priority vector w_i obtained by the AN method is approximately like the solution extracted by the EV method.

C. DIRECT LEAST-SQUARES METHOD (DLS)

Priority evaluation problem can be expressed into a constrained non-linear problem and can be solved by DLS method which is based on optimization approach. The main objective of the DLS method is to minimize the Euclidian distance. The formulated non-linear optimization problem has an unlimited solution and hence it disables any random selection of priorities vectors. Also, the DLS method does not preserve rank as well [43], [44].

$$min \sum_{i=1}^{n} \sum_{j=1}^{n} (a_{ij} - w_i/w_j)^2$$

Such that $\sum_{i=1}^{n} w_i = 1$, $w_i > 0$, and $i = 1, 2, 3, \ldots .n.$

D. WEIGHTED LEAST SQUARES (WLS)

It is an optimization method that eliminates the shortcomings of the DLS method [44], by modifying the DLS objective function such that:

$$min \sum_{i=1}^{n} \sum_{j=1}^{n} (w_i - a_{ij}w_i)^2$$

Solving a non-linear optimization problem numerically is quite a tough task. Therefore, the WLS method can be used

to transform the non-linear optimization problem into a linear equation by performing the differentiation of the DLS method equation.

E. LOGARITHMIC LEAST SQUARES METHOD (LLS)

LLS is a variation of the WLS method. Due to its simple method of calculation, the method is extensively used. The LLS method minimizes the objective function andobtained the desired Geometric mean vector, $\omega_i = (\omega_1, \omega_2, \omega_3, \ldots, \omega_n)^T$, as a multiplicative normalizing constraint such tha:

$$min \sum_{i=1}^{n} \sum_{j=1}^{n} (ln\ a_{ij} - \ln\ w_i + \ln\ w_j)^2$$

Such that $\prod_{i=1}^{n} w_i = 1$, $w_i > 0$, and $i = 1, 2, 3, \ldots .n.$

Gordon Crawford in 1985 [45], proved that the formulated optimization problem's solution is unique and can be calculated as the geometric mean of the elements in each row of square matrix A:

$$w_i = \prod_{j=1}^{n} (a_{ij})^{\frac{1}{n}}, \quad i = 1, 2, 3, \ldots .n.$$

F. GOAL PROGRAMMING METHOD (GP)

GP method for producing the priority vector makes use of logarithms of the elements of matrix A [47]. δ_{ij}^{+} and δ_{ij}^{-} are real numbers that are greater than or equal to 1, but both cannot be greater than 1. It means:

$$\delta_{ij}^{+} = \delta_{ij}^{-} = 1$$

The priority vector is obtained by minimizing the linear goal programming problem as follows:

$$log\Theta = minimize \sum_{i=1}^{n} \sum_{j<1}^{n} \left(log\ \delta_{ij}^{+} + log\ \delta_{ij}^{-} \right)$$

such that

$$log\ v_i - log\ v_j + log\ \delta_{ij}^{+} - log\ \delta_{ij}^{-} = log a_{ij}, i,$$
$$j = 1, 2, 3, \ldots \ldots .n., \quad j > i,$$

v is an unnormalized vector that will be normalized to produce priority vector w.

G. LOGARITHMIC GOAL PROGRAMMING (LGP)

Mostly all the AHP methods are used for generating priority vectors from PCM, but the LGP method generates a consensus priority vector so that ratio of w_i and w_j and the value of a^t_{ij} specified by decision-makers are almost the same [48]. p^t_{ij} and q^t_{ij} *are real numbers* which are greater than or equal to 1, but both cannot be greater than 1. Subject to

$$\left(\frac{w_i}{w_j} \right) * \left(\frac{p^t_{ij}}{q^t_{ij}} \right) = a^t_{ij}$$

If $p^t_{ij} = q^t_{ij} = 1$, it means that the value stipulated by decision-makers are consistent otherwise, the values are inconsistent and need a minimization of the product

$$\prod_{i \in I} \prod_{j \in I} p^t_{ij} q^t_{ij}$$

If T is the index set and M = |T| then for the entire set of PCM values, we need minimization of the product

$$\prod_{t \in \mathrm{T}} \prod_{i \in \mathrm{I}} \prod_{j \in \mathrm{I}} p^t{}_{ij} q^t{}_{ij}$$

The linear goal programming problem will be solved as follows:

$$log\Theta = minimize \, (1/M) \sum_t lg\Theta^t,$$

such that

$$log \, v_i - log \, v_j + log \, p^t{}_{ij} - log \, q^t{}_{ij}$$
$$= log \, a^t{}_{ij}, i,j = 1, 2, 3, \ldots \ldots .n., t \epsilon T,$$

v is an unnormalized vector that will be normalized to produce normalized consensus priority vector *w*.

