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Evaluating and Ranking Cloud-Based E-Learning Critical Success Factors (CSFs) Using Combinatorial Approach

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ABSTRACT Cloud computing has been regarded as one of the significant Information Technology (IT) tools. Many sectors are adopting cloud computing services for its business support. It has also become a new IT paradigm that has transformed the E-Learning system to become more user-friendly. As a result, the E-Learning usage is growing rapidly and being preferred over the conventional teaching-learning process in a big way. This revolutionary change is attributed to the advancement in digital technology. The transformation in digital technology has made the teaching-learning process flexible, easy and convenient for effective knowledge transfer. The cloud-based E-Learning process depends upon many factors of different dimensions that are of significant importance for cloud-based-E-Learning success. Hence they must be studied to successfully analyze their level of importance and fulfill Cloud-based E-Learning positive effectiveness. The current research provides a detailed literature review for cloud-based E-Learning Critical Success Factors (CSFs) of teaching–learning process. Further, the research employs the combinatorial approach to evaluate the diversified dimensions and CSFs of cloud-based E-Learning that helps in quantifying and comparing the influence of various dimensions and CSFs of cloud-based-E-Learning. Four dimensions and fourteen factors have been identified through in-depth literature review and later on evaluated for the prioritization using a combinatorial approach. The influence of such dimensions and factors will help various stakeholders to plan their strategy and resources for the betterment of knowledge transfer through cloud-based-E-Learning.

INDEX TERMS Analytic hierarchy process (AHP), cloud-based E-learning, combinatorial approach, critical success factors (CSFs), Fuzzy AHP, cloud-based E-learning, group decision making (GDM).

I. INTRODUCTION

Cloud computing has witnessed rapid growth and influenced the human lifestyle tremendously through IT. Many organizations are adopting cloud computing particularly to overcome the current economic crisis. Cloud computing can provide different IT services including data-center service without investing huge money in a physical data center. We can get all these services at a cost-effective cheaper price, which makes great competitive advantage by reducing operational expenditure [1].

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Cloud computing can be referred to as ''a model for permitting global and suitable access of IT resources such as servers, storage, services, networks resources and applications that can be rapidly provided with nominal interaction of the service provider and the management [2]''. Due to cloud computing many new ways of business are started without the initial capital investment into infrastructure [2]. The impact of IT has been witnessed largely in various areas of human interactions like social, administration, and business. E-Learning has been significantly included in the business domain as well as in personal teaching-learning. The processed learning relates the consumption of different IT web-based tools that are distributed and are being used on the world wide web for educational purposes [3]. E-Learning considered a prominent technique to teach via electronic information contexts that boost the teaching-learning quality [4]. E-Learning may use internet technology with IT infrastructure to support and control teaching and learning with more efficiency and flexibility [5]. Cloud-based E-Learning has been used in educational institutions widely [6]. Moreover, cloud E-Learning application has also been used in predicting usability factors [7]. Cloud-based E-Learning may be employed in modeling educational usage as a cloud-based tool in virtual learning environments [8].

Over time, the term E-Learning has become exceptionally common and popular as a widely accepted tool for teaching and learning process. Numerous advantages are being offered by E-Learning, hence it is rapidly becoming indispensable as a teaching-learning educational tool. E-Learning has also turned out to be an increasingly important and widespread method for education and knowledge transfer mode. E-learning provides easy and cost-effective sharing of resources due to the flexible usage of Internet. It also helps to monitor the progress of each student and motivate them by combining family life and new learning [9]. E-Learning is providing numerous benefits to the educational sector [10]. It also provides easy access to new information as well as freedom from the constraints of place and time. It accommodates the need for an increased number of students with potential interactivity and flexibility in exchanging written documents/assignments. It also provides cutting-edge communication skills in technical learning education and information culture [11].

Various E-Learning programs provide effective browsing tools to access the available resources on the web. Such modern resources provide easy accessibility and thus preferred over distance education methodology. The revolution in IT and the continuous evolution of hardware and software makes the E-Learning task more attractive, simplified and developed in recent years. Many merits of E-Learning can be obtained if it is implemented in the system successfully. Many critical success factors (CSFs) influence the cloud-based E-Learning process tremendously. Thus, it is imperative to study such CSFs so that effective implementations of cloud-based-Learning may bring more advantages of E-Learning in a real sense.

As discussed above, the present research may help in realizing the following objectives:

- To offer a detailed review of literature on CSFs of cloud-based E-Learning.
- To evaluate and prioritize the CSFs of cloud-based E-Learning using a combinatorial approach.

The paper is structured as follows: section II documents a detailed review of literature, while section III provides the role of CSFs of cloud-based E-Learning. Section IV deals with a framework for CSFs of cloud-based E-Learning. Section V presents a combinatorial approach of AHP–GDM and FAHP methodology, while Section VI provides case illustration using AHP–GDM and FAHP Methodology in the cloud-based E-Learning. Section VII deals with results and discussions on prioritization of CSFs of cloud-based E-Learning. Section VIII represents some limitations of this work and finally, the paper ends with section IX giving conclusions.

II. RELATED WORK

Apart from revisiting cloud-based CSFs for E-Learning identification, review of the literature on various modelings is also carried out and documented here. Many researchers have applied a Multi-Criteria Decision Making (MCDM) based research methodologies in E-Learning. Matsatsinis *et al.* [12] proposed a multi-criteria model using linear programming for E-Learning systems and compared effective factors for an online learning system that evaluates a satisfaction index along with criteria weights. Matsatsinis and Fortsas [13], applied principles of multi-objective linear programming and Multi-Criteria Decision Analysis (MCDA) to analyze and calculate the degree of difficulty for distance and online education trainee's questions. Lo *et al.* [14], applied Fuzzy AHP to evaluate significant factors for executing a successful personalized E-Learning system. They have also discussed how the proposed hierarchical framework allows organizations to evaluate important factors which are influencing the E-Learning system in the phase of implementation with its detailed structural view. Cobo *et al.* [15], provided a new approach to multi-criteria to examine and categorize the interactivity levels of learners in learning management. This research shows that the collective use of data mining and MCDM approach comprising AHP, to provide and identify appropriate behavioral patterns of the users of the learning management system (LMS).

