Hindawi
Applied Computational Intelligence and Soft Computing
Volume 2022, Article ID 4540875, 18 pages
https://doi.org/10.1155/2022/4540875

Research Article

A New Self-Assessment "TQM Hybrid MCDM Fuzzy Model" For Enhancing the KPIs in Mega Universities

Abdul Hamid M. Ragab,[1] Amin Y. Noaman,[1] Ahmed A. A. Gad-Elrab ,[1,2] and Ezz H. Abdul Fatah[3]

[1]*Faculty of Computing and Information Technology, King Abdulaziz University, Jeddah, Saudi Arabia*
[2]*Department of Mathematics and Computer Science, Faculty of Science, Al-Azhar University, Cairo, Egypt*
[3]*Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia*

Correspondence should be addressed to Ahmed A. A. Gad-Elrab; aaahmad4@kau.edu.sa

Received 17 January 2022; Accepted 19 May 2022; Published 18 June 2022

Academic Editor: Babak Daneshvar Rouyendegh (B. Erdebilli)

The key performance indicators (KPIs) are an effective part of benchmarking for measuring the performance of universities aiming to raise the university quality services level. The problem is that there is no general standard analytical evaluation model for assessing KPIs criteria in higher education institutes for evaluating mega universities, and there are inadequacies in the treatment of specific current educational quality standards. In this paper, a hybrid fuzzy analytical model for TQM self-assessment to enhance KPIs in mega universities is proposed. The proposed model produces important weights for TQM-KPIs that are recommended for helping higher authorities at the university for enhancing the demanded total quality services and aid the university to achieve its strategic objectives and to be one of the highly ranked universities. In addition, the European Foundation for Quality Management (EFQM) excellence model enabler criteria were modified and used. Two additional enabler criteria for representing the mega university and the world ranking were proposed. The "TQM Hybrid Fuzzy Model" proposed integrates three fuzzy multiple criteria decision-making (MCDM) submodels including (1) the fuzzy analytic hierarchy process (FAHP), (2) the fuzzy decision-making trial and evaluation laboratory (FDEMATEL), and (3) the fuzzy multiple criteria decision analysis (FVIKOR). Each of these submodels is computed and evaluated analytically. A comparison between them is achieved. Finally, the whole "TQM Hybrid F-MCDM Model" proposed is proved and evaluated analytically and programmed using Excel. Hence, by comparison, it is found that the proposed hybrid fuzzy model is the most effective model for evaluating the TQM-KPIs for enhancing mega universities' organizational assessment. Results show that the subcriteria that occupied the first three positions are the managed and improved distance learning sources and materials, policy, and strategies that are based on the present and future needs and expectations of stakeholders.

1. Introduction

MEGA universities have achieved outstanding improvements in distance learning in the education area; however, there are several challenges to overcome to develop a universal quality model to cater to the needs of the mega universities (MU) to empower its role and innovation capabilities [1–4]. The key performance indicators (KPIs) are an effective part of benchmarking for measuring the performance of universities [5] since they help university decision-makers to participate in community services effectively. To achieve that, in this paper, the development of a hybrid MCDM fuzzy model for total quality management self-assessment is proposed for measuring KPIs to enhance the quality of MU. This is because there is no universal standard analytical model that can be used to assess the KPIs criteria for evaluating MU. Besides, there are shortcomings in the coverage of some current MU educational quality criteria [6]. The method produces important weights for criteria and subcriteria that are recommended for helping decision-makers at MU for enhancing its educational quality services. Moreover, it helps MU to achieve its strategic goals to produce people who are ready to contribute to a better and sustainable quality of life in the country [7]. Moreover, its own precise and suitable KPIs that bring transparency, accountability, and responsibility among its students, faculty, and staff pave the way to academic and scientific development [8]. This paper proposes an efficient fuzzy MCDM hybrid model for TQM self-assessment to enhance KPIs in mega universities to achieve continuous improvement and sustainable development of MU, with a case study on King Abdul-Aziz University (KAU) in the Kingdom of Saudi Arabia as an example of MU to be the pioneer in its region. However, the model can be applied to other mega universities.

In this paper, the used criteria are based on the combination of literature review and empirical research. It is based on research in MU for the sake of in-depth comprehension of university affairs and the environment. A review of the existing literature and an empirical study are handled through questionnaires. Survey questionnaires were developed to collect data about the current situation of MU quality criteria [9, 10]. Three questionnaires were designed for academic leaders and experts including academic staff and students. The questionnaires were developed based on the results from surveys. The criteria and subcriteria of the proposed model are then identified. Then, the proposed model for evaluating KPIs of MU is constructed with several hierarchy levels including various criteria and subcriteria that are used to assess the KPIs recommended. The criteria and subcriteria priorities and weights are then estimated by constructing a pair-wise comparison matrix using the MCDM based on the integration of FAHP, FDEMATEL, and FVIKOR. Finally, the potential issues associated with the proposed hybrid fuzzy model are analyzed and discussed. The rest of the paper is as follows: Section 2 is the literature review. Section 3 describes the main components of the modified EFQM excellence model. Section 4 describes the "TQM Hybrid Fuzzy Model" proposed. Section 5 explains the new model analysis and results. Section 6 investigates the findings and discussions, and Section 7 is the conclusion.

2. Literature Review

In the knowledge-based society of the twenty-first century, no doubt that higher education (HE) is a key element of high value to the welfare of any society [11]. Universities exist to educate, carry out research, and engage in a community with better quality of life [12]. Manpower resource quality plays a vital in the growth and development of a society where the quality of people can be enriched with the high-quality education provided by higher education institutions (HEIs) [13]. On another hand, the increasing competition and the international mobility of students and staff raised the expectations about better education quality. This reflects the need to develop an internal mechanism for quality management as a strategic goal for many of the HEIs [14]. Therefore, HEIs need to be subjected to some benchmarking or performance evaluation [15]. There are a lot of efforts have been made for enhancing the quality of institutions in higher education [16–23].

