Research Article

Selecting The Optimal E-Learning Platform for Universities: A Pythagorean Fuzzy AHP/TOPSIS Evaluation

İsmail Akargöl[1*], İlker Karadağ[2], Ömer Faruk Gürcan[3]

[1] Sivas Cumhuriyet University, Orcid ID: 0000-0002-0721-7064, iakargol@cumhuriyet.edu.tr,
2 Sivas Cumhuriyet University, Orcid ID: 0000-0002-7048-8529, ilkerkaradag@cumhuriyet.edu.tr,
3 Sivas Cumhuriyet University, Orcid ID: 0000-0002-1256-2751, ofgurcan@cumhuriyet.edu.tr
* Correspondence: iakargol@cumhuriyet.edu.tr;

(First received November 15, 2023 and in final form March 25, 2024)

Reference: Akargöl, İ., Karadağ., İ., Gürcan, Ö., E. Selecting The Optimal E-Learning Platform for Universities: A Pythagorean Fuzzy AHP/TOPSIS Evaluation. The European Journal of Research and Development, 4(2), 19-34.

Abstract

As a result of global epidemics and threats, higher education began to widely use e-learning platforms. With the proliferation of online learning in higher education, a systematic and rigorous approach is needed for universities to make informed decisions when selecting e-learning platforms. Presenting a Pythagorean fuzzy hybrid multi-criteria decision-making strategy that aids in solving this challenge is the study's goal. This study presents a comprehensive analysis of four prominent e-learning platforms - Google Meet, Microsoft Teams, Skype, and Zoom - utilizing the Pythagorean Fuzzy Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodologies. By structuring and prioritizing a range of criteria using the Pythagorean Fuzzy AHP model, the study establishes a well-defined framework for the assessment process. Subsequently, the Pythagorean Fuzzy TOPSIS method is applied to rank these platforms based on their overall performance against the identified criteria. The outcomes of this research enable universities to tailor their e-learning platform selection to the unique requirements of their educational programs, ultimately promoting enhanced engagement, accessibility, and learning outcomes for both students and faculty.

Keywords: *E-learning platforms, Pythagorean AHP, TOPSIS*

1. Introduction

Online education, also known as e-learning or distance learning, utilizes digital technologies and the internet to deliver educational content, enabling learning outside of traditional classrooms. Students and instructors engage through online platforms, providing flexibility in schedules and remote access to educational resources. In recent times, the significance and utilization of online education have seen a notable increase.

According to Global Market Insights, the e-learning market size reached approximately USD 400 million in 2022 and is projected to grow at a compound annual growth rate of 14% between 2023 and 2032 [1]. The surge in e-learning platform adoption can be attributed to the flexible learning environment they offer, accommodating various program and course options to meet individual needs. E-learning transcends geographical boundaries, granting students access to educational resources globally. Additionally, factors such as cost-effectiveness, interactive learning materials supported by technological advancements, and student tracking systems contribute to the growing popularity of e-learning. The method's ability to provide continuous feedback and a student-centered learning experience further enhances its appeal. Moreover, e-learning proves valuable during emergencies and crises, supporting sustainable education practices sensitive to environmental factors, as exemplified during the COVID-19 pandemic. The rapid spread of COVID-19 had a profound impact on various sectors globally, with education being significantly affected. Social distancing measures prompted a swift transition to virtual or online operations for schools, universities, government institutions, and businesses [2].

E-learning platforms played a crucial role in ensuring the continuity of education, offering accessibility to a broader audience and providing flexibility in pace and timing. These platforms facilitated collaboration among students and educators, allowing for effective communication and group activities through discussion forums, video calls, and interactive tools [3]. Educators, in response, adapted swiftly, developing inventive methods to engage students in online learning, leading to the creation of new teaching approaches and interactive materials. Educators actively and effectively guide the moral character and personality of students, serving as pivotal figures in the educational process [4]. Numerous e-learning platforms, including Coursera, Udemy, Thinkific, Kajabi, Moodle, and LearnWorlds, have emerged in the market. Platforms supporting video conferencing, such as Zoom, Google Meet, Skype, Webex, and Fuze, also contribute to the online learning process. Evaluating and choosing among these platforms present notable challenges.