Literature review on AHP and FAHP based research methodology have also been carried out. Many researchers have applied AHP and FAHP based research methodology, while others have used a combined approach with AHP in E-Learning.

Bhuasiri *et al.* [16], studied the E-Learning system in developing countries for responsible success-factors. Then, they integrated the Delphi method with AHP to match the importance of factors among a different group of stakeholders including staff members and ICT experts. Finally, they have prioritized and classified CSFs by their level of importance.

Kang *et al.* [17], analyzed and assessed the E-Learning system using the hierarchy concept of AHP. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) has been used to rank criteria. It has been seen that a combination of AHP-TOPSIS can be useful in real life.

Tzeng *et al.* [18], proposed a new integrated MCDM methodology, wherein DEMATEL based methodology was employed in realizing the independent and dependent associations of the E-Learning courses. The fuzzy-based AHP techniques are used with the subjective perception of the E-Learning environment. The experiment results ensure that the suggested model is very significant. The model is skillful in assessing the success of E-Learning programs.

Qin and Zhang [19], obtained three different aspects which affect the training of the stakeholders of online learning consisting of various aspects of organizational and personal characteristics and training. Then, AHP methodology is employed to ascertain the key factors that affect E-Learning training.

Yang and Chen [20], used AHP in E-Learning teaching and learning. This study also analyzes the ability of students in self-learning. AHP method is also used to evaluate expert criteria for developing the influence factors, using a pairwise comparison from the present factors.

Hang *et al.* [21], explored Chinese attitudes with E-Learning implementation based on innovation adoption perspective. After the study, they analyzed 33 criteria for successful adoption behavior of E-Learning. Later on, AHP was used to make hierarchical structural model and evaluation of the important factors which are influencing the adoption intention of E-Learning.

Sharma *et al.* [22], applied AHP to design content for enhancing and improving E-Learning course and computing facilities and also considered social clusters that included researchers, academicians, students' community, alumni employees and staff from the industry.

Gupta *et al.* [23], implemented the AHP model to determine the quality of E-Learning systems. This model is used to weigh and grade (rank) E-Learning quality requirements that were essential to be observed by stakeholders such as learners, educators, institutional management and accreditation bodies. The result derived from the study could benefit the educational system in general.

Jeong and Yeo [24], applied AHP to classify and compute the criteria for the use of E-Learning contents based on multimedia and derived a model for quality. Researchers used a total of nine criteria that were identified from previous research studies.

Kassim *et al.* [25], found different risk and trust-based factors for cloud-based E-Learning from prior studies. They implemented AHP to find the most significant user trust factors.

Based on the above review of literature, it has been seen that AHP and FAHP based research methodologies are widely applied in assessing various aspects of E-Learning. Thus the present new combinatorial approach of AHP-GDM and FAHP will also contribute immensely to the body of literature.

III. ROLE OF CSFS IN CLOUD-BASED E-LEARNING

The key factors are known as CSFs, a phrase that is simply stated as "factors" that remain "critical" towards the "success" of the organization [26], [27]. CSFs was coined in 1978 by John F. Rockart [28] of MIT Sloan School of Management. Subsequently, this concept is widely used by business and data analysis organizations for the smooth implementation of their plans and projects. Rockart defined CSFs as "the limited number of areas in which results, will ensure successful competitive performance for the organization if they are satisfactory" and stressed that the regions of movement "should receive constant and careful attention from management" [29], [30]. CSFs have been used considerably to find existing key factors of critical areas having good performance, which will decide the organizational success. A major focus should be given to such factors to obtain success. Despite the significant importance of CSFs for success in organizational accomplishments, limited research has been done in the area of CSFs for confirming the effective application [31] for E-Learning in higher educational institutes, and scope of the CSFs that will evaluate the success of such educational systems.

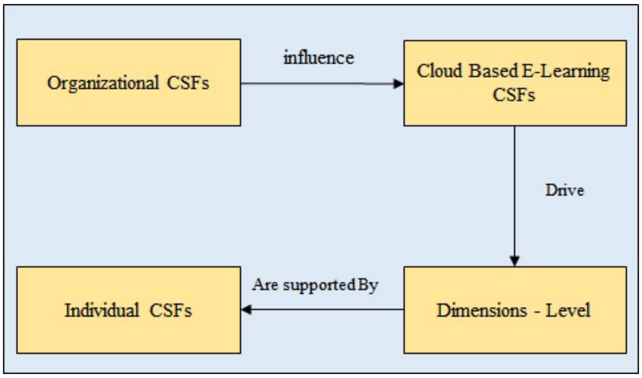

FIGURE 1. Hierarchy in cloud-based E-learning CSFs.

The successful teaching-learning process in E-Learning depends upon several factors. These factors have an impact on the teaching-learning process in an immense way. Many researchers have identified influential factors for E-Learning process. The CSFs are used for strategic planning and regarded as a framework to direct all the concerned stakeholders in defining and determining those elements that are important in the successful achievement of objectives and goals [32], [33]. They considered CSFs as variables that remain essential for the achievement in the execution phase, besides an institute or organization essentially holds CSFs properly and thrives on them to have a successful execution. Consequently, from the above statements and explanation, CSFs are considered to be the most effective variables and features that must be carefully handled during the planning phase to confirm a vigorous and forceful implementation of the whole scheme. Hence, CSFs requisite is measurable, manageable and verifiable so that its accomplishment helps the entire system. Thus, CSFs must be critically handled for any organization to be successful as shown in Figure 1.

IV. FRAMEWORK FOR CSFs OF CLOUD-BASED E-LEARNING

Diverse literature on cloud-based E-Learning has been reviewed thoroughly. Many researchers have shown important findings in this area [34]. Many researchers in their attempts to study CSFs and their effect on cloud-based E-Learning has classified them into several dimensions such as cloud Service Resilience, Institutions' Technological Maturity, Institutions' Organizational Readiness and cloud-based E-Learning Imperatives.