In [22], the authors reported that the HEIs and governments need to change their strategic plans and institutional regulations for the development of the educational process and added that KPIs provide quality assurance to higher education. Insung Jung [23] mentioned that MU has been developed to meet the increasing demand for adults and lifelong learners, and recently, MU placed more emphasis on widening access than assuring quality, but now they recognize quality assurance (QA) as a key issue that needs to be considered. At the same time, QA models are at an early and therefore crucial stage of development. Therefore, MU must produce people who are ready to contribute to a better and sustainable quality of life for the country. Therefore, moreover, with its own precise and suitable KPIs, MU brings transparency, accountability, and responsibility to its students, faculty, and staff, paving the way to academic and scientific development. The KAU, as an example of MU, is one of the few universities in the Middle East that rose to acquire the number one in national rank and number 278 rank among the world-class universities in 2021 (R11). KAU tried to implement KPIs through its current and previous strategic plans to achieve international distinction in the education process. KAU witnessed tremendous quantitative and qualitative progress in academic programs while continuing to maintain its traditional commitment to deliver outstanding education and community service.

Classical MCDM methods [9, 10, 36–40] are not efficient enough due to the identification of many effective criteria in a qualitative way based on the experts' judgments according to the linguistic variables and uncertainty of the problem. Therefore, this paper aims to develop a hybrid fuzzy model for TQM self-assessment for enhancing KPIs in MU to achieve continuous improvement and sustainable development of MU by using fuzzy MCDM methods. KAU is used as an example of a MU case study to be the pioneer in its region. Several of the advanced MCDM hybrid methods are used to assess TQM. Selecting an appropriate method could be a great challenge since individual MCDM methods can produce different rankings (see Table 1). Therefore, it is recommended to use a hybrid fuzzy model to avoid the disadvantages of these individual methods, to get the benefits of their advantages, and to integrate those results for final decision-making [41]. These advantages can be summarized as follows [41].

The qualitative and quantitative data related to the criteria can be collected and used as inputs into the next proposed approach. Integration of subjective and objective criteria are important, because the objective criteria models do not consider the experiences of the decision makers while the subjective criteria model do not consider the performance ratings of the alternatives with respect to different criteria. Fuzzy logic can help to overcome uncertainties arising from human qualitative judgments to provide us with a more appropriate model for real-life assessment. So, to satisfy this goal, FAHP can be the best option for prioritization among the EFQM questions' importance weights, FDEMATEL is the best choice for finding the interconnections and relations among the subcriteria, and FVIKOR is the best method for ranking the final alternatives.

3. Modified EFQM Excellence Model

The EFQM model focuses on customer needs and quality attributes embraced by the customers. In this paper, the

Table 1: Survey of some of the advanced MCDM hybrid methods and objectives.

Method	Objective	References
VIKOR-fuzzy AHP	Selecting the best marketing strategy	Mohaghar et al. [24]
Fuzzy AHP-TOPSIS	Developing personnel prioritization	Malik [42]
FDEMATEL-ANP-AHP in the strategic model SWOT	Developing and prioritizing medical tourism development strategies in the metropolitan area	Taghvaei and Goodarzi [25]
FMCGDSS three ranking methods	Selecting the best information system manager	Chen, and Cheng [26]
Fuzzy AHP-TOPSIS	Evaluating the e-service quality of internet-based banking alternatives to obtain the best-qualified alternative	Ozdagoglu and Guler [27]
Fuzzy AHP-TOPSIS	Selecting the best supplier	Jain et al. [28]
Delphi and fuzzy AHP-TOPSIS	Weighting criteria and prioritizing heat stress indices in surface mining	Asghari, et al. [29]
Fuzzy DEMATEL-AHP-VIKOR	Selecting the best strategy for investing	Mobini and Yazdani [30]
Fuzzy ANP-DEMATEL-VIKOR-TOPSIS	Ranking hospitals	Ali Mohammadian and Shafiei [31]
Hybridized DEMATEL-AHP-TOPSIS model modified by using the interval type-2 fuzzy sets (IT2FS)	Selecting the air traffic control (ATC) radar position that provides a successfully fulfilled role of radar in air traffic management	Petrovic and Kankaras [32]
F-DEMATEL-FAHP-FVIKOR	Selecting the best hospital nurses of the year regarding to some qualitative and quantitative criteria	Taati and Esmaili Dooki [33]
AHP—ELECTRE	Ranking departments based on performance	Şenel, Rouyendegh & Demir [34]
AHP—DEA—AHCA	Categorizing and ranking departments in terms of success groups created by clustering analyses	Şene, Rouyendegh & Tekin, [35]
FAHP-FDEMATEL-FVIKOR	Selecting and prioritizing the best TQM-KPIs in MU	Present study

perception of quality in higher education is modified. It is then followed by the introduction of a modified EFQM excellence model as the basis for the adoption of a measure and self-assessment tool in the higher education areas. The classic EFQM excellence model contains 9 criteria [43]. The enablers criteria include leadership, policy and strategy, employee participations, and resource and process. And the results criteria include customer results, people results, social results, and key performance results. Organization quality assessment is accomplished by scoring and ranking those criteria. Enablers embrace the processes and structures so that they are concerned with how the organization performs its activities [44, 45]. The results concentrate on achievements relating to organizational stakeholders; so, they deal with organizational accomplishments [44, 48]. The modified EFQM (M-EFQM) excellence model of business was introduced based on the TQM concept. The M-EFQM was constructed with seven main criteria. Five of them are the enabler of EFQM, and the remaining two main criteria are proposed for the M-EFQM by considering the mega university and the world ranking, which are "mega online distance Learning" and "Scoring & Ranking." Furthermore, several experts are selected to find the most appropriate scores for criteria and subcriteria. After that, an adaptation of the M-EFQM excellence model of business with the implementation of multicriteria decision-making processes including FAHP, FDEMATEL, and FVIKOR was investigated. Detailed differences of these methods and their influence on the quality assessment policies are studied analytically in Section 4. Finally, by comparing the advantages and disadvantages of each method, the developed hybrid fuzzy model was found as the most effective model of organizational assessment.