This study focuses on comparing four popular video conferencing platforms—Google Meet, Microsoft Teams, Skype, and Zoom—in the context of university education. Criteria such as assessment and evaluation security, transfer capabilities, exam modes, compatibility, result recording, adaptability, logging, threshing, extendibility, and customization are considered. The Pythagorean Fuzzy Analytic Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodologies are applied to select the optimal platform. Contributing to the existing literature, this study introduces the Pythagorean Fuzzy Hybrid MCDM approach to the selection of e-learning platforms, an area where such an approach has been lacking.

The importance ranking of the criteria provides valuable guidance for future studies in this domain. The subsequent sections of this research include a literature survey and the study's content and methodology in Section 2, with the result and conclusion presented in Section 3 and 4.

2. Materials and Methods

Multi-criteria decision-making techniques have gained significant prominence in the realm of research, capturing the attention of numerous scholars. The existing body of literature is replete with studies employing these techniques to address diverse challenges. Table 1 provides a succinct overview of selected studies that have harnessed Pythagorean Fuzzy AHP/TOPSIS techniques. In addition to these, it is noteworthy to mention that the versatility and applicability of these methodologies have spurred continuous exploration and innovation within the academic community. Researchers are continually expanding the boundaries of knowledge by exploring novel avenues for the implementation of multi-criteria decision-making techniques.

Table 1: Studies using Pythagorean Fuzzy AHP/TOPSIS techniques

Author	Subject	Journal/Conference
Dalyan et al. (2022) [5]	ERP Software Selection	INFUS 2022/Proceeding paper
Kose et al. (2022) [6]	Ergonomic Assessment of Setup Process under SMED	Sustainability
Sarkar and Biswas (2021) [7]	The selection of transportation companies	Soft Computing
Çalık (2021) [8]	Green supplier selection in the Industry 4.0 era	Soft Computing
Otay and Jaller (2020) [9]	The wind power farm location selection problem	Journal of Intelligent & Fuzzy Systems
Yildiz et al. (2020) [10]	ATM Site Selection Problem	International Journal Of Information Technology & Decision Making
Yucesan and Gul (2020) [11]	Hospital service quality evaluation	Soft Computing
Ak and Gul (2019) [12]	Information security risk analysis	Complex & Intelligent Systems
Our study(2024)	Selecting the optimal E-Learning platform	-

In some other studies in the literature, only Pythagorean Fuzzy AHP (e.g. Karasan et al. [13], Yucesan and Kahraman [14], Shete et al. [15], Ayyildiz and Gumus [16]) or in some studies only Pythagorean Fuzzy TOPSIS (e.g. Yu et al. [17], Akram et al. [18], Rani et al. [19], Biswas and Sarkar [20]) is used. However, in the literature, multi-criteria decision-making techniques are generally hybridized with another multi-criteria decision-making technique to form a decision-making approach. For example, the Pythagorean Fuzzy AHP technique has been hybridized with other multi-criteria decision-making techniques in some studies (e.g. Mete [21], Gul [22], Lahane and Kant [22], Büyüközkan and Göçer [23], Ayyildiz et al. [24]). Similarly, the Pythagorean Fuzzy TOPSIS technique also has been hybridized with other multi-criteria decision-making techniques in some studies (e.g. Akram et al. [25], Naeem et al. [26], Saeidi et al. [27], Seker and Kahraman [28]).

After this brief literature information about the multi-criteria decision-making techniques used in the study, let's explain the following about our research problem. In our study, we ranked the e-learning platforms that are frequently used in higher education by evaluating them according to multiple criteria. For this, we used a hybrid multi-criteria decision-making approach based on Pythagorean fuzzy logic. In this regard, we believe that our study will contribute to the literature by demonstrating both the techniques employed for the specific problem and the applicability of our proposed solution.

In this research, we introduce a group decision-making framework employing a Pythagorean Fuzzy hybrid of AHP and TOPSIS.

2.1. Preliminaries

Yager [29] initially introduced Pythagorean fuzzy sets, which have found application in addressing uncertainty in diverse areas, similar to interval type-2 fuzzy sets, hesitant fuzzy sets, and intuitionistic fuzzy sets. Pythagorean fuzzy sets serve as a generalization of intuitionistic fuzzy sets, particularly in situations where the latter may fall short in addressing uncertainty. Consequently, Pythagorean fuzzy sets exhibit greater power and flexibility in resolving problems characterized by uncertainty. Detailed exploration of various operations and assumptions related to Pythagorean fuzzy sets can be found in pertinent publications within the literature [22], [30]-[37], [39]. Below, we provide explanations for the definitions of the operators utilized in our study.