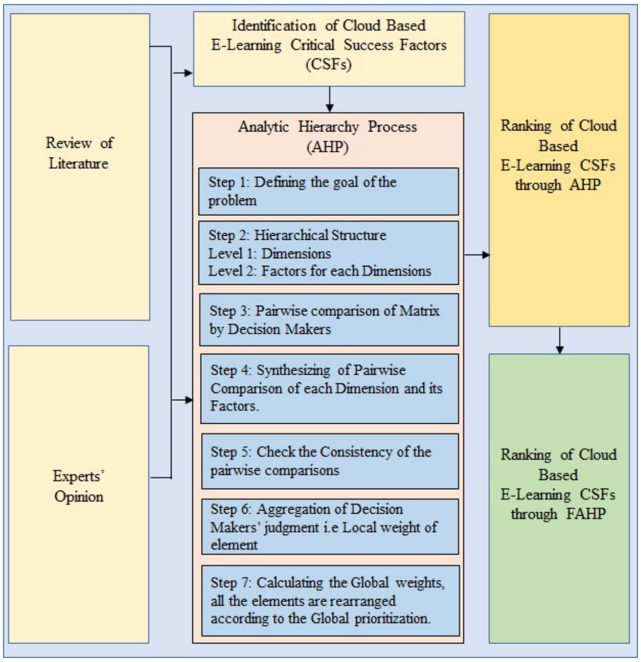

FIGURE 2. Framework for AHP-GDM and FAHP based prioritization of cloud-based e-learning CSFs.

The following steps are used to identify the CSFs impacting cloud-based E-Learning:

- An in-depth analysis of literature on cloud-based E-Learning CSFs.
- Identification of frequently used CSFs for cloud-based E-Learning.

Using the above mentioned methods, a framework for the selection of CSFs has been devised and depicted in Figure 2. Later on, a combinatorial approach like AHP-GDM and FAHP has been applied to CSFs of cloud-based E-Learning to establish its weight and subsequent prioritization. Based on the in-depth literature review of cloud-based E-Learning, 6 dimensions and 18 CSFs have been identified. Finally, 4 dimensions and 14 CSFs were selected after removing the repetition of the dimension and CSFs. The selected dimensions and CSFs have been discussed further and depicted in table 1.

A. CLOUD SERVICE RESILIENCE DIMENSION

The complete environment security is an important responsibility of cloud service providers and producers. A flaw in such a security system may lead to dissatisfaction with stakeholders. Further, accessibility and reliability of E-Learning services are of significant interest to stakeholders hence, must be addressed properly. Service providers may also enter into a customized service-level agreement to take care of the varying student size in a particular course from various universities. Cloud Service Resilience Dimension affects the cloud-based E-Learning system which is influenced by the cloud data security, availability and reliability, customizable service level agreement and cloud Services (SaaS, PaaS, IaaS).

B. INSTITUTIONS' TECHNOLOGICAL MATURITY DIMENSION

Cloud-based E-Learning institutions should try an optimal level of network bandwidth to take advantage of the facility. In addition, cloud systems must be compatible with E-Learning applications. The dimension also includes powerful technical support for all stakeholders [34]. CSFs like Network Bandwidth, Technological Compatibility and Technical Support provide Institutions' Technological Maturity Dimension.

C. INSTITUTIONS' ORGANIZATIONAL READINESS DIMENSION

Cloud-based E-Learning or any other big IS adoption and requires higher management approval and support. It is also important that students, instructors along with the technical staff are trained and prepared to use cloud computing and IT technologies along with E-Learning computing resources [34]. The complexity in the prevailing institutional systems should be simplified. Many researchers considered various important Institutions' Organizational Readiness Dimension as vital. It includes factors like Management Support, Human and Resource Readiness and Utilization Complexity.

D. CLOUD-BASED E-LEARNING IMPERATIVES DIMENSION

In order to close the ecological cycle of cloud-based E-Learning, this dimension is very essential. Many institutions find it difficult to continue cloud-based E-Learning because of the limited cost flexibility hence must be resolved in the real sense. Further, the institution must take care of the system to keep it simple for any complicated task. It is also imperative to have some enhanced benefits in encompassing cloud-based E-Learning systems. Various factors like Cost Flexibility, Ease of Use, Relative Advantage and Design of Innovative Services constitute the cloud-based Learning Imperatives Dimension.

V. A BRIEF OVERVIEW OF THE MCDM BASED RESEARCH METHODOLOGIES

In this section, we present two methodologies; (1) AHP-GDM Methodology (2) Fuzzy AHP Methodology. The AHP-GDM methodology is used for systematic decision-making to solve complex problems with multiple criterions. However, fuzzy AHP is based on the applications of extension principles and fuzzy set theory that is used for more accuracy in decision making.

A. AHP-GDM METHODOLOGY

The AHP is a systematic decision-making process initiated by [53]–[55]. AHP helps in solving complex decision-making problems that are unstructured in nature and involved multiple criteria. Many researchers have applied AHP to solve complex decision-making in various applications [56].

TABLE 1. Cloud-based E-learning CSFs obtained through literature review [34].

Dimensions	CSFs	References
Cloud Service Resilience (CSR)	Cloud Data Security (CDS)	[35], [25], [1], [36], [37], [2], [38], [5], [39], [40], [41], [37], [42], [43], [43], [44], [45], [46], [47]
	Availability and Reliability (AR)	[48], [25], [37], [40], [41], [49], [43]
	Customizable Service Level Agreement (CSLA)	[35], [37], [39], [43]
	Cloud Services (SaaS, PaaS, IaaS) (CS)	[10], [37]
Institutions' Technological Maturity (ITM)	Network Bandwidth (NB)	[35], [1], [5], [49], [42], [50], [44], [47]
	Technological Compatibility (TC)	[51], [36], [37], [39], [41]
	Technical Support (TS)	[1], [35], [36], [37], [39], [41]
Institutions' Organizational Readiness (IOR)	Management Support (MS)	[51], [35], [25], [1], [5], [41], [49], [42], [44], [46], [47]
	Human Readiness (HR)	[35], [1], [50], [44], [47]
	Utilization Complexity (UC)	[51], [37], [2]
Cloud-based E-Learning Imperatives (CEI)	Cost Flexibility (CF)	[51], [36], [37], [38], [41], [49], [50], [44], [47]
	Ease of Use (EoU)	[52], [2], [43]
	Relative Advantage (RA)	[51], [37], [2]
	Design of Innovative Services (DIS)	[39], [1]

TABLE 2. Saaty's nine-point scale [53]–[55].