In this section, a TQM three-stage model is proposed for selecting and ranking institutions and universities in higher education to treat ambiguity and uncertainty in the evaluation of HE institutions and universities. The new model depends on a fuzzy framework that integrates three MCDM fuzzy techniques. These techniques are FAHP, FDEMATEL, and FVIKOR. It is constructed of three phases. In Phase 1, the proposed model defines the decision-making problem (DM). Then, it constructs the hierarchical structure of criteria (identify criteria, subcriteria (alternatives), and questions by a consultant with experts and reviewing the literature). In Phase 2, the proposed model defines and transforms criteria, subcriteria, and questions into linguistic variables and fuzzy values. In Phase 3, the proposed model evaluates the main TQM criteria and subcriteria by using multiple steps. Firstly, it calculates the importance of the weight of TQM evaluation criteria by using FAHP. Secondly, it determines the most effective criteria and subcriteria by using FDEMATEL, which uses the output importance weights of FAHP with the relationship weights of FDEMATEL to get the combined weights of criteria and subcriteria. Thirdly, it prioritizes a set of available alternatives for criteria and subcriteria by using FVIKOR. Finally, it determines if the results by FVIKOR are satisfied or not. In case of its results are satisfied, then the results are accepted. While in the case of its results are not satisfied, then the proposed model will tune the criteria by fuzzy transformation phase and repeat the process. Figure 1 shows a flowchart of the model presented in the paper.

To carry out the integration of the submodels FAHP, FDEMATEL, and FVIKOR in the proposed hybrid MCDM fuzzy model, the following processes are followed.

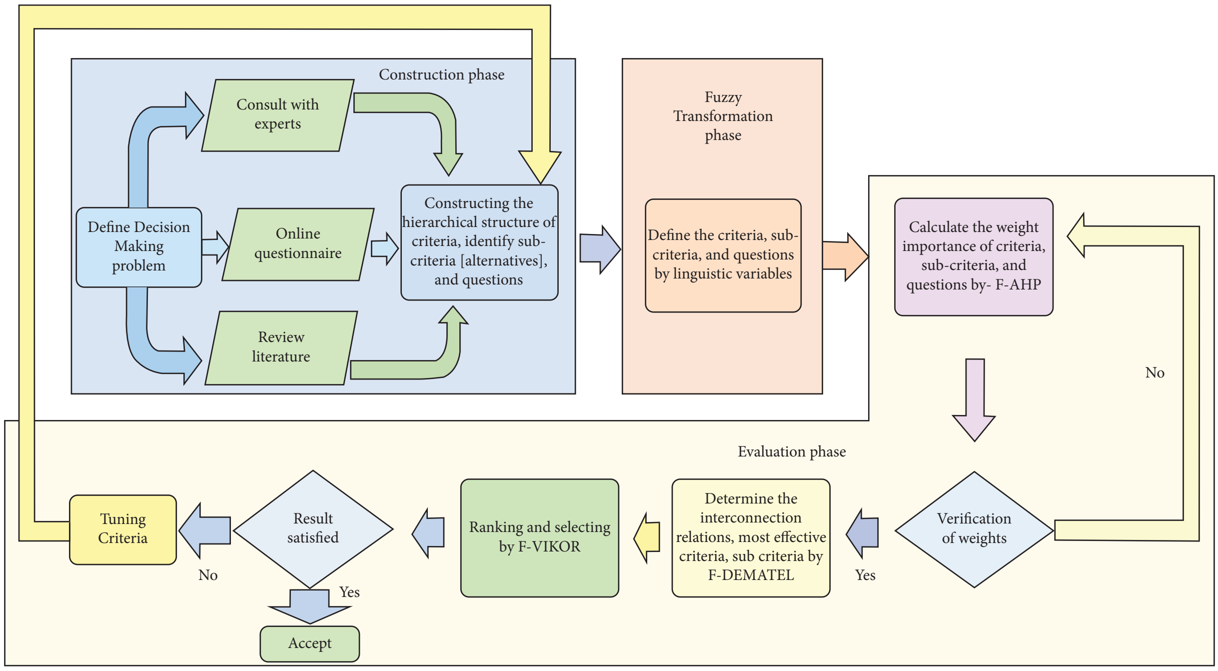

Figure 1: The hybrid MCDM fuzzy model is proposed for TQM self-assessment. The TQM hybrid MCDM fuzzy model proposed.

Table 2: Triangular fuzzy conversion scale for main criteria comparisons.

Linguistic scale	Crisp scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Equally important (EI)	1	(1, 1, 1)	(0, 0, 0)
Moderate important (MI)	3	(1, 3, 5)	(1/5, 1/3, 1)
Strong important (SI)	5	(3, 5, 7)	(1/7, 1/5, 1/3)
Very strong important (VSI)	7	(5, 7, 9)	(197, 1/7, 1/5)
Extremely strong important (ESI)	9	(7, 9, 9)	(1/11, 1/9, 1/7)

Table 3: Triangular fuzzy conversion scale for the subcriteria scored.

