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Application of Multi-Criteria Decision-Making Models for Assessment of Education Quality in Water Resources Engineering

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Abstract: Assessing and improving the quality of education in universities can play a prominent role in developing countries. This study aims to demonstrate an extensive methodology with a related algorithm for assessing the quality of education in Water Resource Engineering (WRE) based on Klein's learning model and using the hybrid fuzzy-AHP-TOPSIS (FAT) method. Four out of the top ten universities in Iran, including Iran University of Science and Technology (IUST), Amirkabir University of Technology (AUT), Shiraz University (SU), and Khajeh Nasir al-Din Toosi University of Technology (KUT), are considered as case studies. First, participants answered questions based on Klein's model so that the weight coefficients according to the fuzzy-AHP technique were extracted. Second, these coefficients were transferred to the TOPSIS environment, where the previously prioritized criteria were utilized to select the ideal solution. Finally, the relative closeness of universities (CC) as a performance evaluation criterion in the form of CC(IUST) = 0.54, CC(AUT) = 0.49, CC(SU) = 0.45, and CC(KUT) = 0.39 was obtained. The sensitivity analysis was performed based on the number and type of Klein's qualitative criteria on the model, and Fourier series expansion curves were used to better compare the results of the proposed algorithm. The presented algorithm in this research can be a good basis for education assessment models in universities.

Keywords: multi-criteria decision-making; fuzzy-AHP-TOPSIS method; Klein's pattern

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1. Introduction

Engineering departments in universities are live laboratories or actual testing grounds where novel solutions are created, developed, and evaluated for efficacy before being implemented in full at the community level [1–4]. Among several branches of engineering, Water Resource Engineering (WRE) is taught in numerous engineering universities around the world because water is an essential resource for humans, ecosystems, and economic growth [5–8].

The planning and management of water resources and the design and implementation of water projects are only a few of the many areas that WRE addresses. One of the primary factors in raising the standard of WRE instruction in colleges and universities may be the availability of challenges in the field [9–11]. In addition, evaluating students' experience is essential for improving the quality of education in universities [12–14]. For instance, in response to the expansion of technology and population, have universities embraced and put into practice effective strategies for managing water resources or maximizing the use of already-existing waters [15]? How do we address global challenges due to an uneven distribution of water resources, where some countries have severe water shortages [16,17] while others experience major flooding [18]? Such queries highlight the need to establish high-quality scientific environments, particularly in the field of WRE. It is widely believed that higher education provides a range of general benefits, including increased awareness and adaptability, alignment between goals and actions, personal and professional development, and changes in behavior [19–21].

Naveed et al. [22] identified the key factors contributing to success in the context of remote learning in Saudi higher education institutions. These factors were validated using the combined Content Validity and Reliability Analysis (CVARA) technique. The identified components were categorized into five groups: student, instructor, design and content, system and technology, and institutional management services. Makki et al. [23] utilized Goal Programming (GP) to plan the enrollment of university students. Their findings revealed that this technique could be applied to various aspects of university management, including human resource planning, teaching load distribution, faculty-to-student ratios, accreditation, quality standards, lab capacity planning, equipment procurement, and financial planning. Numerous studies have been conducted on the efficiency of engineering education, particularly in Civil Engineering, to address challenges faced by universities [24]. Paul [25] developed SecondLife, a web-based virtual reality tool designed for civil and environmental engineering students. This tool highlights the importance of students developing their employability skills from the beginning of the academic year, alongside their university instruction, thereby enhancing the university's engagement with industry. Ahammed and Smith [26] employed SPSS statistical tests to predict students' performance in a three-year course on creating Water Resource Engineering (WRE) systems at the University of South Australia. They examined the relationship between students' online engagement and their academic success.

The Multi-Criteria Decision-Making (MCDM) approach is a widely used method for decision-making across various fields. One of the MCDM techniques, the Analytical Hierarchy Process (AHP), is a powerful and intuitive tool that involves pairwise comparisons of alternatives based on expert assessments. This approach helps to separate and distinguish the elements of a problem by assigning weights to them [27–30]. The AHP technique has been utilized by Tsinidou et al. [31] to assess the relative importance of qualitative factors influencing student satisfaction. According to existing studies [32,33], the increasing use of the AHP method in educational settings has led to the prioritization of more relevant parameters aimed at enhancing both the quantitative and qualitative aspects of educational institutions and research centers. While researchers also apply alternative methods such as FUCOM, BWM, DIBR, and LBWA, their use is often constrained by specific objectives and limitations. In contrast, this study opted for the AHP method due to its widespread popularity among researchers [34–38].

There are several computational methods available for multi-criteria decision-making, each with its own advantages and limitations. For example, the VIKOR method is commonly used in decision-making processes that employ compromise programming. This method is particularly useful when the decision-maker faces challenges in determining the relative importance of criteria, whether proportional or non-proportional. In such scenarios, the VIKOR method helps identify a solution that takes into account multiple criteria simultaneously [39].

Another method, called MABAC, has been proposed specifically for ranking research alternatives. It determines rankings based on the distance from the geometric mean of the available options. However, it is important to note that the applicability of this method is limited to certain scenarios, and the resulting rankings may not provide sufficient value or accuracy for all types of problems [40]. MAIRCA is another MCDM technique that generates rankings for different options after performing the necessary computations. The inputs for this method include the decision matrix, criterion weights, and types of criteria. Key concepts such as gap, actual weight, and theoretical weight are integrated into the method and influence the final ranking. Notably, the best option in this technique is determined by the one with the smallest gap. It can be said that this method follows a comprehensive process to reach a solution [40].

Among the newer ranking methods for multi-criteria decision-making problems is the MARCOS method. Similar to the TOPSIS method, alternatives are ranked by constructing a decision matrix. However, the MARCOS method alone cannot calculate criterion weights and is typically used in conjunction with other techniques, such as AHP [41,42]. In this particular study, the TOPSIS method was employed. The use of the TOPSIS method allows for the identification of the best possible solutions within the range of problem criteria, while properly accounting for the importance of each criterion [43,44]. The advantages of this method include its ability to handle both positive and negative criteria, accommodate both quantitative and qualitative criteria, and convert qualitative criteria into quantitative measures. Additionally, its computational simplicity is another notable benefit [45–47].