Degree of Relative Importance	Description
1	Equally preferred
3	Moderately preferred
5	Essentially preferred
7	Very strongly preferred
9	Extremely preferred
2, 4, 6, 8	Intermediate importance between two adjacent judgments

In AHP, the expert's experience and knowledge are utilized in making a final opinion. Expert's opinion is taken into consideration for the pairwise comparison. In AHP single decision-maker (DM) gives an opinion which may be biased and may lead to misleading judgment. The biases that exist in simple decision-making may be removed by using group decision making. More decision-makers (DMs) may be employed to form a pairwise comparison, which is not biased in decision making. Pairwise decisions made by various decision-makers may be synthesized using geometric means. The final synthesized the decision matrix provides higher accuracy as compared to a single DM. Saaty's decision scale as shown in table 2 may be used for comparing decision matrix [53]–[55].

The basic steps of AHP are illustrated here:

Step 1: Various dimensions and CSFs of cloud based E-Learning are grouped to form comparison matrix 'D' may be referred to problem decision matrix. Each factor of the 'D' matrix will be judged using Saaty's 9 point scale as mentioned in table 2. The factor of the 'D' matrix, , d_{mn} indicates the relative level of importance of the m^{th} with that of the n^{th} in terms of its requirement.

$$D = \begin{bmatrix} d_{11} & d_{12} & \ldots & d_{1n} \\ d_{21} & d_{12} & \ldots & d_{2n} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ d_{km} & d_{km} & \ldots & d_{mn} \end{bmatrix} \quad (1)$$

Step 2: The geometric means (GM) of each pairwise decision of all decision matrices may be obtained. The priority vector (PV) value is obtained by normalizing each geometric mean value.

Step 3: The overall summation can be obtained by summing the product sum of vector column of each decision matrix, pair wise decision matrix along with PV values of corresponding row that gives principal Eigen values as follow:

$$(\lambda_{max}),\ i.e.,\ \lambda_{max} = \sum_{i,j=1}^{k} C_j PV_i \quad (2)$$

where c_j indicates column vector sum.

Step 4: The decision matrix may be subjected to inconsistency check by using equation (3):

$$InconsistencyIndex = \frac{\lambda_{max} - n}{n-1} \quad (3)$$

where n is the number of elements of each of the matrix.

Step 5: The Random Index ($R.I.$) is used in ascertaining the consistency. It may be calculated using equation (4).

$$RandomIndex = \frac{1.98(n-2)}{n} \quad (4)$$

Step 6: The Inconsistency Ratio (I.R.) plays a vital in the decision matrix. The inconsistency ratio is the ratio of inconstancy index to random index. In case of obtaining I.R.>10% the decision matrix may be subjected to further revision until the condition is satisfied.

Step 7: : Pairwise comparison matrices (A_i, $i = 1, 2, ..., n$) (for each main E-Learning dimension is constructed. Table 2 may be employed to assign weights to such matrices. The $P.V.$ values, principal Eigen values, $I.I.$ and $I.R.$ may be obtained using the steps documented in Steps 2-6.

TABLE 3. Triangular fuzzy scale for fuzzy analytic hierarchy process.

Linguistics scale for importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Equally Importance (EI)	(1/2,1,3/2)	(2/3,1,2)
Weakly more importance (WMI)	(1,3/2,2)	(1/2,2/3,1)
Strongly more importance (SMI)	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more importance (VSMI)	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more importance (AMI)	(5/2,3,7/2)	(2/7,1/3.2/5)

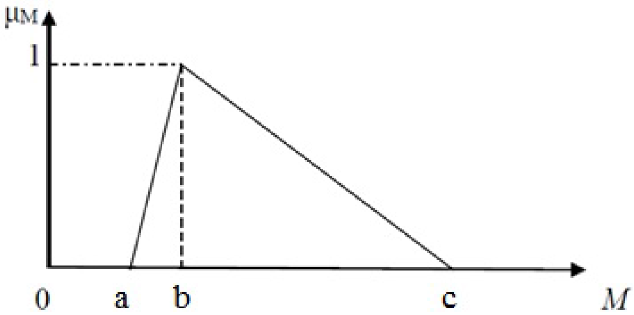

FIGURE 3. Triangular fuzzy number (*M*).

B. FUZZY AHP METHODOLOGY

The Fuzzy based AHP methodology uses fuzzy set theory along with extension principal. FAHP is mainly preferred over AHP because of its accuracy in decision making. The decision-makers' error resulting out of biasness and vagueness in decision-making may be removed or reduced by applying fuzzy-based methodology [1]. This section describes the fuzzy set theory, the basic theory of extension principles and its application in the fuzzy state.

1) FUZZY SET THEORY

Fuzzy based theory is vital in decision making. The decision process in its ordinary form i.e. crisp form may acquire judgmental biases and vagueness. Sometimes, the information in crisp nature may be vague, incomplete or imprecise. In such a scenario, the use of fuzzy knowledge becomes mandatory. A set of triangular fuzzy numbers (a, b, c) or trapezoidal form (a, b, c, d) may be used to derive the decision-making [58]. A typical Triangular Fuzzy Number (TFN) is shown in figure 3.