Linguistic scale	Crisp scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Equally important (EI)	1	(1, 1, 1)	(0, 0, 0)
Moderate important (MI)	3	(1, 4, 8)	(1/8, 1/4, 1)
Strong important (SI)	5	(4, 8, 12)	(1/12, 1/8, 1/4)
Very Strong important (VSI)	7	(8, 12, 16)	(1/16, 1/12, 1/8)
Extremely Strong important (ESI)	9	(12, 16, 20)	(1/20, 1/16, 1/12)

3.1. Phase 1: Construction Phase. It is consisting of the following three steps.

3.1.1. Step 1: The Identification of Criteria and Their Subcriteria. A set of main criteria and their subcriteria are identified and proposed as indicatedinTables 2–5. Moreover, a group of decision-makers (DMs) is asked to give a score for each subcriterion in the questionnaires.

3.1.2. Step 2: Opinions and Score Collection. A group of responses and opinions are collected from DMs are mainly for the rating of the specified criteria and subcriteria. The DMs group consists of many experts to form linguistic data for rating the submodels FAHP, FDEMATEL, and FVIKOR.

3.1.3. Step 3: Constructing a Hierarchical Structure. A hierarchical structure of the TQM-MCDM problem is constructed. This hierarchical structure is divided into two levels. The first level describes the focus of the main criteria of the TQM-MCDM problem, while the second level explains the subcriteria of each main criteria.

3.2. Phase 2: Fuzzy Transformation. In this phase, three sessions of data collection are conducted for determining the linguistic rating and fuzzy scaling of criteria and subcriteria. In the first session, DMs are asked to rate in five-point scales of pair-wise comparison of fuzzy AHP varying from “equally important (EI)” to “extremely strong important (ESI)”. The proposed five-point scales and linguistic variables for criteria and subcriteria are shown in Tables 2 and 3. In the second session, we are asked to specify the rating of FDEMATEL by using five linguistic scales varying from "no influence (NO)" to "very high influence (VH)" over the criteria and subcriteria of the MCDM problem. The linguistic scales and variables of FDEMATEL are shown in Table 4. In the third session, DMs are asked to specify the rating FVIKOR by using seven linguistic scales varying from "very poor (VP)" to "very good (VG)" over the criteria concerning a set of available alternatives. The proposed linguistic scales and variables for FVIKOR are shown in Table 5).

3.3. Phase 3: TQM Evaluation. In this phase, FAHP, FDEMATEL, and FVIKOR are integrated to evaluate the criteria and subcriteria of the proposed TQM model with a set of available alternatives. This phase is consisting of the following fourteen steps.

3.3.1. Step 1: Constructing a Pair-Wise Comparison for FAHP. Here, the pair-wise comparison is constructed between all criteria and subcriteria of the hierarchical structure based on the preferences of DMs which are defined in the construction phase (phase 1). The pair-wise comparison constructs the following matrix C.

$$C=\begin{bmatrix} 1 & \tilde{a}_{12} & \tilde{a}_{13} & \cdots\cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \cdots\cdots & \tilde{a}_{2n} \\ \tilde{a}_{31} & \tilde{a}_{32} & 1 & \cdots\cdots & \tilde{a}_{3n} \\ \vdots & \vdots & \vdots & 1 \cdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \tilde{a}_{n3} & \cdots\cdots & 1 \end{bmatrix}=\begin{bmatrix} 1 & \tilde{a}_{12} & \tilde{a}_{13} & \cdots\cdots & \tilde{a}_{1n} \\ \frac{1}{\tilde{a}_{21}} & 1 & \cdots & \cdots\cdots & \tilde{a}_{2n} \\ \frac{1}{\tilde{a}_{31}} & \frac{1}{\tilde{a}_{32}} & 1 & \cdots\cdots & \tilde{a}_{3n} \\ \vdots & \vdots & \vdots & 1 \cdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \ddots & \vdots \\ \frac{1}{\tilde{a}_{n1}} & \frac{1}{\tilde{a}_{n2}} & \frac{1}{\tilde{a}_{n3}} & \cdots\cdots & 1 \end{bmatrix}. \quad (1)$$

3.3.2. Step 2: Aggregating the Preferences of DMs. The resulted pair-wise comparison matrices are aggregated by using the geometric mean defined by Buckly in [47] where each element, $\tilde{a}_{12}$, of a matrix is calculated as follows:

$$\tilde{a}_{ij}=\left(\tilde{a}_{ij}^{1}\otimes\tilde{a}_{ij}^{2}\otimes\tilde{a}_{ij}^{3}\otimes\cdots\otimes\tilde{a}_{ij}^{m}\right)^{1/m}, \quad (2)$$

where m is the total number of DMs.

3.3.3. Step 3: Calculating the Fuzzy Weights and Relative Fuzzy Weights by FAHP. The aggregated comparison matrix of each criterion and subcriteria is constructed by using the following equation:

$$\tilde{a}_{j}=\left(\tilde{a}_{k1}\otimes\tilde{a}_{k2}\otimes\tilde{a}_{k3}\otimes\cdots\otimes\tilde{a}_{km}\right)^{1/m}, \quad (3)$$

Table 4: The fuzzy linguistic scale for FDEMATEL.

Linguistic scale	Crisp scale	Triangular fuzzy scale
No influence (NO)	0	(0, 0, 0.25)
Very low influence (VL)	1	(0, 0.25, 0.5)
Low influence (L)	2	(0.25, 0.5, 0.75)
High influence (H)	3	(0.5, 0.75, 1)
Very high influence (VH)	4	(0.75, 1, 1)

Table 5: Linguistic variables for alternatives comparison.