The Technique for the Order of Preference to Similarity to the Ideal Solution, or TOPSIS method, is another widely recognized MCDM approach used by many researchers [42,48,49]. When combined with AHP, the resulting AHP-TOPSIS hybrid method has provided a robust tool that has gained significant popularity among academics in recent years. In this approach, the AHP model first determines the weights of the problem criteria, which are then applied in the TOPSIS model to rank the alternatives. İnce and Hakan Isik [46] used the AHP-TOPSIS combination to select learning objects from a variety of options in web-based educational systems, such as texts, data, figures, and tables. Alqahtani and Rajkhan [50] employed the AHP and TOPSIS methods to identify the most beneficial aspects of e-learning during the COVID-19 pandemic. However, some researchers, including Huynh-Cam et al. [51], have applied alternative algorithms, such as Decision Trees (DT) and Random Forest (RF) Algorithms, to estimate and identify key factors in university students' learning.

Fuzzy set theory is a powerful mathematical tool widely used in various scientific fields. It is particularly useful when the data are qualitative, when there are insufficient data points, when the data lack precision, or when they originate from uncertain sources. Fuzzy concepts are ideal for finding optimal solutions in such cases [52]. Moreover, fuzzy methods are commonly used to quantify approximation, experimental results, and non-classical events [53]. Since emotions often influence decision-making in MCDM problems, various levels of vagueness can arise in the solutions. Therefore, it is recommended to use fuzzy concepts in these problems to better handle uncertainty and imprecision [54].

Some researchers have applied MCDM techniques in fuzzy environments to solve engineering challenges, particularly in Civil Engineering [55]. While MCDM approaches and their combinations help decision-makers rank and select the best alternatives in various contexts [56–58], few studies have explored the use of hybrid fuzzy combinations of these methods to address challenges in university education [59–62]. In general, fuzzy approaches or MCDM methods have been sporadically or inefficiently applied to the quantitative and qualitative evaluation of teaching and learning outcomes in higher education.

Universities and higher education institutions play a crucial role in the health and development of any society. In this study, to assess the educational status of Iranian universities, four top universities that consistently compete with each other in terms of amenities and education quality were selected: Iran University of Science and Technology (IUST), Amirkabir University of Technology (AUT), Shiraz University (SU), and Khajeh Nasir al-Din Toosi University of Technology (KUT). The study aimed to evaluate the quality of education from the perspective of master's students in Water Resource Engineering (WRE) using questionnaires. After reviewing various sources, it was concluded that MCDM techniques are rarely employed to assess educational quality in universities. In this study, the combined AHP and TOPSIS method was applied in a fuzzy environment, as this combination offers robust mathematical calculations, effectively handles weighting and normalization of initial data, and provides more reliable results. One key advantage of converting data into a fuzzy form is that it reduces the impact of random and outlier data, leading to improved results, better decision-making, and more realistic future planning. While many criteria have been proposed by researchers to evaluate educational quality, this study adopted the model proposed by Klein, which includes diverse, comprehensive, and measurable parameters. Klein's model consists of nine parameters: aims and objectives, content, learning activities, teacher role, materials and resources, grouping, location, time, and assessment [63–66]. These parameters were used as the criteria in the AHP-TOPSIS method, with the four selected universities serving as the alternatives. After performing the calculations, the final ranking of the universities, or relative closeness coefficient, was determined. The results were further analyzed using Fourier series expansion and sensitivity analysis, with figures and tables included to present the findings.

2. Methodology

2.1. Klein's Learning Pattern and Gathering Data

Klein proposed nine parameters that define the state of education in environments such as schools and universities [63–67]. These parameters, along with their descriptions and specifications, are presented in Table 1. As shown, the nine measurable parameters outlined by Klein include: aims and objectives, content, learning activities, teacher role, materials and resources, grouping, location, time, and assessment. For each parameter, both a simple definition and a more detailed description are provided, accompanied by concrete examples to ensure that readers can fully comprehend their meaning and application [63,64,67–70].

Table 1. Description and characteristics of criteria based on Klein's learning pattern [63–69].

Aims and Objectives	-Definition: Objectives for teaching and learning are defined as the current or expected elements of learning that represent the desired outcomes, based on the information available today. -Description: These objectives are shaped by past experiences, considering the skills, talents, and needs of students, as well as technological and scientific advancements. They must align with societal norms, customs, and laws; be evaluable, adaptable, and applicable across various regions; and address cognitive, emotional, and physical aspects, among others.

Table 1. *Cont.*

Content	-Definition: It is defined as the facts, ideas, concepts, processes, generalizations, attitudes, beliefs, and skills with which students engage as they experience the curriculum. -Description: Achieving curriculum goals involves considering human and moral values; focusing on knowledge, skills, and processes; ensuring relevance to students' interests, abilities, and future careers; quantifying and qualifying the content; logically linking concepts and topics; employing a specific methodology; and standardizing the approach, among other factors.
Learning activities	-Definition: Activity refers to what students engage in during the learning process, whether actively or passively. They may be passive, simply reading a book, or active, collaborating with the teacher or classmates. For example, they may work with a computer. -Description: Activities should focus on enhancing scientific, social, and individual skills, considering one's own talents and abilities, establishing logical connections between learning content and goals, recognizing factors influencing study and learning, interacting with others, conducting projects and research, and participating in conferences and meetings, among other aspects.
Teaching role	-Definition: It is defined as the task carried out by a teacher or a teaching tool, such as a computer, written text, or television, aimed at facilitating learning and conveying concepts. -Description: Effective teaching involves having a clear teaching plan; applying diverse methods; adhering to ethical standards in the classroom; fostering hope, enthusiasm, and engagement; encouraging student participation in discussions; helping students discover new facts and concepts; and enabling them to assess their own performance, among other strategies.
Materials and Resources	-Definition: It refers to the objects, places, and people used to facilitate the learning process. -Description: These include resource individuals, textbooks, magazines, computers and software as technologies, videotapes, records, games, and educational facilities such as specialized laboratories with their equipment. Additionally, they encompass the use of diagrams and maps for better understanding, flowcharts and algorithms to solve problems, compiling lists of scientific sources, and other similar tools.
Grouping	-Definition: It refers to the collective participation of individuals in any form. Without mutual assistance, individual knowledge may not contribute to the accurate or deep development of concepts. -Description: Student collaboration involves exchanging information, knowledge, and skills, promoting social and ethical communication, increasing collective participation, engaging in coordinated activities, and grouping students by talent and interest.
Location	-Definition: Maintaining calm and managing normal emotions are essential for effective learning. Therefore, the learning environment's location should be given priority. -Description: This includes the availability of other educational spaces such as libraries; the condition of educational spaces in terms of capacity, lighting, acoustics, and cleanliness; the creation of rest and recovery areas; the location of classrooms; the management of educational centers; and the conditions of laboratories, among other factors.
Time	-Definition: Developing a training program requires adequate and specific time to carry out a pre-planned, comprehensive, complex, and logical process. -Description: This involves allocating learning time, managing time effectively, and setting time for conclusions, exams, rest, and other activities.
Assessment	-Definition: It should be conducted through various methods. For instance, administering tests, organizing competitions, or solving problems can significantly enhance the learning process. -Description: This includes conducting exams, analyzing performance, addressing weaknesses, and reinforcing strengths.