H. FUZZY PREFERENCE PROGRAMMING (FPP)

Mikhailov [50], [51] developed an FPP method to generate crisp priorities from inconsistent interval or fuzzy comparison judgments rather than the numerical values. FPP transformed the prioritization problem into a linear problem.

If interval judgments $a_{ij} = (l_{ij}, u_{ij})$ are consistent then component ratios of the priority vectors will satisfy the inequalities:

$$l_{ij} \leq \frac{w_i}{w_j} \leq u_{ij}, \quad \text{where } l_{ij} \text{ and } u_{ij} \text{ are the intervals,}$$
$$i = 1, 2, 3, \ldots \ldots .n-1, \quad j = 1, 2, 3, \ldots .n, j > i$$

Then

$a_{ij}w_j$ - $w_i = 0$ and can be represented as a linear equation $m = \frac{n(n-1)}{2}$ and matrix form as R*w* = 0

And if interval judgments $a_{ij} = (l_{ij}, u_{ij})$ are inconsistent, it means that the interval judgments are not satisfied by any of the priority vectors. In this scenario, we need to find a priority vector that can approximately satisfy all the interval judgments. Matrix form must be satisfied as

$$\mathrm{R}w \approx 0$$

The method generates a priority vector and transform the prioritization problem into a linear program by using FPP. max μ (μ is the measure of intersection that is also a Consistency index-CI)

such that

$$\mu d_j^+ + R_j w \leq d_j^+,$$
$$\mu d_j^- - R_j w \leq d_j^-, \quad j = 1, 2, 3, \ldots .m, \ 1 \geq \mu \geq 0;$$
$$\sum_{i=1}^n w_i = 1, w_i > 0, \quad i = 1, 2, 3, \ldots .n.$$

d_j^- and d_j^+ are tolerance parameters whose values can be set equal for practical implementation of FPP.

I. SINGLE VALUE DECOMPOSITION (SVD)

SVD is an approach used for deriving associated weight vectors in an easy way in AHP. The weight vector associated with the largest singular value of a PCM produces weights

up to acceptable values [53]. The SVD of matrix A can be represented by:

$$\mathrm{A} = \mathrm{UDV^T},$$

where A is a (m x n) matrix, D is a diagonal (k x k) matrix having positive diagonal elements as $\alpha_1, \alpha_2, \ldots \ldots \alpha_k$, U and V are the matrix whose columns are orthonormal. SVD of matrix A in terms of dyads can be written as:

$$\mathrm{A} = \sum_{i=1}^k \alpha_i u_i v_i{}^T,$$

Diagonal elements of the diagonal matrix D are known as singular values, u and v are left and right singular vectors that form the orthonormal basis for columns and rows of matrix A in (m x n) dimensional spaces.

Frobenius norm of a matrix is

$$||A||^2{}_{\mathrm{F}} = \sqrt{\left(\sum_{i=1}^n \sum_{j=1}^n a^2{}_{ij}\right)}$$

$\mathrm{A}_{[\mathrm{K}*]} = \sum_{i=1}^{k*} \alpha_i u_i v_i{}^T$, is a (m x n) matrix with rank k*. It is formed by the largest k* singular value of a matrix A and its corresponding singular weight vector. $\mathrm{A}_{[\mathrm{K}*]}$ is the rank k* least-squares approximation of A that minimizes the Frobenius norm to
$||A - X||^2_{\mathrm{F}} = \sum_{i=1}^n \sum_{j=1}^n (a_{ij} - x_{ij})^2$ for all matrices X of the rank k∗ or less.

J. INTERVAL PRIORITY (IP)

Due to the uncertainty of judgments from DM, the weights of priority should be obtained as an interval. In 2004 [55], derive the estimated weight interval of priorities from PCM. The degree of inconsistency in data is the summation of the width of the obtained interval priorities.

The interval weights W_i is obtained from PCM a_{ij} based on the following conditions:

First, the PCM a_{ij} must be present in the expected interval comparison W_{ij}. It means:

$$a_{ij} \in W_{ij} \leftrightarrow \frac{\underline{w_i}}{\overline{w_j}} \leq a_{ij} \leq \frac{\overline{w_i}}{\underline{w_j}}, \quad \text{Where } \overline{w}_i, \overline{w}_j \text{ and } \underline{w}_i, \underline{w}_j$$

are upper and lower bound of W_i and W_j respectively.