Linguistic scale	Crisp scale	Triangular fuzzy scale
Very poor (VP)	0	(0, 1, 1)
Poor (P)	1	(0, 1, 3)
Medium poor (MP)	2	(1, 3, 5)
Fair (F)	3	(3, 5, 7)
Medium good (MG)	4	(5, 7, 9)
Good (G)	5	(7, 9, 10)
Very good (VG)	6	(9, 9, 10)

where $j=1,2,\ldots,m$ and $k=$ triangular fuzzy numbers.

Then, the fuzzy weight of criteria and subcriteria, w_j^{FA}, is calculated as follows:

$$w_j^{FA}=\tilde{a}_j\otimes\left(\tilde{a}_1\otimes\tilde{a}_2\otimes\tilde{a}_3\otimes\cdots\otimes\tilde{a}_m\right)^{-1}, \quad j=1,2,\ldots,m. \quad (4)$$

Then, the relative fuzzy weights of subcriteria, rw_j^{FA}, are calculated by the following equation:

$$rw_j^{FA}=cw_j^{FA}\otimes sw_j^{FA}, \quad (5)$$

where cw_j^{FA} and sw_j^{FA} are the weights of criteria and its related subcriteria, respectively.

3.3.4. Step 4: Defuzzifying and Normalizing the Fuzzy Weights of FAHP. Triangular fuzzy weights are deffuzified, and it is calculated by the following formula [48–50]:

$$Z=\frac{a_1+a_2+a_3}{3}, \quad (6)$$

where Z is the deffuzified value of the fuzzy number $\tilde{Z}=(a_1,a_2,a_3)$.

And, the normalized weights for criteria and subcriteria are calculated by the following formula:

$$NZ_j=\frac{Z_j}{\sum_{r=1}^{P} Z_r}, \quad (7)$$

where Z_j and Z_r are the deffuzified values of criteria/subcriteria j and r, respectively.

3.3.5. Step 5: Generating the Initial Direct-Relation Matrix, $\tilde{A}$, For FDEMATEL. Based on the fuzzy number score x_{ij}^{k} which is given k[th] decision-maker that indicates the influential level of criteria i on criteria j, the matrix $n\times n$ is calculated by aggregating the scores of all decision-makers in Phase 2, and each element of the aggregated matrix is defined as follows:

$$\widetilde{A} = \left[\widetilde{A}_{ij}\right]_{n\times n} = \left[\left(\widetilde{a}_{ij,1}, \widetilde{a}_{ij,2}, \widetilde{a}_{ij,3}\right)\right]_{n\times n}, \tag{8}$$

where

$$\widetilde{a}_{ij,1} = \min_{1\le k\le m}\left\{a^k_{ij,1}\right\}, \tag{9}$$

$$\widetilde{a}_{ij,2} = \frac{\sum_{k=1}^{m} a^k_{ij,2}}{m}, \tag{10}$$

$$\widetilde{a}_{ij,3} = \max_{1\le k\le m}\left\{a^k_{ij,3}\right\}. \tag{11}$$

Matrix $\widetilde{A}$ describes the initial direct relation that a criterion or a subcriterion influences on and received from other criteria or subcriteria.

3.3.6. Step 6: Calculating the Normalized Initial Direct-Relation Matrix $\widetilde{D}$ of FDEMATEL. Based on the initial direct-relation matrix, $\widetilde{A}$, the normalized initial direct-relation matrix, $\widetilde{D}$, can be calculated as follows:

$$\widetilde{D} = \frac{\widetilde{A}}{s}, \tag{12}$$

where s is a scalar value which is calculated as follows:

$$s = \max\{s_u, s_v\}, \tag{13}$$

where s_u is the sum of each row of the matrix $\widetilde{A}$ which represents the total direct effects the criterion i gave to the other criteria and s_v is the sum of each column of the matrix $\widetilde{A}$ which represents the total direct effects received by other criteria by criterion i. s_u and s_v are defined as follows:

$$s_u = \max_{1\le i\le n}\left\{\sum_{u=1}^{n}\widetilde{A}_{ij}\right\}, \tag{14}$$

$$s_v = \max_{1\le i\le n}\left\{\sum_{v=1}^{n}\widetilde{A}_{ij}\right\}. \tag{15}$$

3.3.7. Step 7: Constructing $n\times n$ Total Relation Matrix B of FDEMATEL. Based on the normalized initial direct-relation matrix, $\widetilde{D}$, the total relation matrix B is calculated as follows:

$$B = \left[B_{ij}\right]_{n\times n} = \left[\left(b_{ij,1}, b_{ij,2}, b_{ij,3}\right)\right]_{n\times n}, \tag{16}$$

where

$$b_{ij,1} = \widetilde{D}_1 \times \left(I - \widetilde{D}_1\right)^{-1}, \tag{17}$$

$$b_{ij,2} = \widetilde{D}_2 \times \left(I - \widetilde{D}_2\right)^{-1}, \tag{18}$$

$$b_{ij,3} = \widetilde{D}_3 \times \left(I - \widetilde{D}_3\right)^{-1}, \tag{19}$$

where I is the identity matrix.