The qualitative parameters proposed by Klein were evaluated for four prominent universities in Iran: Iran University of Science and Technology (IUST), Shiraz University (SU), Amirkabir University of Technology (AUT), and Khajeh Nasir al-Din Toosi University of Technology (KUT), all of which rank among the top ten universities in the country. The study's population consisted of 112 WRE students from these institutions, referring to the academic year 2020. Data were collected through questionnaires and interviews. WRE students were asked to complete surveys to share their opinions on the quality of education at their respective universities, based on the nine criteria. Given the pairwise comparison approach of the AHP method, participants were provided with questionnaires that presented the prioritization of both the four universities (alternatives) and the nine qualitative criteria proposed by Klein. Participants were instructed to complete the questionnaires based on their university's specific conditions to assess the relative importance of the criteria. The questionnaires included the aforementioned items to gather participants' opinions and evaluate the current educational state.

2.2. Fuzzy-AHP Method

Combining MCDM and fuzzy methods is an effective approach to solving decision-making problems in situations where information and preferences are unclear or uncertain. In other words, the ability to make logical and justifiable decisions in complex and ambiguous contexts is enhanced through the fuzzification of data [7,30,52,71–74]. As shown in Figure 1, multiple steps are involved in addressing the problem using the fuzzy-AHP method:

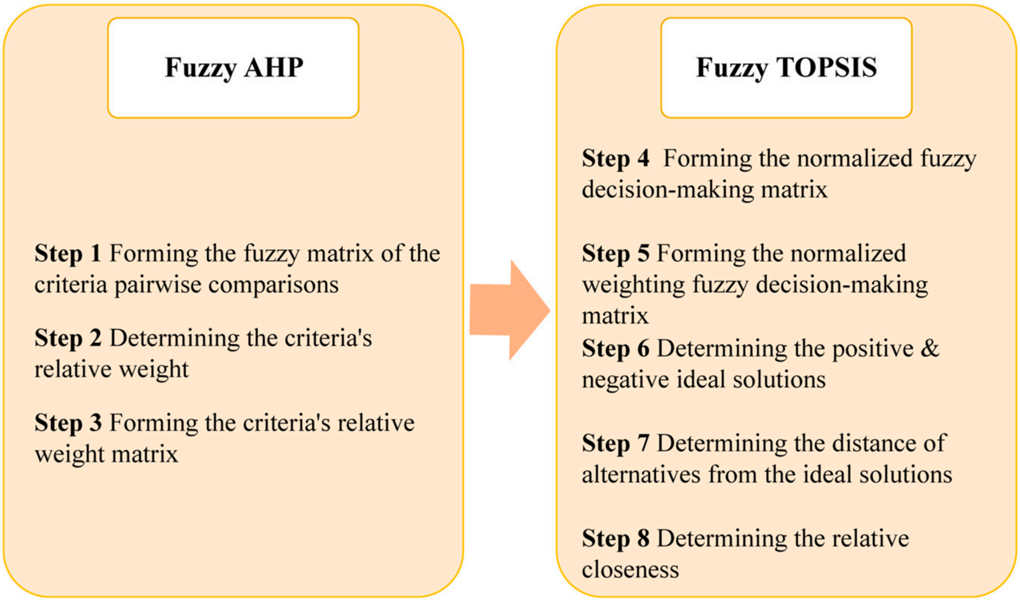

Figure 1. Step-by-step flowchart for implementing the hybrid FAT method [30,49,56,74,75].

Initially, questionnaires are designed and distributed to specialists based on the criteria and alternatives of the problem. The questions should effectively compare all criteria individually while keeping the objectives of the problem in mind. Following this, the triangular fuzzy matrix corresponding to the experts' responses is constructed using Chang's development analysis [72], which is a traditional method similar to the classical AHP approach.

Step 1: Formation of the pairwise comparison matrix, following established guidelines in the literature [72].

Step 2: Calculation of the relative weight of criteria using fuzzy expansion relationships.

Step 3: Creation of a relative weight matrix of criteria, adhering to fuzzy rules, based on the findings from the previous step. This matrix consists of one row, with the number of columns corresponding to the total number of criteria in the problem, and it is used in subsequent phases.

2.3. Fuzzy-TOPSIS Method

The typical TOPSIS method aims to select solutions that are closest to the ideal positive solution and farthest from the ideal negative solution simultaneously. The ideal positive solutions maximize the project's benefit criteria while minimizing its cost criteria, whereas the ideal negative solutions do the opposite. The TOPSIS approach fully utilizes the available data and generates a numerical rating for the alternatives [71].

Step 4: In this step, the participants who completed the initial questionnaire are provided with a follow-up questionnaire to rate the quality of education in their respective universities using a numeric scale of 1 to 9. These numerical ratings can be based on the descriptions provided in the pairwise comparison table of the AHP method. A non-fuzzy decision-making matrix is then compiled based on the questionnaire responses. In certain cases, data normalization techniques and the interpretation of linguistic variables may be necessary [49,73,74].