Definition 1. Interval-valued Pythagorean fuzzy weighted geometric operator

"Let Ψ be the set of all interval-valued Pythagorean fuzzy numbers and $a_j = ([\mu^L_{a_j}, \mu^U_{a_j}], [\vartheta^L_{a_j}, \vartheta^U_{a_j}])$ (j= 1, 2, …, n) be a collection of interval-valued Pythagorean fuzzy numbers, and let IVPFWG: $\Psi^n \longrightarrow \Psi$, if

$IVPFWG_w^{(a_1,a_2,a_3,\ldots,a_n)}$

$$=([\prod_{j=1}^{n}(\mu^{L}{}_{a_j})^{w_j}, \prod_{j=1}^{n}(\mu^{U}{}_{a_j})^{w_j}],[\sqrt{1-\prod_{j=1}^{n}(1-(\vartheta^{L}{}_{a_j})^2)^{w_j}}, \sqrt{1-\prod_{j=1}^{n}(1-(\vartheta^{U}{}_{a_j})^2)^{w_j}}]) \quad (1)$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weighted vector of a_j (j = 1, 2, …, n) with $w_j \in [0,1]$ and $\sum_{j=1} w_j = 1$, then IVPFWG is called interval-valued Pythagorean fuzzy weighted geometric operator. Specially if $w = (\frac{1}{n}, \frac{1}{n}, \ldots, \frac{1}{n})^T$, then interval-valued Pythagorean fuzzy weighted geometric operator is reduced to interval-valued Pythagorean fuzzy geometric operator" [38].

***Definition* 2. Pythagorean fuzzy weighted averaging (PFWA)**

"Let $\beta_j = P(u_{\beta_j}, v_{\beta_j})$ (j=1,2,…,n) be a collection of PFNs, the new PFWA operator is defined as below:

$$\text{PFWA}(\beta_1, \beta_2, \ldots, \beta_n) = w_1\beta_1 \oplus w_2\beta_2 \oplus \ldots w_n\beta_n = P(\sqrt{1-\prod_{j=1}^{n}(1-(u_{\beta_j})^2)^{w_j}}, \prod_{j=1}^{n}(v_{\beta_j})^{w_j}) \quad (2)$$

where w_j indicates the importance degree of β_j, satisfying $w_j \geq 0$ (j=1,2,…,n) and $\sum_{j=1}^{n} w_j = 1$" [39].

2.2. PFAHP

The PFAHP approach with six steps of the procedure is presented as follows;

"Step 1: $A = (a_{ik})_{m\times m}$ is a pairwise comparison matrix that is created using expert linguistic evaluation. The linguistic terms that are given are presented in Table 2 [40].

Table 2: Linguistic Terms

Linguistic variables	Pythagorean fuzzy numbers			
	μ_L	μ_U	v_L	v_U
Certainly Low Importance-CLI	0.00	0.00	0.90	1.00
Very Low Importance-VLI	0.10	0.20	0.80	0.90
Low Importance-LI	0.20	0.35	0.65	0.80
Below Average Importance-BAI	0.35	0.45	0.55	0.65
Average Importance-AI	0.45	0.55	0.45	0.55
Above Average Importance-AAI	0.55	0.65	0.35	0.45
High Importance-HI	0.65	0.80	0.20	0.35
Very High Importance-VHI	0.80	0.90	0.10	0.20
Certainly High Importance-CHI	0.90	1.00	0.00	0.00
Exactly Equal-EE	0.1965	0.1965	0.1965	0.1965

Step 2: The difference matrices $D = (d_{ik})_{m\times m}$ between the lower and upper values of the membership and non-membership functions are calculated. Equation (3) and Equation (4) are used.

$$d_{ik_L} = \mu_{ik_L}^2 - v_{ik_U}^2 \quad (3)$$

$$d_{ik_U} = \mu_{ik_U}^2 - v_{ik_L}^2 \quad (4)$$

Step 3: Interval multiplicative matrix $S = (s_{ik})_{m\times m}$ is calculated. Equation (5) and Equation (6) are used.