3.3.8. Step 8: Determining the Structural Correlation Analysis of FDEMATEL. Assume that r and c are $n\times 1$ vectors for indicating the sum of rows and the sum of columns of matrix Z, respectively, as follows:

$$r = \left[r_i\right]_{n\times 1} = \left[\sum_{j=1}^{n} Z_{ij}\right]_{n\times 1}, \tag{20}$$

$$c = \left[c_j\right]_{n\times 1} = \left[\sum_{i=1}^{n} Z_{ij}\right]_{n\times 1}. \tag{21}$$

When $i = j\left(\left(-b \pm \sqrt{b^2 - 4ac}\right)/2a\right)$, the sum of influences $r_j + c_j$ gives the degree of importance that criterion j plays in the problem and is denoted as $D_j + R_j$. Also, the difference in influences $r_j - c_j$ gives the net effects that criterion j contributes to the problem and is denoted as $D_j - R_j$. When $D_j - R_j$ positive, criterion j is called a net causer, which means that it has a significant impact on the other criteria. On the contrary, when $D_j - R_j$ negative, criterion j is called a net receiver, which means that it is influenced by the other criteria.

3.3.9. Step 9: Calculating New Expected Value $D_j + R_j$ and $D_j - R_j$ by FAHP/FDEMATEL. Here, the fuzzy weights from step 3, w_j^{FA} are multiplied by values of $D_j + R_j$ and $D_j - R_j$ to calculate their new expected values as follows:

$$E\left(D_j + R_j\right) = w_j^{FA} \otimes \left(D_j + R_j\right), \tag{22}$$

$$E\left(D_j - R_j\right) = w_j^{FA} \otimes \left(D_j - R_j\right). \tag{23}$$

3.3.10. Step 10: Calculating the Final Weights by Combining FAHP/FDEMATEL. Firstly, the defuzzification process of fuzzy numbers $E(D_j + R_j)$ and $E(D_j - R_j)$ is done by the following formula [51–53]:

$$X = \frac{x_1 + x_2 + 2\cdot x_3}{4}, \tag{24}$$

where X is the defuzzified crisp value of a fuzzy number $\widetilde{X} = (x_1, x_2, x_3)$.

Then, the final combining weights by FAHP/FDEMATEL, w_i^c, are calculated by using the following proposed formula:

$$w_j^c = \frac{w_j}{\sum_{i=1}^{n} w_i}, \tag{25}$$

where

$$w_j = \left[\left[E\left(D_j + R_j\right)\right]^2 + \left[E\left(D_j - R_j\right)\right]^2\right]^{1/2}. \tag{26}$$

These combining weights will be the input weights of criteria and subcriteria for FVIKOR (Step 12).

3.3.11. Step 11: Constructing the Causal Diagram. The casual diagram is constructed based on the new $D_j + R_j$ and $D_j - R_j$ value. In this diagram, $D_j + R_j$ represents its horizontal axis vector and is called "prominence" which describes the important degree that criterion j plays in the system, while

$D_j - R_j$ represents its vertical axis and is called "relation" which describes the net effect the criterion j contributes to the system. When $D_j - R_j$ is positive, criterion j is a net causer, and when $D_j - R_j$ is negative, criterion j is a net receiver [54, 55].

3.3.12. Step 12: Constructing a Comparison Matrix with Alternatives for FVIKOR. Firstly, a comparison matrix V between criteria/subcriteria and a group of alternatives is constructed as follows:

$$P = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ \vdots \\ A_y \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & C_3 & \cdots & \cdots & C_n \end{array} \\ \begin{bmatrix} \tilde{p}_{11} & \tilde{p}_{12} & \tilde{p}_{13} & \cdots & \cdots & \tilde{p}_{1n} \\ \tilde{p}_{21} & \tilde{p}_{22} & \tilde{p}_{23} & \cdots & \cdots & \tilde{p}_{2n} \\ \tilde{p}_{31} & \tilde{p}_{32} & \tilde{p}_{33} & \cdots & \cdots & \tilde{p}_{3n} \\ \vdots & \vdots & \vdots & \cdots & \cdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{p}_{y1} & \tilde{p}_{y2} & \tilde{p}_{y3} & \cdots & \cdots & \tilde{p}_{yn} \end{bmatrix} \end{array}. \quad (27)$$

An element $\tilde{p}_{ij}$ of the matrix indicates the performance rating of the ith alternative A_i, concerning the jth criterion C_j [56]. This rating is defined by using fuzzy numbers equivalent to linguistic variables which are shown in Table 5 and are described in Phase 2.

3.3.13. Step 13: Ranking the Alternatives by FVIKOR. Firstly, the best x_j^+ and the worst x_j^- values of all criteria are determined as follows:

$x_j^+ = \max\{f_{ij}\}$ and $x_j^- = \min\{f_{ij}\}$ if the jth criterion is a benefit.

$x_j^+ = \min\{f_{ij}\}$ and $x_j^- = \max\{f_{ij}\}$ if the jth criterion is a loss.

Where $j = 1, 2, \ldots, n$ and f_{ij} is the normalized value of $\tilde{p}_{ij}$.

Secondly, the maximum group utility S_i and the minimum individual regret i of the alternative A_i are calculated as follows:

$$S_i = \sum_{j=1}^{n} \left(w_j^c . \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-} \right),$$
$$R_i = \max_{1 \le j \le n} \left\{ \left(w_j^c \cdot \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-} \right) \right\}. \quad (28)$$

Thirdly, the aggregate values Q_i for each alternative A_i are computed by using the following formula:

$$Q_i = v \cdot \left(\frac{S_i - S^-}{S^+ - S^-} \right) + (1 - v) \cdot \left(\frac{R_i - R^-}{R^+ - R^-} \right), \quad (29)$$

where $S^- = \min\{S_i\}$, $S^+ = \max\{S_i\}$, $R^- = \min\{R_i\}$, $R^+ = \max\{R_i\}$, and v is a constant and equals 0.5, usually.