Step 5: In this step, the normalized weighted fuzzy decision matrix is constructed using the fuzzy weight matrix of problem criteria from Step 2, along with the normalized fuzzy decision matrix obtained in Step 4 [49,73–75].

Step 6: The calculation of the fuzzy positive ideal solution ($\tilde{A}^*$) and fuzzy negative ideal solution ($\tilde{A}^-$).

Step 7: The sum of the distances of the ith alternative from the positive ideal solution in the jth criteria, i.e., d_i^*, and the sum of the distances of the ith alternative from the negative ideal solution in the jth criteria, i.e., d_i^-, are calculated.

Step 8. The relative closeness coefficient (CC_i), which represents the closeness to an ideal solution or the distances to the fuzzy positive-ideal solution (d_i^*) and the fuzzy negative-ideal solution (d_i^-) simultaneously by taking the relative closeness to the fuzzy positive-ideal solution, is calculated based on the following relationship [49,50,73–75].

$$CC_i = d_i^- / \left(d_i^- + d_i^*\right) \quad i = 1,\ 2,\ \ldots,\ m, \tag{1}$$

where CC_i has a value between 0 and 1 according to the above equation. In general, the value of relative closeness will be closer to one if an alternative is closer to the positive ideal solution. Furthermore, one choice with a higher CC_i value is superior to another.

Figure 2 specifies the problem's purpose, qualitative educational criteria based on Klein's model, the alternatives or universities involved in the study, and the instruments required to address the problem using the FAT approach.

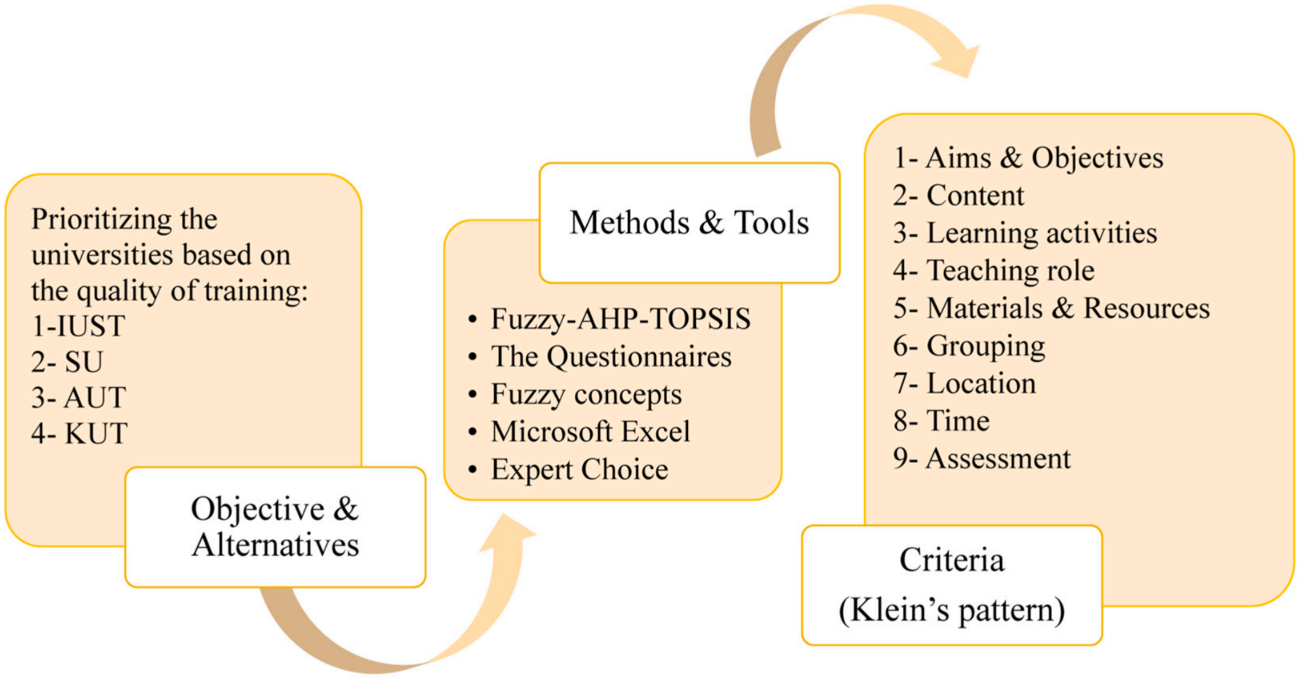

Figure 2. Illustration of the components in the fuzzy-AHP-TOPSIS approach, including the objective, criteria, alternatives, and tools used for decision-making [31,63,65,67,68,70].

3. Results and Discussion

In this research, data were first collected through questionnaires provided to WRE students. Initial calculations were performed, and then the data were transferred to a fuzzy environment using a triangular fuzzy rule to conduct pairwise comparisons and assign weights. Following this, step-by-step calculations for TOPSIS were carried out using Excel software, and the results are presented in separate tables. Below is a detailed description of the process and the data presented in the tables. Table 2 shows a pairwise comparison of matrix criteria for the AHP method in a triangular fuzzy environment. The mean values were calculated in a defined range limited to 1 to 3.5 in the fuzzy environment. However, in a pairwise comparison using the AHP approach, the numerical values of preferences for crisps often range between 1 and 9 [30]. The rules for forming this matrix must be followed precisely; for example, the values on the matrix's main diameter must be (1, 1, 1), the fuzzy triple values of each matrix array must be reversed, and the position of these values relative to each other must be adjusted, etc. More information on the creation of this matrix may be found elsewhere [76,77]. Table 2 also displays the relative weighted coefficients of criteria for the fuzzy-AHP approach based on the preceding steps 2 and 3.

Table 2. Pairwise comparison matrix and weighting coefficients of criteria in the fuzzy environment [32,71,72].