The Fuzzy set theory facilitates the arithmetic operations between the set of two TFNs [59]. TFNs may be represented by M_1 and M_2 as (a_1, b_1, c_1) and (a_2, b_2, c_2) respectively. Two TFNs may be subjected to various arithmetic operations like fuzzy addition and fuzzy subtraction as represented by $\oplus$ and $\ominus$ using the operational rules:

$$\tilde{M}_1 \oplus \tilde{M}_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \quad (5)$$

$$\tilde{M}_1 \ominus \tilde{M}_2 = (a_1 - a_2, b_1 - b_2, c_1 - c_2) \quad (6)$$

$$\tilde{M}_1 \otimes \tilde{M}_2 = (a_1 a_2, b_1 b_2, c_1 c_2) \quad (7)$$

$$\lambda \otimes \tilde{M}_1 = (\lambda a_1, \lambda b_1, \lambda c_1,) \text{ where } \lambda > 0, \ \lambda \in R \quad (8)$$

$$\tilde{M}_1^{-1} = \left(\frac{1}{c_1}, \frac{1}{b_1}, \frac{1}{a_1}\right) \quad (9)$$

2) USE OF EXTENSION PRINCIPAL IN FUZZY DECISION MAKING

In case of two triangular fuzzy numbers (TFNs), the comparison may be carried out using the extent analysis principles [60]. Two sets as objective and goal may be considered as $X = x_1, x_2, \ldots\ldots\ldots, x_n$ and $U = u_1, u_2, \ldots\ldots\ldots, u_n$ for objective and goal respectively, the extent analysis may be carried out. The element can be further resolved using extension principal as:

$$M_{gi}^1, M_{gi}^2 \ldots\ldots M_{gi}^m, \quad i = 1, 2, \ldots\ldots, n \quad (10)$$

where $M_{gi}^j (j = 1, 2, \ldots., m)$ are TFNs and represented as (a, b, c). The research methodology based on extension principal [60] may be used as follows:

Step 1: Establishing structure hierarchy for goal Expert's judgement is used in establishing the hierarchical structure for the defined goal. The prioritizing of dimensions and CSFs of cloud based E-Learning can be appropriately placed at the top and middle of hierarchy structure as shown in figure 5

Step 2: Establishing the pairwise comparison for cloud-based E-Learning dimensions and CSFs using TFN In order to compare the dimensions and CSFs of cloud based E-Learning the judgment may be obtained from DMs. TFNs may be employed in establishing the relation between two CSFs.

Step 3: Obtaining the value of fuzzy synthetic extent

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j\right]^{-1} \quad (11)$$

Using fuzzy summation of TFNs, m extent analysis values $\sum_{j=1}^{m} M_{gi}^j$, may be derived as follows

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} a_j, \sum_{j=1}^{m} b_j, \sum_{j=1}^{m} c_j\right) \quad (12)$$

and $[\sum_{j=1}^{n} \sum_{j=1}^{m} M_{gi}^j]^{-1}$ the fuzzy summation of $M_{gi}^j (j = 1, 2, \ldots, m)$ values may be obtained as

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} a_j, \sum_{i-1}^{n} b_j, \sum_{j=1}^{n} c_j\right) \quad (13)$$

The inverse of the vector may be obtained as:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} c_i}, \frac{1}{\sum_{i=1}^{n} b_i}, \frac{1}{\sum_{i=1}^{n} a_i}\right) \quad (14)$$

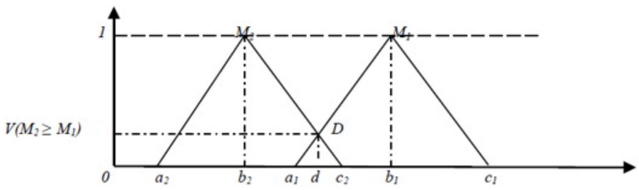

FIGURE 4. The intersection of TFNs [42].

Step 4: Obtaining the degree of possibility of supremacy for two TFNs i.e., $M_2 = (a_2, b_2, c_2) \geq M_1 = (a_1, b_1, c_1)$

$$V(M_2 \geq M_1) = \sup_{y \geq x}[min(\mu_{M1}(x), \mu_{M2}(y))] \quad (15)$$

and can be represented as:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M2}(d) \quad (16)$$

$$\mu_{M2}(d) = \begin{cases} 1, & if\ b_2 \geq b_1, \\ 0, & if\ a_1 \geq c_2 \\ \dfrac{a_1 - c_2}{(b_2 - c_2) - (b_1 - a_1)}, & otherwise \end{cases} \quad (17)$$

In group decision making process K DMs may be involved, thus the subsequent pairwise comparisons yield n elements. A set of K matrices, $\check{A}_k = \{\check{a}_{ijk}\}$, where $\check{A}_k = \check{a}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$ gives relative preference of element i to j, as conveyed by DM k . The aggregation may be obtained using the Equation (18).

$$a_{ij} = min(a_{ijk}), \quad k = 1, 2, \ldots k$$
$$b_{ij} = \sqrt[k]{\prod_{k=1}^{K} b_{ijk}}$$
$$c_{ij} = max(c_{ijk}), \quad k = 1, 2, \ldots k \quad (18)$$

Figure 4 represents the intersection of two TFNs. The ordinate d may be obtained by the possible highest intersection indicated as D between μM_1 and μM_2. Thus M_1 and M_2 may be obtained through the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

Step 5: Obtain the degree of possibility for a given convex fuzzy number such that it is greater than k convex

Fuzzy number $M_1(i = 1, 2, ..., k)$ may be defined as

$$V(M \geq M_1, M_2, ..., M_k) = V[(M \geq M_1) \quad and \quad (M \geq M_2\ and ....and\ (M \geq M_k))]$$
$$= min\ V(M \geq M_i), i = 1, 2, ..., k \quad (19)$$

Considering

$$d(A_i) = min\ V(S_i \geq S_k) for\ k = 1, 2, ..., m;\ k \neq i \quad (20)$$

Weight vector may be derived as

$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T$ such that $A_i(i = 1, 2, ..., n)$ has n elements.

Step 6: Obtain the normalized weight vectors.