$$s_{ik_L} = \sqrt{1000^{d_{ik_L}}} \quad (5)$$

$$s_{ik_U} = \sqrt{1000^{d_{ik_U}}} \quad (6)$$

Step 4: By using equation (7) the determinacy value $\tau = (\tau_{ik})_{m\times m}$ is obtained.

$$\tau_{ik} = 1 - \left(\mu_{ik_U}^2 - \mu_{ik_L}^2\right) - (v_{ik_U}^2 - v_{ik_L}^2) \quad (7)$$

Step 5: To obtain the matrix of weights $T = (t_{ik})_{m\times m}$ before normalization, the determinacy degrees are multiplied with $S = (s_{ik})_{m\times m}$. Equation (8) is used.

$$t_{ik} = (\frac{s_{ik_L}+s_{ik_U}}{2})\tau_{ik} \quad (8)$$

Step 6: The priority weights of criteria (w_i) are normalized by using equation (9).

$$w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m}\sum_{k=1}^{m} t_{ik}} \quad (9)$$

"[12].

2.3. PFTOPSIS

The PFTOPSIS approach with five steps of the procedure is presented as follows;

"Step 1: Pythagorean fuzzy number-based decision matrix $Z = (C_j(x_i))_{m\times n}$ is formed. C_j $(j = 1,2, \dots, n)$ refers to the values of criteria and x_i $(i = 1,2, \dots, m)$ refers to the alternatives. The the weights of criteria are determined by PFAHP explained in the previous section.

Step2: Pythagorean fuzzy positive ideal solution (PIS) and negative ideal solutions (NIS) are determined. Equation 10 and equation 11 are used.

$$x^+ = \{C_j, \max_i s\ (C_j(x_i)) | j = 1,2, \dots, n\} \quad (10)$$

$$x^- = \{C_j, \min_i s\ (C_j(x_i)) | j = 1,2, \dots, n\} \quad (11)$$

Step 3: The distances from Pythagorean fuzzy PIS and NIS are determined. Equation 12 and equation 13 are used.

$$D(x_i, x^+) = \frac{1}{2}\sum_{j=1}^{n} w_j\left(\left|(\mu_{ij})^2 - (\mu_j^+)^2\right| + \left|(v_{ij})^2 - (v_j^+)^2\right| + \left|(\pi_{ij})^2 - (\pi_j^+)^2\right|\right)$$
(12)

$$D(x_i, x^-) = \frac{1}{2}\sum_{j=1}^{n} w_j\left(\left|(\mu_{ij})^2 - (\mu_j^-)^2\right| + \left|(v_{ij})^2 - (v_j^-)^2\right| + \left|(\pi_{ij})^2 - (\pi_j^-)^2\right|\right)$$
(13)

Step4: The revised closeness $\xi(x_i)$ of the alternative x_i is determined by using equation 14.

$$\xi(x_i) = \frac{D(x_i, x^-)}{D_{max}(x_i, x^-)} - \frac{D(x_i, x^+)}{D_{min}(x_i, x^+)} \quad (14)$$

Step5: The alternative with the highest revised closeness $\xi(x_i)$ value is the best alternative "[12].

2.4 An Empirical Case Study

In this study, the challenge revolves around evaluating video conferencing software commonly utilized in digital learning through a multifaceted approach and identifying the optimal solution. To address this objective, the criteria employed for problem-solving are derived from Atıcı *et al.* (2022) [3]. The ten criteria and/or sub-criteria, featuring the highest weights as revealed in the outcomes of this investigation, along with their corresponding explanations, are delineated below:

"C44- assessment & evaluation security refers to ensure assessment & evaluation (exam, test) security.
C910-transfer is the knowledge transfer gained in the process between the teacher and student.
C11-compatibility is that the matching of metadata to content.
C91-diferent exam mode is that measurement can be made with various methods and techniques.
C14-adaptability is related that platform can be customized according to user needs.
C92-result record is the regulation of recording the assessment score.
C84-threshing is that the training method is enriched with online training materials.
C41-logging is the registration of the user's access information.
C12-extendibility is content and architecture purposed according to the following needs.
C13-customization means users can customize the platform according to their needs."