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Aims and Objectives	**Content**	**Learning Activities**	**Teaching Role**	**Materials and Resources**	**Grouping**	**Location**	**Time**	**Assessment**
C1	(1, 1, 1)	(1/2, 1, 3/2)	(2, 5/2, 3)	(2/3, 1, 2)	(3/2, 2, 5/2)	(3/2, 2, 5/2)	(2, 5/2, 3)	(1, 3/2, 2)	(1/3, 2/5, 1/2)
C2	(2/3, 1, 2)	(1, 1, 1)	(2/5, 1/2, 2/3)	(2, 5/2, 3)	(3/2, 2, 5/2)	(5/2, 3, 7/2)	(2/3, 1, 2)	(2/5, 1/2, 2/3)	(1/2, 2/3, 1)
C3	(1/3, 2/5, 1/2)	(3/2, 2, 5/2)	(1, 1, 1)	(2/5, 1/2, 2/3)	(2/3, 1, 2)	(3/2, 2, 5/2)	(3/2, 2, 5/2)	(2, 5/2, 3)	(1, 3/2, 2)
C4	(1/2, 1, 3/2)	(1/3, 2/5, 1/2)	(3/2, 2, 5/2)	(1, 1, 1)	(3/2, 2, 5/2)	(2, 5/2, 3)	(1/3, 2/5, 1/2)	(2/3, 1, 2)	(3/2, 2, 5/2)
C5	(2/5, 1/2, 2/3)	(2/5, 1/2, 2/3)	(1/2, 1, 3/2)	(2/5, 1/2, 2/3)	(1, 1, 1)	(1/2, 2/3, 1)	(2/5, 1/2, 2/3)	(1, 3/2, 2)	(3/2, 2, 5/2)
C6	(2/5, 1/2, 2/3)	(2/7, 1/3, 2/5)	(2/5, 1/2, 2/3)	(1/3, 2/5, 1/2)	(1, 3/2, 2)	(1, 1, 1)	(2/3, 1, 2)	(3/2, 2, 5/2)	(2/3, 1, 2)
C7	(1/3, 2/5, 1/2)	(1/2, 1, 3/2)	(2/5, 1/2, 2/3)	(2, 5/2, 3)	(3/2, 2, 5/2)	(1/2, 1, 3/2)	(1, 1, 1)	(1/2, 2/3, 1)	(3/2, 2, 5/2)
C8	(1/2, 2/3, 1)	(3/2, 2, 5/2)	(1/3, 2/5, 1/2)	(1/2, 1, 3/2)	(1/2, 2/3, 1)	(2/5, 1/2, 2/3)	(1, 3/2, 2)	(1, 1, 1)	(2, 5/2, 3)
C9	(2, 5/2, 3)	(1, 3/2, 2)	(1/2, 2/3, 1)	(2/5, 1/2, 2/3)	(2/5, 1/2, 2/3)	(1/2, 1, 3/2)	(2/5, 1/2, 2/3)	(1/3, 2/5, 1/2)	(1, 1, 1)
	Weighting coefficients ($\times 10^{-4}$)								
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9
	(899, 1564, 2653)	(743, 1227, 2167)	(763, 1301, 2211)	(719, 1241, 2122)	(470, 823, 1415)	(482, 831, 1556)	(635, 1116, 1879)	(596, 1032, 1747)	(504, 864, 1459)

Table 3 depicts a decision matrix created in step 4 to be used in the fuzzy-TOPSIS approach. Initially, the questionnaire was described in crisp terms and on a scale of 1 to 9 based on nine qualitative educational characteristics. Then, it was completed by students from the four universities. After that, the data were entered into this table using statistical procedures such as averaging and bounding the crisp definitive values in a definable fuzzy range [73]. Table 3 also depicts the normalized weighted fuzzy decision matrix generated by the fuzzy-TOPSIS algorithm in step 5.

Table 3. Decision matrix based on the participants' perspectives for fuzzy-TOPSIS method and normalized weighting [37,49,56,71,73–75].

	Decision Matrix Based on the Participants's Perspectives for Fuzzy-TOPSIS Method in Different Universities				Normalized Weighting Fuzzy Decision-Making Matrix in Different Universities			
Criteria	**SU**	**KUT**	**AUT**	**IUST**	**SU**	**KUT**	**AUT**	**IUST**
C1	(0, 0.1, 0.3)	(0.1, 0.2, 0.4)	(0, 0.1, 0.3)	(0.1, 0.3, 0.5)	(0, 156, 796)	(90, 313, 1061)	(0, 156, 796)	(90, 469, 1327)
C2	(0, 0.1, 0.2)	(0.1, 0.2, 0.4)	(0.1, 0.2, 0.4)	(0.1, 0.3, 0.5)	(0, 123, 433)	(74, 245, 867)	(74, 245, 867)	(74, 368, 1083)
C3	(0.3, 0.5, 0.7)	(0, 0.1, 0.3)	(0, 0.1, 0.3)	(0.1, 0.2, 0.4)	(229, 651, 1548)	(0, 130, 663)	(0, 130, 663)	(76, 260, 884)
C4	(0.1, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.4, 0.6, 0.8)	(72, 248, 849)	(216, 620, 1486)	(216, 620, 1486)	(288, 744, 1698)
C5	(0, 0.1, 0.3)	(0, 0.1, 0.2)	(0.2, 0.4, 0.6)	(0.1, 0.2, 0.4)	(0, 82, 424)	(0, 82, 283)	(94, 330, 849)	(47, 165, 566)
C6	(0.1, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0, 0.1, 0.2)	(0, 0.1, 0.3)	(48, 166, 623)	(144, 415, 1090)	(0, 83, 311)	(0, 83, 467)
C7	(0.3, 0.5, 0.7)	(0, 0.1, 0.3)	(0.5, 0.7, 0.9)	(0.1, 0.3, 0.5)	(190, 558, 1315)	(0, 111, 563)	(317, 781, 1691)	(63, 335, 940)
C8	(0.4, 0.6, 0.8)	(0.1, 0.3, 0.5)	(0.1, 0.2, 0.4)	(0.3, 0.5, 0.7)	(238, 619, 1397)	(053, 309, 0875)	(60, 206, 699)	(179, 516, 1223)
C9	(0.2, 0.4, 0.6)	(0.3, 0.5, 0.7)	(0.4, 0.6, 0.8)	(0.1, 0.3, 0.5)	(101, 346, 876)	(151, 432, 1021)	(201, 518, 1167)	(50, 259, 730)

Data normalization involves removing the measurement scale from the data, making it easier to compare different data points. As a result, the decision matrix becomes dimensionless. Various methods can be used for data normalization, such as linear or vector methods, but in the TOPSIS, the vector method is typically employed. Based on this approach, the results presented in this table have been derived [49,71,73–75].