The normalized weight vector may be obtained using Equation (21)

$$W = (d(A_1), d(A_2), ..., d(A_n))^T \quad (21)$$

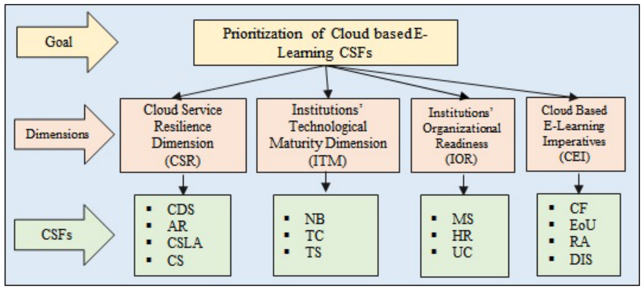

FIGURE 5. MCDM model for cloud-based E-learning.

Step 7: Obtaining the overall score of each dimension and CSFs of cloud-based E-Learning for the prioritization

The priority weights of each dimension and CSFs of cloud-based E-Learning may be derived considering local weighs and global weights. Thus, the global weight so derived may be rearrange to give the required rankings

VI. APPLICATION OF MCDM BASED METHODOLOGIES IN THE CLOUD BASED E-LEARNING

A combinatorial approach of AHP-GDM and FAHP has been used in deriving and ranking CSFs of cloud-based E-Learning. AHP-GDM provides a synthetic assessment from DMs whereas FAHP helps in removing biases present in the decision making. DMs play a critical role in qualitative assessment. Six DMs having more than 5 years' experience in E-Learning. Apart from the core E-Learning engagements, they also had long exposure for the hardware and software management in E-Learning. The DMs were convinced to unite for the academic and research cause for which they agreed without any reservation whatsoever. A detailed review of the literature was carried out for identifying CSFs of cloud-based E-Learning. Four main dimensions such as Cloud Service Resilience (CSR), Institutions' Technological Maturity (ITM), Institutions' Organizational Readiness (IOR) and cloud-based E-Learning Imperatives (CEI) were identified. Figure 5 shows the framework for evaluating and prioritizing the cloud-based E-Learning CSFs.

Three decision-makers (DMs) i.e., DM_1, DM_2 and DM_3 assessed four dimensions that are given in table 4, 5, and 6. The synthesizing of three decision matrix has also been carried out by GM and presented in table 7. Similarly, pairwise comparison of all the factors of main dimensions such as cloud Service Resilience (CSR), Institutions' Technological Maturity (ITM), Institutions' Organizational Readiness (IOR) and cloud-based E-Learning Imperatives (CEI) have been carried out by three DMs i.e., DM_1, DM_2 and DM_3 . Table 8 shows the composite weights of CSFs of cloud-based E-Learning obtained through AHP-GDM.

Similarly, FAHP has been used in calculating the weighs of the dimensions and CSFs of cloud-based E-Learning the required ranking. TFN scale as shown in table 3 has been applied in obtaining the weights of cloud-based E-Learning CSFs and its factors. The systematic methodology as

TABLE 4. Pairwise comparison of dimensions of cloud-based E-learning using AHP-GDM by DM_1.

CSFs	CSR	ITM	IOR	CEI	Weightages
Cloud Service Resilience (CSR)	1	3	1/2	3	0.3205
Institutions' Technological Maturity (ITM)	1/3	1	1/2	2	0.1703
Institutions' Organizational Readiness (IOR)	2	2	1	3	0.4038
Cloud Based E-Learning Imperatives (CEI)	1/3	1/2	1/3	1	0.1055

TABLE 5. Pairwise comparison of dimensions of cloud-based E-learning using AHP-GDM by DM_2.

CSFs	CSR	ITM	IOR	CEI	Weightages
Cloud Service Resilience (CSR)	1	3	1/2	3	0.3141
Institutions' Technological Maturity (ITM)	1/3	1	1/2	2	0.1667
Institutions' Organizational Readiness (IOR)	2	2	1	4	0.4244
Cloud Based E-Learning Imperatives (CEI)	1/3	1/2	1/4	1	0.0947

TABLE 6. Pairwise comparison of dimensions of cloud-based E-learning using AHP-GDM by DM_3.

CSFs	CSR	ITM	IOR	CEI	Weightages
Cloud Service Resilience (CSR)	1	3	2	1/2	0.3088
Institutions' Technological Maturity (ITM)	1/3	1	2	3	0.2911
Institutions' Organizational Readiness (IOR)	1/2	1/2	1	1/3	0.1070
Cloud Based E-Learning Imperatives (CEI)	2	1/3	3	1	0.2932

TABLE 7. Synthesizing results of dimensions of cloud-based E-learning using AHP-GDM.

CSFs	CSR	ITM	IOR	CEI	Weightages
Cloud Service Resilience (CSR)	1.00	3.00	0.79	1.65	0.3347
Institutions' Technological Maturity (ITM)	0.33	1.00	0.79	2.29	0.2193
Institutions' Organizational Readiness (IOR)	1.26	1.26	1.00	1.59	0.2923
Cloud Based E-Learning Imperatives (CEI)	0.61	0.44	0.63	1.00	0.1538

TABLE 8. Composite weightage table of CSFs of cloud-based E-learning obtained through AHP-GDM.