Second, interval weights W_i will be normalized only if

$$\sum_i \overline{w}_i - \max_j \left(\overline{w}_j - \underline{w}_j\right) \geq 1,$$
$$\sum_i \underline{w}_i - \max_j \left(\overline{w}_j - \underline{w}_j\right) \leq 1$$

Third, the objective function to narrow the estimated interval weights W_{ij} is as follows:

$$\min_{\overline{w}_i, \underline{w}_i} \sum_i \left(\overline{w}_i - \underline{w}_i\right)$$

K. LINEAR PROGRAMMING METHOD (LP)

Bala in 2005 [56], developed an approach for producing priority vector. The approach is composed of two stages. A Linear program to establish a consistency bound for a given PCM is formulated in stage one. Further, in the second phase, the established consistency bound is used in Linear Program to yield an optimal priority vector.

Establishing the consistency bound for a given PCM is formulated as:

Minimize $\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} z_{ij}$

Such that $x_i - x_j - y_{ij} = \ln a_{ij}$,

$\quad i,j = 1, 2, 3, \ldots \ldots n.$ and $i \neq j$

$\quad z_{ij} \geq y_{ij}, \quad i,j = 1, 2, 3, \ldots \ldots n.$ and $i < j$

$\quad z_{ij} \geq y_{ji}, \quad i,j = 1, 2, 3, \ldots \ldots n.$ and $i < j$

Here $x_i = \ln(w_i), y_{ij} = \ln(\varepsilon_{ij}), z_{ij} = |y_{ij}|$. ε_{ij} is the error that occurs in the estimation of a_{ij}.

CI can be evaluated as:

$$CI_{LP} = 2z*/n(n-1),$$

CI_{LP} is the average value of the decision variable z_{ij} for the elements in the above diagonal of the matrix. The first stage linear program produces a set of all priorities, and it may be possible that multiple solutions exist in this first stage. Therefore, to generate the optimal priority vector using Linear Program, a further minimization of the maximum of errors will be done as follows:

Minimize $z_{\max}$

Such that

$$\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} z_{ij} = z^*,$$

$x_i - x_j - y_{ij} = \ln a_{ij}$,

$i,j = 1, 2, 3, \ldots \ldots n.$ and $i \neq j$

$z_{ij} \geq y_{ij}, \quad i,j = 1, 2, 3, \ldots \ldots n.$ and $i < j$

$z_{ij} \geq y_{ji}, \quad i,j = 1, 2, 3, \ldots \ldots n.$ and $i < j$

$z_{\max} \geq z_{ij}, \quad i,j = 1, 2, 3, \ldots \ldots n. and i < j$

z_{max} is the maximum errors value.

L. CORRELATION COEFFICIENT MAXIMIZATION (CCM)

Saaty's definition [42], [58], conclude that a PCM will be perfectly consistent if all the elements of a matrix hold

$$A = a_{ij} = a_{ik} * a_{kj}$$

CCM approach for the estimation of priorities from a PCM was proposed by Ying-Ming [57]. The priorities which are highly correlated to each column of a PCM are not consistent and can be concluded in other ways. As the names imply, this approach maximizes the correlation coefficient between priorities and each column of a PCM as follows:

Max $R = \sum_{j=1}^{n} R_j$

$$= \sum_{j=1}^{n} \sum_{i=1}^{n} \frac{\sqrt{a_{ij} - \bar{a}_j}}{\sqrt{\sum_{k=1}^{n} (a_{kj} - \bar{a}_j)^2}}$$

$$\times \frac{w_i - \bar{w}}{\sqrt{\sum_{k=1}^{n} (w_k - \bar{w})^2}}$$

If

$b_{ij} = \dfrac{a_{ij} - \bar{a}_j}{\sqrt{\sum_{k=1}^{n} (a_{kj} - \bar{a}_j)^2}}, \quad$ where $\bar{a}_j = \dfrac{1}{n} \sum_{i=1}^{n} a_{ij}$,

$i,j = 1, 2, 3, \ldots \ldots n$ and

$\hat{w}_i = \dfrac{w_i - \bar{w}}{\sqrt{\sum_{k=1}^{n} (w_k - \bar{w})^2}}, \quad$ where $\bar{w} = \dfrac{1}{n} \sum_{i=1}^{n} w_i = \dfrac{1}{n}$

CCM method can estimate the priorities for a consistent matrix A as follows:

Max R $= \sum_{j=1}^{n} \sum_{i=1}^{n} b_{ij} \hat{w}_i = \sum_{i=1}^{n} (\sum_{j=1}^{n} b_{ij}) \hat{w}_i$;

such that $\sum_{i=1}^{n} \hat{w}_i^2 = 1, \quad \sum_{i=1}^{n} \hat{w}_i = 0$

Transformed weights $\hat{w}*_i = \dfrac{\sum_{j=1}^{n} b_{ij}}{\sqrt{\sum_{i=1}^{n} (\sum_{j=1}^{n} b_{ij})^2}}$,

$i = 1, 2, 3, \ldots \ldots n$

Maximized sum of correlation coefficient

$$R* = \sqrt{\sum_{i=1}^{n} \left(\sum_{j=1}^{n} b_{ij}\right)^2}$$

Weight assignment coefficient

$$\beta* = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} (a_{ij} - 1)(\hat{w}*_i - a_{ij}\hat{w}*_j)}{n \sum_{i=1}^{n} \sum_{j=1}^{n} (\hat{w}*_i - a_{ij}\hat{w}*_j)^2}$$

FinalPriorities $w*_i = \dfrac{1}{n} + \beta\hat{w}*_i$,

$i = 1, 2, 3, \ldots \ldots n.$

M. COSINE MAXIMATION (CM)

Gang, in 2014 [59], proposed a cosine maximization (CM) method which increases the cosine similarity measure (CSM) or the sum of the cosine of an angle between priority vector and each column vector of a consistency matrix to derive a reliable priority vector.

In 2019, Mohammed [4] has implemented the CM method to extract priority vectors for evaluating cloud services. The model was based on eight important identified parameters related to cloud certifications, security issues, policies, reliability, performance, etc. The PCM derived from

$$\text{Maximize C} = \omega \frac{\sum_{j=1}^{n} \sum_{i=1}^{n} (_i a_{ij})}{\sqrt{\sum_{k=1}^{n} \omega^2_k} \sqrt{\sum_{k=1}^{n} a_{kj}^2}}$$

Suck that priority vector condition

$$\begin{cases} \sum_{i=1}^{n} \omega_i = 1, \\ \omega_i \geq 0, \quad i = 1, 2, 3, \ldots n \end{cases}$$

TABLE 4. Prioritization methods in AHP.

Prioritization Method	Advantage	Disadvantage/ Limitation	Reference(s)
EV	For small deviation of consistency, ratios give desired priority vector.	Give unreliable output for the matrix having a high inconsistency level.	[41]
AN	An extremely simple method for deriving priority vector.	Not acceptable for scientific calculation.	[42], [43]
DLS	Minimize the Euclidian distance between the actual and solution matrix	Generate multiple solutions and does not preserve the rank	[43], [44]
WLS	Conceptually easier than the Eigenvector method and eliminates the shortcomings of the DLS method	Useful to use when weight estimates for each data point are known. Avoid using it with heterogeneous data.	[44]
LLS	Less computational time and easy to understand	Does not work perfectly if the decision matrix is inconsistent	[45], [46]
GP	Minimize the deviation variable and fulfill multiple goals	The problem becomes complex if the values of matrix A are inconsistent.	[48]
LGP	PCM does not need to be reciprocal. Statistical assumptions are not required.	Collecting data from surveys for calculating the higher-order terms is a challenging task for producing a non-linear utility function	[48], [49]
FPP	The method eliminates the shortcoming of the existing prioritization methods for the interval pairwise comparison matrix.	FPP may produce multiple conflict priority vectors for a fuzzy PCM that lead to different conclusions.	[51], [52]
SVD	Frobenius norm in SVD provides direct analytical relation between the consistency measurement and weight vector. Time saving and more justified outcomes.	The Jacobian matrix needs to be modified if there is any joint failure.	[53], [54]
IP	This is an effective and simple calculation approach for the data having uncertainty.	Row dominance relations are missing.	[55]
LP	An easy and straightforward approach with less computational time. The output of LP is easily interpretable by the user. LP can handle both single and inter-bounds values.	Difficult to express constraints and objective functions for nonlinear problems. Parameters assumed in LP are constant.	[56]
CM	Statistical assumptions are not required. Computation and interpretation of CCI are easy in the AHP environment.	Consistency value for incomplete and imprecise matrix cannot be determined.	[59]