To create a FAT problem, the relative weight coefficients of the problem's criteria generated by the fuzzy-AHP technique are combined with the fuzzy matrix values of the fuzzy-TOPSIS method via mathematical procedures. The weighted coefficients of the relevance of the criteria and the grading of the importance of universities are thus established statistically, rather than qualitatively, depending on the desired criteria. Following step 6, the ideal positive and negative solutions to the issue are derived in columns 2 and 3 of Table 4. In addition, the distance of alternatives from these ideal positive and negative values is calculated in columns 4–11 based on qualitative education criteria [30,37,48,51,56].

Table 4. Fuzzy positive ($\tilde{A}^*$) and negative ($\tilde{A}^-$) ideal solutions, and the sum of distances from the positive (d^*) and negative (d^-) ideal solutions ($\times 10^{-4}$) [30,49,56,73–75].

Col. 1	**Col. 2**	**Col. 3**	**Col. 4**	**Col. 5**	**Col. 6**	**Col. 7**	**Col. 8**	**Col. 9**	**Col. 10**	**Col. 11**
Criteria	$\tilde{\mathbf{A}}^*$	$\tilde{A}^-$	***d**** **(SU)**	***d***$^-$ **(SU)**	***d**** **(KUT)**	***d***$^-$ **(KUT)**	***d**** **(AUT)**	***d***$^-$ **(AUT)**	***d**** **(IUST)**	***d***$^-$ **(IUST)**
C1	(90, 469, 1327)	(0, 156, 796)	359	0	178	185	359	0	0	359
C2	(74, 368, 1083)	(0, 123, 433)	403	0	144	264	144	263	0	403
C3	(229, 651, 1547)	(0, 130, 663)	0	607	607	0	607	0	452	155
C4	(288, 744, 1698)	(72, 248, 849)	581	0	148	434	148	434	0	581
C5	(94, 330, 849)	(0, 82, 283)	289	82	361	0	0	361	191	172
C6	(145, 415, 1090)	(0, 83, 311)	311	188	0	496	496	0	416	90
C7	(317, 781, 1691)	(0, 112, 564)	263	517	779	0	0	779	526	255
C8	(238, 619, 1397)	(60, 206, 699)	0	480	366	117	480	0	122	358
C9	(201, 518, 1167)	(50, 259, 730)	204	102	102	204	0	306	306	0
Sum			2410	1975	2685	1700	2233	2143	2014	2374

Finally, the relative closeness coefficients for the four universities analyzed are CC(IUST) = 0.54, CC(AUT) = 0.49, CC(SU) = 0.45, and CC(KUT) = 0.39. The value of CC is always between 0 and 1. The closer the alternative is to the positive ideal, the closer the relative closeness to 1. As a result, the ranking of universities in terms of qualitative WRE education is IUST > AUT > SU > KUT, with IUST having a higher relative performance. Following the preceding steps, the proposed problem was calculated for 18 specific situations, and the relative closeness for the criterion and four institutions is shown in Tables 4 and 5. These tables can provide many conclusions, but some of the most significant ones are shown in the following table:

Table 5. Relative closeness for all four universities with consideration of selected criteria [30,49,73–75].

Considered Criteria Number	The Relative Closeness of the Universities			
	SU	KUT	AUT	IUST
1	0	0.55	0	1
1 and 2	0	0.60	0.40	1
1, 2 and 3	0.44	0.32	0.17	0.67
1, 2, 3 and 4	0.26	0.48	0.38	0.81
1, 2, 3, 4 and 5	0.25	0.42	0.48	0.76
1, 2, 3, 4, 5 and 6	0.27	0.50	0.41	0.68
1, 2, 3, 4, 5, 6 and 7	0.38	0.39	0.52	0.58
1, 2, 3, 4, 5, 6, 7 and 8	0.50	0.30	0.38	0.54
1, 2, 3, 4, 5, 6, 7, 8 and 9	0.45	0.39	0.49	0.54

- Table 5 shows that while SU has seen significant quality growth and performs very well with the addition of criterion number 3, it has experienced a loss in quality status based on the relative closeness coefficient with the addition of criterion numbers 4, 5, 6, and 7. Furthermore, when the data in rows 2 and 3 of the table are compared, it is clear that SU is the only one whose relative proximity has increased with the addition of criterion number 3. In other words, when compared to the other three institutions, the quality status of criterion number three, i.e., learning activities, has been determined to be very important and effective. This issue is also noticeable in rows 3 and 7 of Table 3.

- KUT has the lowest relative closeness for nine quality criteria, as shown by the last two rows of Table 5. To prevent further decreases in relative closeness, it is advised that this university tighten its requirements for numbers 8, time, and 9, assessment. Other quality criteria should also be taken into account.

- As previously mentioned, the superiority of one alternative over others increases for a given set of criteria as the relative closeness approaches one. In Table 6, the maximum relative closeness is 0.58, while the minimum is 0.30. It is determined that, in the respondents' opinion, university conditions have gotten worse and that all institutions, even prestigious ones, should make plans and try to raise educational standards.

Table 6. Relative closeness coefficient for all four universities with the removal of a single criterion [30,49,56,74,75].

Considered Criteria Number	The Relative Closeness of the Universities			
	SU	KUT	AUT	IUST
All, except 1	0.50	0.36	0.52	0.50
All, except 2	0.48	0.37	0.48	0.50
All, except 3	0.37	0.45	0.57	0.58
All, except 4	0.52	0.34	0.43	0.46
All, except 5	0.48	0.42	0.44	0.55
All, except 6	0.47	0.30	0.55	0.58
All, except 7	0.46	0.39	0.31	0.53
All, except 8	0.39	0.42	0.54	0.55
All, except 9	0.50	0.30	0.38	0.54

- According to Table 6, the standard deviation of the values for relative proximity is somewhat greater than 0.1 for rows 6 and 9, almost equal to 0.05 (the minimum value) for rows 2 and 5, and ranges from 0.1 to 0.05 in the remaining cases. Accordingly, it can be claimed that eliminating quality criteria 2 and 5 and adding quality criteria 6 and 9 causes the least change in the relative closeness values for each of the four universities. In other words, of the nine quality criteria considered, these four quality characteristics had the most influence on the superiority of institutions over one another based on the relative closeness coefficient.