Finally, the alternatives are ranked by sorting by values of S_i, R_i, and Q_i values in decreasing order. Therefore, the results will be three ranking lists, and the alternative (A^1) which is ranked the best by the minimum of $\{Q_i\}$ is proposed as an optimal solution if the following two conditions are satisfied.

Condition 1. $Q(A^2) - Q(A^1) \ge (1/(y - 1))$ where A^2 the alternative with the second is the position in the ranked list by Q and y is the number of alternatives.

Condition 2. Alternative A^1 must be the best ranked by S or/and R.

3.3.14. Step 14: Results Evaluation. In this step, the proposed model determines if the results by FVIKOR in Step 12 are satisfied or not. In case of its results are satisfied, then the results will be accepted. While, in the case, its results are not satisfied, then the proposed model will tune the criteria by fuzzy transformation phase and repeat the process.

4. TQM Hybrid MCDM Fuzzy Model Analysis and Results

In this section, a case study of TQM-KPIs self-assessment to enhance KPIs in mega universities, the case study KAU, was conducted to demonstrate the efficacy of the proposed model.

4.1. TQM-KPIs Evaluation Using the Proposed Model and Recommendations. Table 6 shows the proposed set of criteria and subcriteria and their scores based on the opinion of decision-makers. As shown in Table 6, all scores have the value of 20 based on suggestions of decision-makers to show that all subcriteria have equally the same effect on its main criteria. In this evaluation, three DMs = {E1, E2, E3} were invited to evaluate the criteria and subcriteria of the TQM-KPIs self-assessment problem. Based on M-EFQM, 7 criteria and 35 subcriteria, where each criterion including 5 subcriteria, are proposed for the TQM-KPIs self-assessment problem. As described in Phase 1 of the proposed model, based on the opinion of DMs, each subcriterion is evaluated and scored. The first five criteria are the enablers of EFQM, which are leadership, policy & strategy, people, partnership & resources, product, and service & process. The remaining two main criteria are proposed for considering the mega university and the world ranking, including mega online distance learning and scoring & ranking. Moreover, the hierarchical structure of the TQM- KPIs self-assessment problem is identified as shown in Figure 2. Besides, questionnaires are developed to collect data about the current situation of MU quality criteria at KAU as an example of a MU case study. Three questionnaires are designed including "academic leaders and experts," "academic staff," and "students." The questionnaires are being developed based on the results from the surveys included, criteria, and the subcriteria of the proposed model.

By applying Phase 2, the three DMs were asked to provide ratings of the criteria and subcriteria using the linguistic scales as shown in Tables 2 and 3 for FAHP. Tables 7 and 8 show the linguistic variables and their corresponding fuzzy decision matrix of the main criteria using E1 for FAHP. Moreover, they were asked to rate the criteria

Table 6: The proposed M-EFQM model criteria and subcriteria and their scores based on the opinion of decision-makers.

Criteria	Subcriteria	Scores
A Leadership	A1. Leaders develop the mission, vision, values, and ethics and are role models of a culture of excellence A2. Leaders are personally involved in ensuring the university's management system is developed, implemented, and continually improved A3. Leaders are involved with and interact with customers, partners, and representatives of society A4. Leaders motivate, support, and recognize the university's people, and nurture a culture of excellence A5. Leaders identify and champion organizational change.	20 20 20 20 20
B Policy & strategy	B1. Policy and strategy are based on the present and future needs and expectations of stakeholders B2. Policy and strategy are based on information from performance measurement, research, learning, and externally related activities B3. Policy and strategy are developed and reviewed B4. Policy and strategy are communicated and deployed through a framework of key processes B5. Policy and strategy are based on mission and vision of the university	20 20 20 20 20
C People	C1. People's resources are planned, managed, and improved C2. People's knowledge and competencies are identified, developed, and sustained C3. People are involved and empowered C4. People within the university have a dialogue C5. People are rewarded, recognized, and cared for.	20 20 20 20 20
D Partnership and Resources	D1. Internal and external partnerships are managed D2. Finances and managed D3. Buildings, equipment, and materials are managed D4. Technology is managed D5. Information and knowledge are managed.	20 20 20 20 20
E Product, service, & process	E1. Processes are systematically designed and managed E2. Processes are improved as needed, using innovation to fully satisfy and generate increasing value for students, staff, and other stakeholders E3. Academic courses, professional services, and internal services are designed and developed based on customer needs and expectations E4. Academic courses, commercial services, and internal services are developed and delivered E5. Student, commercial, and internal customer relationships are managed and enhanced.	20 20 20 20 20
F mega online distance-learning	F1. Distance-learning sources and materials are managed and improved F2. Distance-learning systems and frameworks are designed and developed based on customer needs and expectations F3. The credibility of the institution is satisfied according to national/international standards of distance learning F4. Quality assurance or quality management systems for e1/learning are planned and managed F5. Preenrolment information and guidance about the e1/learning courses are described, managed, and improved.	20 20 20 20 20
G scoring & ranking	G1. Teaching quality is managed and enhanced G2. Research quality is managed and enhanced G3. Internationalization collaboration is planned, managed, and improved G4. Graduates and the labor market G5. Web activities are planned, managed, and improved.	20 20 20 20 20

and subcriteria using the linguistic scales as shown in Table 4 for FDEMATEL.

Tables 9 and 10 show the linguistic variables and their corresponding fuzzy decision matrix of the main criteria using E1 for FDEMATEL. Moreover, DMs were asked to rate the criteria and subcriteria using the linguistic scales as shown in Table 3 concerning the ten available alternatives for FVIKOR. Table 11 shows the linguistic variables and their corresponding fuzzy decision matrix of the main criteria, and Table 12 shows the fuzzy decision matrix of alternatives for the main criteria for FVIKOR.