Sr. No.	Main CSFs	Weightages	Sub-CSFs	Local Weights	Global Weights	Overall Ranking
1	Cloud Service Resilience (CSR)	0.3347	Cloud Data Security (CDS)	0.287	0.096	4
			Availability & Reliability (AR)	0.196	0.066	7
			Customizable Service Level Agreement (CSLA)	0.108	0.036	11
			Cloud Services (SaaS, PaaS, IaaS) (CS)	0.409	0.137	2
2	Institutions' Technological Maturity (ITM)	0.2193	Network Bandwidth (NB)	0.607	0.133	3
			Technological Compatibility (TC)	0.230	0.050	9
			Technical Support (TS)	0.164	0.036	12
3	Institutions' Organizational Readiness (IOR)	0.2923	Management Support (MS)	0.540	0.158	1
			Human Readiness (HR)	0.287	0.084	5
			Utilization Complexity (UC)	0.173	0.051	8
4	Cloud Based E-Learning Imperatives (CEI)	0.1538	Cost Flexibility (CF)	0.459	0.071	6
			Ease of Use (EoU)	0.157	0.024	13
			Relative Advantage (RA)	0.112	0.017	14
			Design of Innovative Services (DIS)	0.272	0.042	10

described in the earlier section has been followed to establish the weights. Table 9 shows the weights of cloud-based E-Learning CSFs. Table 10 shows the composite weightages of CSFs of Cloud based E-Learning obtained through FAHP TFN scale. The prioritization obtained using AHP-GDM and FAHP may be compared and shown in table 11.

TABLE 9. Pairwise comparison of dimensions of cloud-based E-learning using FAHP.

CSFs	CSR	ITM	IOR	CEI	Weightages
Cloud Service Resilience (CSR)	(1,1,1)	(1/2, 1,3/2)	(1/2, 1,3/2)	(1,3/2,2)	0.2647
Institutions' Technological Maturity(ITM)	(2/3,1/2,2)	(1,1,1)	(1,3/2,2)	(1/2, 2/3,1)	0.2495
Institutions' Organizational Readiness (IOR)	(2/3,1/2,2)	(1/2,2/3,1)	(1,1,1)	(3/2,2,5/2)	0.2730
Cloud Based E-Learning Imperatives(CEI)	(1/2,2/3,1)	(1,3/2,2)	(2/5,1/2, 2/3)	(1,1,1)	0.2128

TABLE 10. Composite weightages of CSFs of cloud-based E-learning obtained through FAHP.

Sr. No.	Main CSFs	Weightages	Sub-CSFs	Local Weights	Global Weights	Overall Ranking
1	Cloud Service Resilience (CSR)	0.2647	Cloud Data Security (CDS)	0.272	0.072	7
			Availability & Reliability (AR)	0.277	0.073	6
			Customizable Service Level Agreement (CSLA)	0.155	0.041	13
			Cloud Services (SaaS, PaaS, IaaS) (CS)	0.297	0.078	4
2	Institutions' Technological Maturity (ITM)	0.2495	Network Bandwidth (NB)	0.591	0.147	2
			Technological Compatibility (TC)	0.212	0.053	9
			Technical Support (TS)	0.198	0.049	10
3	Institutions' Organizational Readiness (IOR)	0.2730	Management Support (MS)	0.546	0.149	1
			Human Readiness (HR)	0.293	0.080	3
			Utilization Complexity (UC)	0.161	0.044	12
4	Cloud Based E-Learning Imperatives (CEI)	0.2128	Cost Flexibility (CF)	0.367	0.078	5
			Ease of Use (EoU)	0.218	0.046	11
			Relative Advantage (RA)	0.155	0.033	14
			Design of Innovative Services (DIS)	0.260	0.055	8

TABLE 11. Comparison of composite weightages of CSFs of cloud-based E-learning using AHP-GDM and FAHP.

Sr. No.	Main CSFs	Weightages		Sub-CSFs	Local Weights		Global Weights		Overall Ranking	
		AHP-GDM	FAHP		AHP-GDM	FAHP	AHP-GDM	FAHP	AHP-GDM	FAHP
1	Cloud Service Resilience (CSR)	0.3347	0.2647	Cloud Data Security (CDS)	0.287	0.272	0.096	0.074	4	7
				Availability & Reliability (AR)	0.196	0.277	0.066	0.076	7	6
				Customizable Service Level Agreement (CSLA)	0.108	0.155	0.036	0.042	11	13
				Cloud Services (SaaS, PaaS, IaaS) (CS)	0.409	0.297	0.137	0.081	2	3
2	Institutions' Technological Maturity (ITM)	0.2193	0.2495	Network Bandwidth (NB)	0.607	0.591	0.133	0.147	3	1
				Technological Compatibility (TC)	0.230	0.212	0.050	0.053	9	9
				Technical Support (TS)	0.164	0.198	0.036	0.049	12	10
3	Institutions' Organizational Readiness (IOR)	0.2923	0.2730	Management Support (MS)	0.540	0.546	0.158	0.145	1	2
				Human Readiness (HR)	0.287	0.293	0.084	0.078	5	5
				Utilization Complexity (UC)	0.173	0.161	0.051	0.043	8	12
4	Cloud Based E-Learning Imperatives (CEI)	0.1538	0.2128	Cost Flexibility (CF)	0.459	0.367	0.071	0.078	6	4
				Ease of Use (EoU)	0.157	0.218	0.024	0.046	13	11
				Relative Advantage (RA)	0.112	0.155	0.017	0.033	14	14
				Design of Innovative Services (DIS)	0.272	0.260	0.042	0.055	10	8

VII. RESULTS AND DISCUSSIONS

CSFs of cloud-based E-Learning are very important in E-Learning process. In order to find out the significance of each CSFs, a systematic approach is required. The present research attempts to quantify the CSFs of cloud-based E-Learning using MCDM based methodologies. The results obtained by both methods are also compared in order to ascertain the correct prioritization. The could-based E-Learning users like universities and training institutions may find the prioritization of CSFs useful in allocating the resources in an optimized and effective manner.

The combinatorial approach of AHP-GDM and FAHP may be used in deriving the weights and ranking. Comparison of weights of cloud-based E-Learning using AHP-GDM and FAHP may be useful in understanding the importance of each CSFs. The comparison of weights of CSFs of cloud-based E-Learning obtained using AHP-GDM and FAHP is shown in Figure 6.

Similarly, comparison of a rank of cloud-based E-Learning using FAHP-GDM and FAHP may be obtained and compared. Figure 7 shows the comparison of the rank of cloud-based E-Learning obtained by using AHP-GDM and FAHP.

TABLE 12. Classification of CSFs of cloud-based E-learning with reference to its severity of influence in AHP-GDM and FAHP.