The weight values are determined by assessing these criteria through the PFAHP method explained in section 3.2. Decision makers express their perspectives on the criteria using the linguistic terms provided in Table 2. Subsequently, these linguistic terms are transformed into interval-valued Pythagorean fuzzy numbers, as illustrated in Table 3. Next, these values are computed using the Pythagorean fuzzy weighted geometric (IVPFWG) operator, as depicted in Table 4. Ultimately, the relative importance of each criterion is determined by integrating the opinions of the three decision-makers.

Table 3: Matrix of Criteria for Pairwise Comparison According to Expert Opinions

	C44	C910	C11	C91	C14	C92	C84	C41	C12	C13
C44	EE, EE, EE	AAI, AAI, EE	CHI, VHI, CHI	AAI, AI, VHI	AI, AI, AAI	VHI, CHI, VHI	VHI, VHI, BAI	HI, VHI, AAI	VHI, CHI, AAI	CHI, CHI, AAI
C910	BAI, BAI, EE	EE, EE, EE	AAI, HI, CHI	EE, EE, VHI	AI, EE, AAI	HI, HI, CHI	HI, HI, EE	AI, HI, AAI	CHI, VHI, AAI	CHI, VHI, HI
C11	CLI, VLI, CLI	BAI, LI, CLI	EE, EE, EE	LI, LI, EE	EE, EE, LI	AAI, AI, EE	AAI, AI, VLI	AAI, AI, BAI	AI, AAI, LI	AI, AAI, CLI
C91	BAI, AI, VLI	EE, EE, VLI	HI, HI, EE	EE, EE, EE	EE, EE, LI	AI, EE, EE	EE, AI, LI	LI, EE, BAI	AI, AI, LI	AI, AI, CLI
C14	AI, AI, BAI	AI, EE, BAI	EE, EE, HI	EE, EE, HI	EE, EE, EE	AI, EE, CHI	BAI, LI, EE	AAI, EE, HI	HI, EE, EE	HI, EE, EE
C92	VLI, CLI, VLI	LI, LI, CLI	BAI, AI, EE	AI, EE, EE	AI, EE, CLI	EE, EE, EE	LI, AI, VLI	AI, EE, BAI	AAI, AI, VLI	AAI, AI, VLI
C84	VLI, VLI, AAI	LI, LI, EE	BAI, AI, VHI	EE, AI, HI	AAI, LI, EE	HI, AI, VHI	EE, EE, EE	BAI, EE, HI	AAI, AI, EE	AAI, AI, EE
C41	LI, VLI, BAI	AI, LI, BAI	BAI, AI, AAI	HI, EE, AAI	BAI, EE, LI	AI, EE, AAI	AAI, EE, LI	EE, EE, EE	EE, EE, LI	EE, EE, LI
C12	VLI, CLI, BAI	CLI, VLI, BAI	AI, BAI, HI	AI, AI, HI	LI, EE, EE	BAI, AI, VHI	BAI, AI, EE	EE, EE, HI	EE, EE, EE	AI, AI, EE
C13	CLI, CLI, BAI	CLI, VLI, LI	AI, BAI, CHI	AI, AI, CHI	LI, EE, EE	BAI, AI, VHI	BAI, AI, EE	EE, EE, HI	AI, AI, EE	EE, EE, EE

Table 4: Matrix of Aggregated Pairwise Criteria Comparisons

	C44	C910	C11	C91	C14	C92	C84	C41	C12	C13
C44	([0.197,0.197] [0.197,0.197])	([0.392, 0.438], [0.31,0.39])	([0.866, 0.966], [0.06,0.116])	([0.583, 0.685], [0.34,0.435])	([0.481, 0.582], [0.43, 0.521])	([0.832, 0.932], [0.09, 0.165])	([0.609, 0.716], [0.35, 0.434])	([0.659, 0.777], [0.25,0.353])	([0.735, 0.837], [0.22,0.292])	([0.766, 0.868], [0.21,0.269])
C910	([0.29, 0.343], [0.48,0.563])	([0.197,0.197][0. 197,0.197])	([0.684, 0.803], [0.24, 0.337])	([0.313, 0.325], [0.18,0.198])	([0.366, 0.414], [0.36,0.436])	([0.724, 0.862], [0.17, 0.29])	([0.438, 0.504], [0.2,0.31])	([0.543, 0.658], [0.36,0.463])	([0.736, 0.838], [0.22, 0.291])	([0.778, 0.898], [0.13, 0.235])