- The standard deviation of relative proximity values fluctuates in most rows of Table 6 within a relatively small range of 0.1 to 0.05, indicating that there is intense competition among the four universities for the best academic programs. The probability of changing the preferred universities' rankings and domination over the others in subsequent years is very high. According to the data in this table, institutions are highly competitive, and their relative proximity to one another is changing.

- The IUST has the lowest and highest values of the standard deviation of the data in each column, respectively, of 0.04 and 0.09, according to Table 6 and simple calculations. For the other universities, the standard deviation is roughly 0.05. It can be inferred that IUST's integrated management for the concurrent control and promotion of the nine quality criteria is reasonably good and that each of the quality criteria has been thoroughly taken into account. Namely, the values assessed for this university's quality criteria are not significantly different, and eliminating each of the quality criteria has no significant impact on this university's superiority over the other three universities. In contrast, some quality standards of AUT are substantially higher than at other universities, while others are significantly lower.

- When the data in Tables 4 and 5 are compared, it is clear that IUST is closer to the positive ideal than the other three universities, except for row 4 of Table 6, where SU has the best performance with a relative closeness of 0.52. This demonstrates that the values chosen for criterion 4, the teaching role, at IUST, are high and significant from the perspective of the competent people who submitted the surveys. AUT is in direct competition with IUST, according to rows 1, 3, and 7 of Table 6.

Because relative comparison occurs in MCDM approaches [30,49,56], there is a periodic fluctuation in the results values caused by reducing or increasing one or more criteria. The relative-closeness coefficient is employed in this study for the AHP-TOPSIS approach, which analyses and evaluates four universities. This characteristic of MCDM approaches allows for the application of Fourier series expansion [78] to determine the significance of criteria and evaluate the situation more clearly. However, the Taylor series expansion [79] can also be used to evaluate the obtained results by taking into account related considerations and assumptions.

A Fourier series is a periodic function extension in terms of an infinite algebraic sum of sines and cosines functions that form a link between these two types of trigonometric functions. Figure 3 depicts the change in relative-closeness coefficients based on the number of quality criteria for the problem as well as the relative-closeness coefficients, as shown in Table 5, except for its first row. It is worth noting that using only one criterion resulted in fitting curves falling down the horizontal axis. Each curve in Figure 3 corresponds to one of the four chosen universities; hence, only a sort of third-order Fourier series expansion with a high R-square (from 0.90 to 0.99) is fitted. These curves represent a regular pattern of activity, from which a wide variety of inferences can be inferred, which are briefly discussed below:

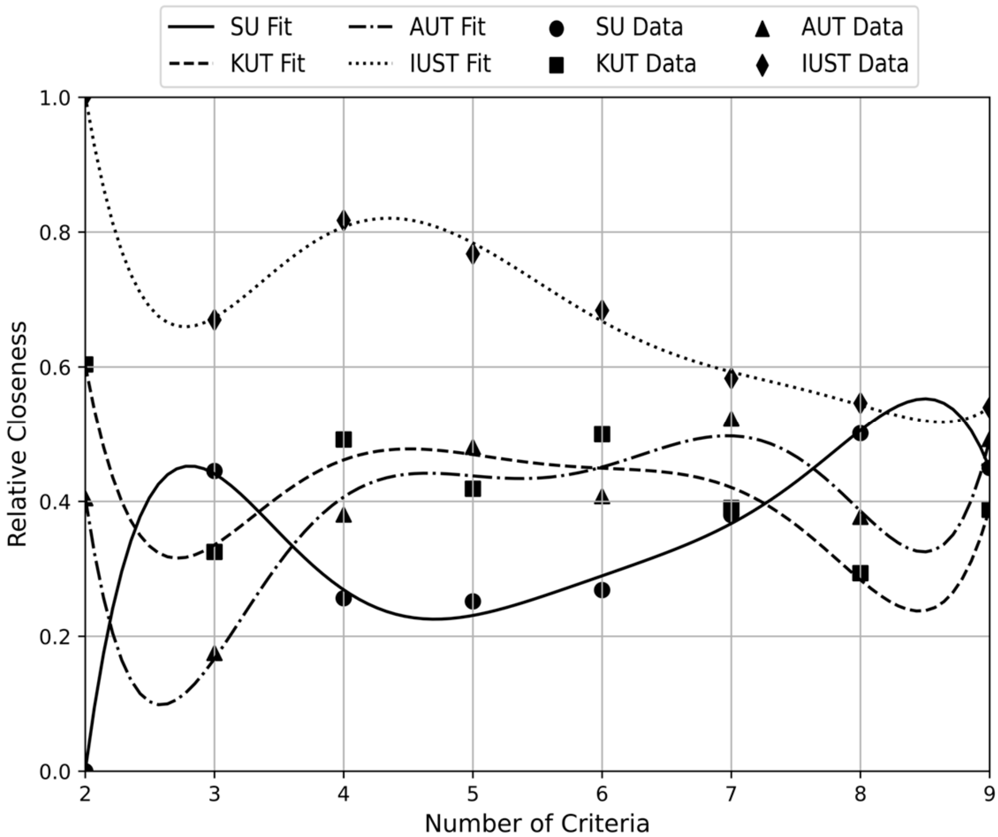

Figure 3. Analyzing the changes in education quality across four universities based on relative-closeness coefficients and number of criteria (Table 5).

- For IUST, as the number of quality criteria increased, the slope of the curve fell, indicating that the university's performance decreased. One of the reasons is that this university paid close attention to some criteria while paying little attention to others. Another reason for this behavior is the AHP-TOPSIS model's relative comparison of criteria.