AHP-GDM based classification		
Gr.-I High Influence	**Gr.-II Moderate Influence**	**Gr.-III Low Influence**
1.Management Support (MS) 2.Cloud Services (SaaS, PaaS, IaaS) (CS) 3.Network Bandwidth (NB) 4.Cloud Data Security (CDS) 5.Human Readiness (HR)	6.Cost Flexibility (CF)* 7.Availability & Reliability (AR) 8.Utilization Complexity (UC) 9.Technological Compatibility (TC) 10.Design of Innovative Services (DIS)	11.Customizable Service Level Agreement (CSLA) 12.Technical Support (TS) 13.Ease of Use (EoU) 14.Relative Advantage (RA)
FAHP based classification		
Gr.-I High Influence	**Gr.-II Moderate Influence**	**Gr.-III Low Influence**
1.Network Bandwidth (NB) 2..Management Support (MS) 3.Cloud Services (SaaS, PaaS, IaaS) (CS) 4.Cost Flexibility (CF) 5.Human Readiness (HR)	6.Availability & Reliability (AR) 7.Cloud Data Security (CDS) 8.Design of Innovative Services (DIS) 9.Technological Compatibility (TC) 10.Technical Support (TS)	11.Ease of Use (EoU) 13.Customizable Service Level Agreement (CSLA) 12.Utilization Complexity (UC) 14.Relative Advantage (RA)

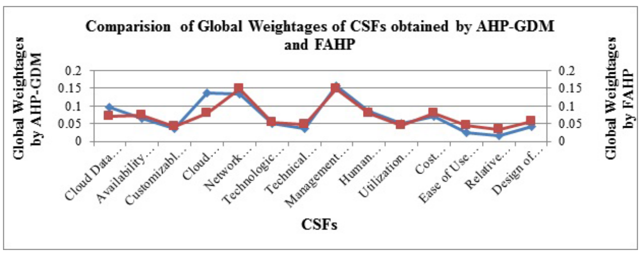

FIGURE 6. Comparison of weightage of CSFs of cloud-based E-learning obtained using AHP-GDM and FAHP.

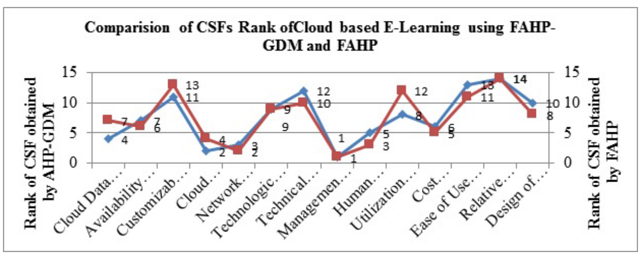

FIGURE 7. Comparison of ranks of CSFs of cloud-based E-learning obtained using AHP-GDM and FAHP.

From the MCDM based result analysis, it has been found that four dimensions of cloud-based E-Learning have the priorities viz. Cloud Service Resilience (CSR) > Institutions' Organizational Readiness (IOR) > Institutions' Technological Maturity (ITM) > cloud-based E-Learning Imperatives (CEI) as the corresponding weights are 0.3347 >0.2923 > 0.2193 > 0.1538, where '>' represents 'more importance'. Similar prioritization is obtained by Fuzzy AHP method. The respective weights obtained are as 0.2647 > 0.273 > 0.2495 > 0.2128 where '>' represents 'more importance'.

Based on the weights obtained by AHP-GDM and FAHP two prioritization sequences are obtained. The prioritization obtained may further be grouped. The three groups i.e. GR.I having High Influence, Gr.II- Moderate Influence and III-Low influences are obtained as shown in table 12.

However, based on the Fuzzy AHP the weights are varying and thus the group classification. Based on the FAHP, CSFs namely. Network Bandwidth (NB), Management Support (MS), Cloud Services (SaaS, PaaS, IaaS) (CS), Cost Flexibility (CF) and Human Readiness (HR) are classified in Gr.-I which has high influence. The CSFs namely Availability and Reliability (AR), Cloud Data Security (CDS) , Design of Innovative Services (DIS), Technological Compatibility (TC) and Technical Support (TS) are classified in Gr.-II which has moderate influence. Whereas, the CFSs namely Ease of Use (EoU), Customizable Service Level Agreement (CSLA), Utilization Complexity (UC) and Relative Advantage (RA) are classified in Gr.-III which has low influence.

It is further observed that Cost Flexibility (CF) shifts from Gr.II to Gr.I. Similarly Cloud Data Security (CDS) moves from Gr.I to Gr,II. Utilization Complexity (UC) moves from Gr.II to Gr.III.and lastly Technical Support (TS) shifts from Gr.III to Gr.II. The results thus obtained indicate the priority of fourteen cloud-based E-Learning CSFs as shown in table 11.

VIII. LIMITATIONS AND SCOPE FOR FUTURE WORK

The selection of cloud-based E-Learning may vary for a given region and may also be influenced by social, economic and geographical conditions. In the present research assessment and prioritization cloud-based CSFs have been obtained in the Kingdom of Saudi Arabia (KSA). Fourteen cloud-based CSFs are chosen which may be further expanded. In the present research six DMs are involved for the MCDM based methodologies for assessing and prioritizing the cloud-based E-Learning CSFs, the strength of DMs may further be increased.

IX. CONCLUSION

The dimensions and CSFs of the cloud-based E-Learning system play a very significant role in the successful teaching-learning process. Hence, it is very pertinent to investigate the influence of the dimensions and CSFs of the cloud-based E-Learning system to know its influence on the teaching-learning process. Once the influence of each CSFs is ascertained, the stakeholders like university management, instructors and students will be able to control the effect of each such dimension and CSFs. The combinatorial approach of AHP-GDM and FAHP methodology may prove to be successful in classifying the CSFs in various grades of influence like High Influence, Moderate Influence and Low Influence. This particular CSFs classification will further help stakeholders to deploy resources like time, money, service infrastructure enhancement etc. in controlling and improving the teaching-learning system.

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