Optimal objective function value C^* is calculated as:

$$C^* = \sqrt{\sum_{i=1}^{n}\left(\sum_{j=1}^{n} b_{ij}\right)^2}$$

In the process of decision-making, improper consistency may lead to inconsistent results. A consistency improvement method is a major approach that eventually increases the ranking reputation for a given priority method. The accuracy and reliability of ranking evaluation can be achieved if PCM in AHP is consistent. Adjustment to the comparison matrix is done to yield a revised matrix until and unless it does not achieve the value of CR < 0.1. Multiple approaches are described by researchers for improving the consistency of a PCM in the AHP method. In 2016, Gaurav [60], describes an efficient CMM method to identify the priority vector in AHP. Free from statistical modeling, the CMM method modifies the entries of the PCM until the Cosine Consistency Index (CCI) value is not achieved up to 0.90. The method is an extension of CM developed by Gang [41], WAM or WGM form is used to modify the matrix to yield a better consistency rating of ≈ 0.90. Both WAM and WGM form uses almost same average number of iterations to achieve a CCI value ≥ 0.90. NSGA II and SPEA2 are two evolutionary algorithms [61] that jointly can be used to improve the consistency index. NSGA II is a variant of the Genetic Algorithm used to perform non-dominated sorting for parent and child populations. Best non-dominated solutions are maintained in fronts. The last front is used to produce solutions based on the strategy of crowded distance. The non-dominated solutions from past generations are stored in an external archive
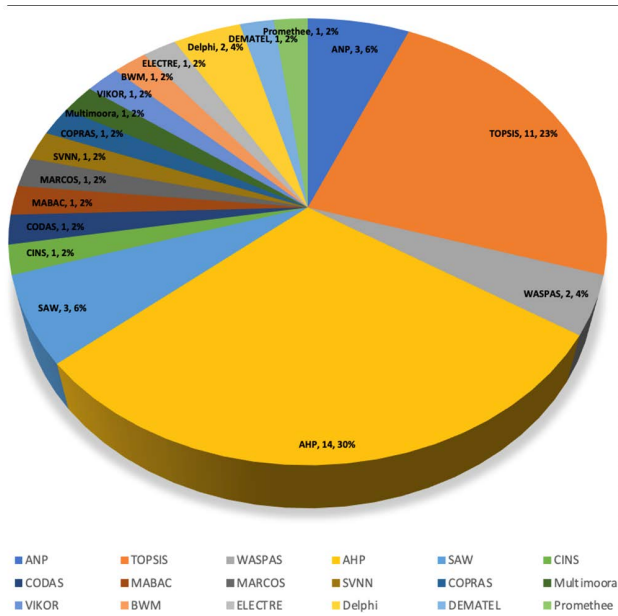
FIGURE 2. Choice of MCDM methods for CSS by various researchers.

TABLE 5. Choice of MCDM methods for CSS by various researchers.

MCDM Methods	Count of choices by researchers
ANP	3
TOPSIS	11
WASPAS	2
AHP	14
SAW	3
CODAS	1
MABAC	1
MARCOS	1
SVNN	1
COPRAS	1
CINS	1
MULTIMOORA	1
VIKOR	1
BWM	1
ELECTRE	1
DELPHI	2
DEMATEL	1
PROMETHEE	1

maintained by SPEA2. After each generation, the archive gets updated and SPEA2 computes a strength value for each solution.

VI. RESULTS

The decision for the selection of cloud service is a challenging issue. In the literature review, various methods based on MCDM approach are discussed for the problems of CSS. This work analyzed various contributions of the researchers. 22 articles on cloud selection using MCDM methods are reviewed, and it is concluded that majority of the researchers consider AHP as the best technique for CSS. The choice of selection of various MCDM techniques for CSS is shown in Table 5 and graphically in Figure 2.

VII. CONCLUSION AND FUTURE WORK

The need for best decision-making has increased in CSS during the last few years. Before offering the solutions to any problem, the proper diagnosis and the level of its accuracy is very crucial. Decision yielded with in the given timeframe ascertains its accuracy. Business Analysts intensively use mathematical-based statistical models, data-orientated methods such as data mining, machine learning methods, and MCDM methods for decision-making. This research work presents various MCDM techniques that are used for ranking a set of alternatives. AHP is the oldest and most extensively used technique for decision-making based on MCDM approach. Various methods used for deriving priority vectors from a PCM in AHP are discussed along with their advantages and limitations. Furthermore, the strengths and weaknesses of various MDCM techniques are discussed to help the researchers about the current trends in the field of decision making. Although this paper presents most of the recently used MCDM techniques, there is a lack of acceptance among researchers from their perspective of understanding for these MCDM methods. It is open for a researcher to choose any MCDM method depending on one's interest. Future work may focus on providing common trends and consistent priority improvement methods in AHP for CSS.

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