- The behavior of the SU and KUT is in direct opposition to one another, as seen by this figure, which is also in agreement with Figure 3. That is, students might select one of these two universities based on the importance of their desired criteria.

- The most fluctuations, as shown in the previous figure, occur at AUT. That is, changing the quantity and kind of quality criteria has a significant impact on the relative closeness coefficient.

- The fluctuating trend of the relative-closeness coefficients at AUT is regular, intense, and has a short-wave height. This ensures that, despite the high sensitivity of the quality criteria, quality control is carried out correctly and on time.

- The fluctuating pattern of the relative-closeness coefficients is generally mild for SU and KUT, with multiple wavelengths but normal wave heights. This is because, practically, all criteria are taken into consideration, although this attention to the criterion is not particularly high. Furthermore, the shifting tendency at these two universities is diametrically opposed because specific criteria in one university receive more attention than in the other.

Figure 4 shows the changes in the relative closeness coefficients for the removal of only one of the quality criteria (except the removal of criterion 1) for four universities. The curves shown were fitted by second-order Fourier series expansion with a high correlation coefficient between 0.85 and 0.97. This figure leads to the following findings:

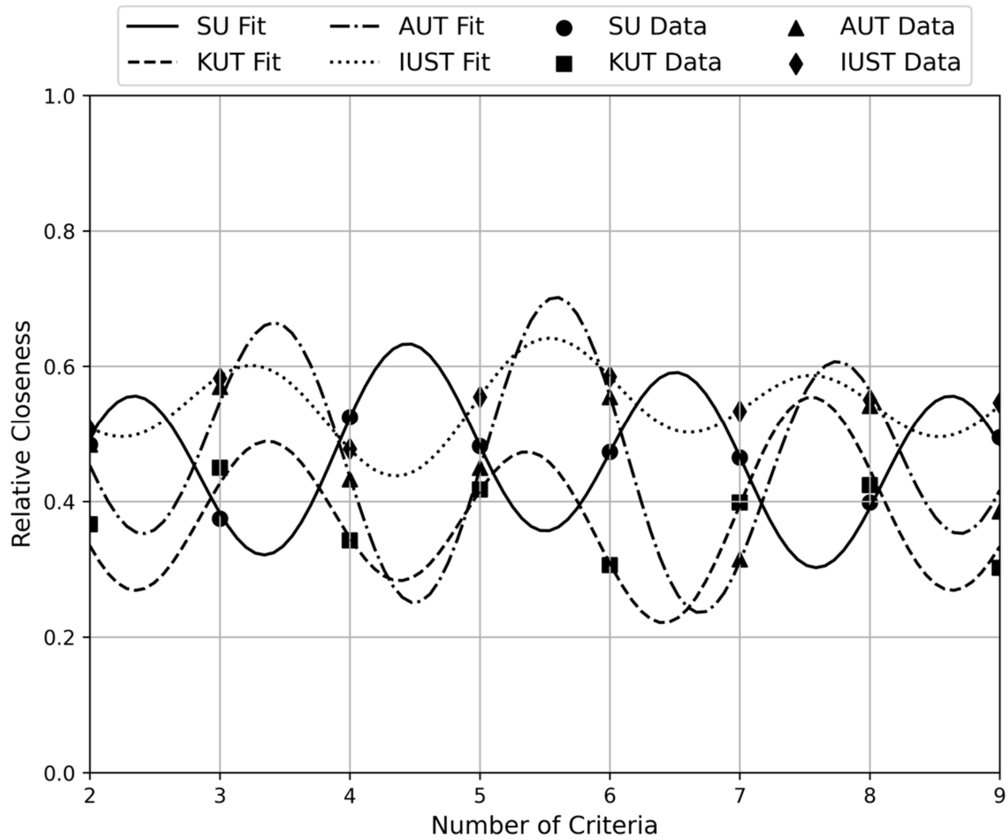

Figure 4. Analyzing the changes in education quality across four universities based on relative-closeness coefficients with the removal of a single criterion (Table 6).

- The values on the vertical axis in this figure range from 0.2 to 0.7, while those in Figure 3 range from 0 to 1. This indicates that, in general, the relative-closeness coefficients decrease as the number of criteria increases due to the relative nature of the comparisons and the systematic influence of the criteria on each other.

- The highest and lowest curves generally represent IUST and KUT, respectively, and as a result, they have the highest and lowest relative-closeness coefficients.

This study provides a comprehensive examination of some Iranian universities. It is important to highlight that these cases not only generate significant interest among beneficiaries, including civil engineering students but also shed light on the impact of decision support systems on decision-making processes. Additionally, they foster a sense of active engagement in real-world political scenarios [77,80].

4. Conclusions

Quantitative research on evaluating the quality of education in higher education institutions using MCDM techniques has been limited thus far. This study aimed to demonstrate the application of powerful techniques in MCDM to assess the quality of education in educational institutions. Sensitivity analysis and scenario comparison were utilized to gain a better understanding of influential factors and identify suitable patterns for educational development and future planning. To compare and evaluate the quality of education in universities, the study employed the FAT approach [30,49,56,74,75] and Klein's learning model [63,67,68]. The FAT method emphasized criteria weighting and fuzzification using the AHP technique [77,81] and weighting criteria based on university type with the TOPSIS method [44,73], determining relative-closeness coefficients for prioritizing universities. The educational quality in the field of Civil Engineering was investigated in four renowned Iranian universities.

The findings revealed the ranking of universities in terms of WRE education quality from the perspective of students in 2020, considering nine quality parameters. The rankings were as follows: IUST > AUT > SU > KUT, indicating the superior relative performance of IUST. Furthermore, eighteen specific situations were explored using various qualitative criteria, tables, graphs, and Fourier series expansion, revealing noteworthy features worthy of investigation and evaluation.

The material presented in the previous section represents a comprehensive analysis, an evaluation example, and a key guide for numerous academic case studies that can always be adapted.

Future research should broaden the scope by considering additional universities, faculty members, students, and academic subjects to examine the quality of education in universities more comprehensively. The methodology presented in this study can be applied to assess the quality of WRE education in different countries, enhance graduates' capabilities, and assist universities in addressing weaknesses and highlighting strengths.

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