C11	([0.000, 0.000], [0.88,1.000])	([0.000, 0.000], [0.76,1.000])	([0.197,0.197][0.197,0.197])	([0.199, 0.29], [0.57,0.709])	([0.198, 0.238], [0.44, 0.553])	([0.367, 0.415], [0.36,0.435])	([0.294, 0.417], [0.61,0.725])	([0.444, 0.545], [0.47,0.561])	([0.368, 0.501], [0.52,0.644])	([0.000, 0.000], [0.7,1.000])

Table 4: Continuation of Matrix of Aggregated Pairwise Criteria Comparisons

C91	([0.252, 0.368], [0.65,0.758])	([0.158, 0.198], [0.56,0.662])	([0.438, 0.504], [0.2,0.31])	([0.197,0.197][0.197,0.197])	([0.198, 0.238], [0.44, 0.553])	([0.261, 0.279], [0.32,0.372])	([0.26, 0.334], [0.49,0.613])	([0.24, 0.315], [0.53,0.647])	([0.345, 0.474], [0.54,0.663])	([0.000, 0.000], [0.71,1.000])
C14	([0.415, 0.515], [0.49,0.588])	([0.316, 0.367], [0.44,0.521])	([0.292, 0.313], [0.2,0.26])	([0.292, 0.313], [0.2,0.26])	([0.197,0.197][0.197,0.197])	([0.431, 0.478], [0.3,0.356])	([0.241, 0.316], [0.53,0.645])	([0.414, 0.47], [0.27,0.353])	([0.296, 0.317], [0.2, 0.261])	([0.296, 0.317], [0.2, 0.261])
C92	([0.000, 0.000], [0.85,1.000])	([0.000, 0.000], [0.78,1.000])	([0.315, 0.366], [0.44,0.523])	([0.261, 0.279], [0.32,0.372])	([0.000,0.000][0.69,1.000])	([0.197,0.197][0.197,0.197])	([0.208, 0.338], [0.68,0.799])	([0.316, 0.367], [0.44,0.521])	([0.294,0.417][0.61,0.725])	([0.294,0.417][0.61,0.725])
C84	([0.176, 0.296], [0.72,0.834])	([0.199, 0.29], [0.57,0.709])	([0.5, 0.605], [0.43,0.523])	([0.384, 0.439], [0.32,0.402])	([0.281, 0.358], [0.47,0.59])	([0.617, 0.735], [0.3,0.403])	([0.197,0.197][0.197,0.197])	([0.355, 0.414], [0.38,0.465])	([0.367, 0.415], [0.36,0.435])	([0.367, 0.415], [0.36,0.435])
C41	([0.192, 0.317], [0.69,0.812])	([0.317, 0.444], [0.57,0.688])	([0.442, 0.543], [0.47,0.563])	([0.415,0.471][0.27,0.352])	([0.241, 0.316], [0.53,0.645])	([0.366, 0.414], [0.36,0.436])	([0.281, 0.358], [0.47,0.59])	([0.197,0.197][0.197,0.197])	([0.198, 0.238], [0.44,0.553])	([0.198, 0.238], [0.44,0.553])
C12	([0.000, 0.000], [0.8,1.000])	([0.000, 0.000], [0.8,1.000])	([0.468, 0.583], [0.44,0.542])	([0.509, 0.623], [0.4,0.498])	([0.198, 0.24], [0.44,0.559])	([0.5,0.605][0.43,0.523])	([0.315, 0.366], [0.44,0.523])	([0.292, 0.313], [0.2,0.26])	([0.197,0.197][0.197,0.197])	([0.343, 0.392], [0.39,0.474])

C13	([0.000, 0.000], [0.85,1.000])	([0.000, 0.000], [0.82,1.000])	([0.521, 0.628], [0.43,0.512])	([0.566, 0.67], [0.38,0.464])	([0.198, 0.24], [0.44,0.559])	([0.5,0.605][0.43 ,0.523])	([0.315, 0.366], [0.44,0.523])	([0.292, 0.313], [0.2,0.26])	([0.343, 0.392], [0.39,0.474])	([0.197,0.197][0. 197,0.197])

Table 5: Criteria of Weights

Criteria	Weights
C44	0,375
C910	0,229
C11	0,032
C91	0,041
C14	0,071
C92	0,029
C84	0,068
C41	0,046
C12	0,054
C13	0,06

3. Results

Criterion weights, acquired through the PFAHP method, serve as inputs for evaluating alternatives. These weight values are instrumental in determining the optimal e-learning platform alternatives through the application of PFTOPSIS. Linguistic variables, defined by Pythagorean fuzzy numbers illustrated in Table 5, are employed to assess potential substitutes for e-learning platforms. Decision makers, utilizing the linguistic terms outlined in Table 6, evaluate the alternatives based on the specified criteria. Subsequently, each decision maker's assessment is expressed in the form of Pythagorean fuzzy numbers and amalgamated using the Pythagorean fuzzy weighted averaging (PFWA) operator. The resulting Aggregated Pythagorean decision matrix is presented in Table 7.

Table 6: Linguistic Terms and Pythagorean Fuzzy Numbers

Linguistic Term	Corresponding Pythagorean Fuzzy Number (u,v)
Very poor (VP)	(0.15, 0.85)
Poor (P)	(0.25, 0.75)
Medium poor (MP)	(0.35, 0.65)
Medium (M)	(0.50, 0.45)
Medium good (MG)	(0.65, 0.35)
Good (G)	(0.75, 0.25)
Very good (VG)	(0.85, 0.15)

Table 7: Aggregated Pythagorean decision matrix

	S1, Google Meet	S2,Microsoft Teams	S3, Skype	S4, Zoom
C44	(0.7, 0.304)	(0.62, 0.371)	(0.46, 0.509)	(0.35, 0.65)
C910	(0.73, 0.28)	(0.74, 0.265)	(0.56, 0.415)	(0.66, 0.34)

C11	(0.75, 0.25)	(0.75, 0.25)	(0.69, 0.314)	(0.73, 0.28)
C91	(0.7, 0.304)	(0.66, 0.341)	(0.53, 0.467)	(0.61, 0.381)
C14	(0.7, 0.304)	(0.77, 0.237)	(0.62, 0.371)	(0.7, 0.304)
C92	(0.75, 0.25)	(0.73, 0.281)	(0.66, 0.341)	(0.7, 0.304)
C84	(0.72, 0.302)	(0.72, 0.304)	(0.51, 0.491)	(0.51, 0.491)
C41	(0.83, 0.178)	(0.83, 0.179)	(0.73, 0.281)	(0.73, 0.28)
C12	(0.79, 0.216)	(0.75, 0.257)	(0.61, 0.381)	(0.72, 0.286)
C13	(0.83, 0.178)	(0.79, 0.212)	(0.81, 0.199)	(0.77, 0.237)

Following the creation of the Pythagorean fuzzy decision matrix in the PFTOPSIS method, positive ideal solution (PIS) and negative ideal solution (NIS) values are determined, and closeness coefficients are calculated. These derived values are depicted in Table 8. The prioritized order of e-learning platforms is as follows: S1≥S2≥S3≥S4. Consequently, the top-ranked alternative is S1.

Table 8: Closeness Coefficients of Suppliers

	$D(x_i, x^+)$	$D(x_i, x^-)$	$\xi(x_i)$	**Rank**
S1, Google Meet	0.01	0.22	0.00	1
S2, Microsoft Teams	0.04	0.19	-3.76	2
S3, Skype	0.17	0.05	-22.59	3
S4, Zoom	0.19	0.04	-24.31	4

4. Conclusion

Online learning platforms enhance student-faculty interaction, increase educational accessibility, and elevate the overall learning experience. These platforms play a crucial role in addressing the evolving educational landscape and shaping future learning environments within universities. In the conducted study, utilizing the Pythagorean Fuzzy AHP/TOPSIS evaluation, it was established that Microsoft Teams exhibited superior performance, aligning seamlessly with the identified criteria for an optimal E-Learning Platform for Universities. The carefully selected criteria, weighted appropriately, significantly contributed to its elevated ranking and suitability for meeting the educational needs and requirements of universities.

This evaluation process highlights the importance of employing structured methodologies such as Pythagorean Fuzzy AHP/TOPSIS in intricate decision-making scenarios. This ensures a systematic and well-informed selection of the optimal solution, aligning with specified criteria and catering to the preferences of stakeholders.

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