By applying Step 1 to Step 4 in Phase 3, the proposed model calculates the final fuzzy weight of criteria and subcriteria of FAHP by using equations (1)–(7). Table 13 shows the final fuzzy, average, and normalized weights (w_j^{FA}) of the main criteria by FAHP. Moreover, by applying Step 4 to Step 9, the proposed model calculates the final fuzzy weight of criteria and subcriteria of FDEMATEL by using equations (8) to (26).Tables 14–16 show the final fuzzy values, crisp values, aggregated, and normalized combining weights (w_j^c) of the main criteria by FDEMATEL.

The causal diagram and influence relation map (IRM) of the criteria are shown in Figure 3 (as described in Step 11 in Phase 3). It confirms that criteria C, D, F, and D are the most influential criteria on other criteria. Moreover, the causal diagram of the subcriteria is shown in Figure 4. It confirms

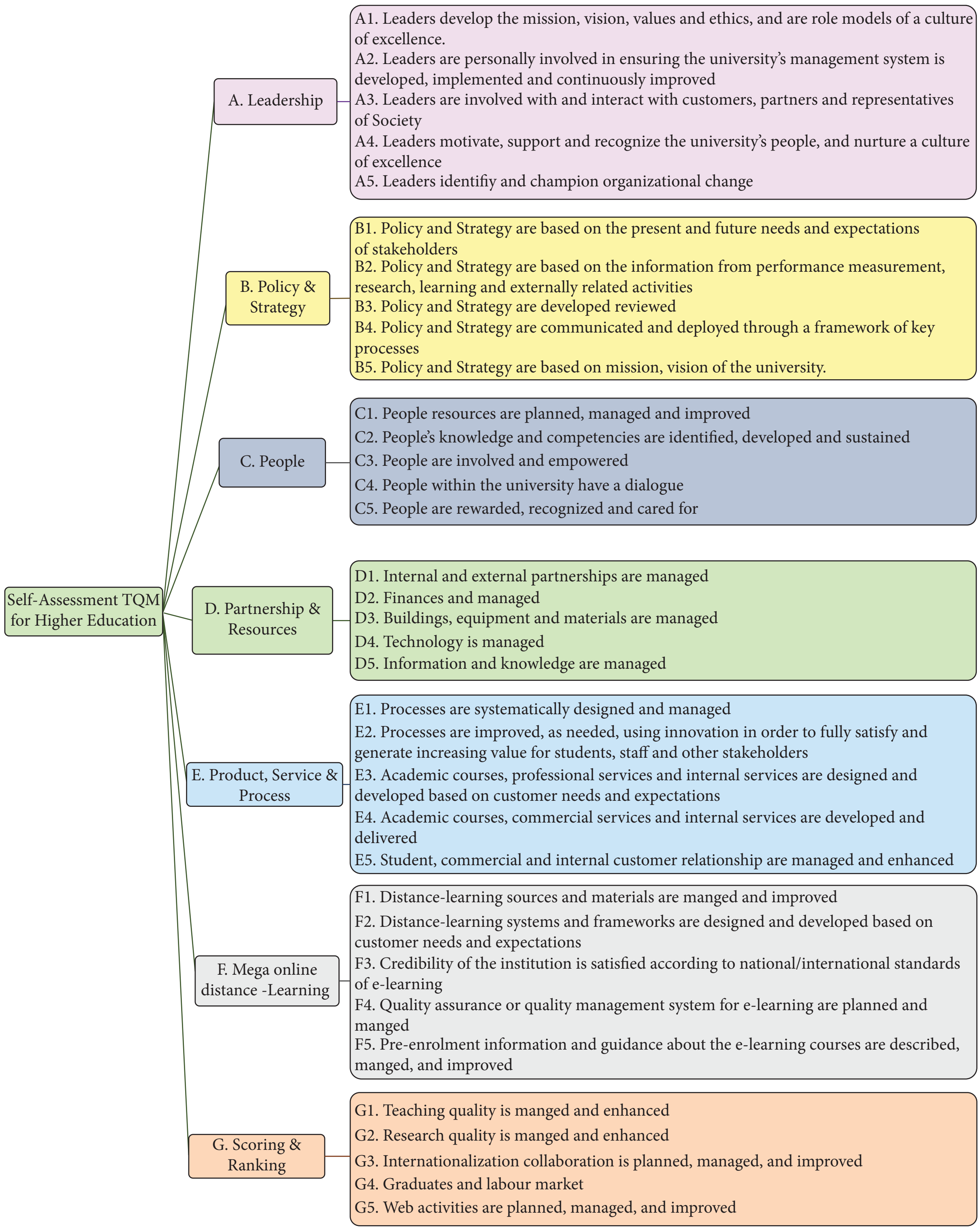

Figure 2: The hierarchical structure of criteria and subcriteria.

that A5 from A, B5 from B, C1, C5 from C, D5 from D, E5 from E, F5 from F, and G5 from G are the most influential criteria on other subcriteria in each main criterion. It is the real source that affects the other criteria directly.

By applying Step 10 in Phase 3, the proposed model calculates the final combining weight of criteria and subcriteria for FAHP/FDEMATEL by using equation (25). Table 16 shows the combined weights of the main criteria by FAHP/FDEMATEL. The fuzzy weights for subcriteria are obtained by a similar calculation.

As a result, Table 17 shows the final FAHP weights, combining the weights of FAHP/FDEMATEL, and the relative

Table 7: Linguistic variables of criteria using DM's opinion [Decision Maker 1 (E1)] for FAHP.

	A	B	C	D	E	F	G
A	1	EI	EI	EI	EI	EI	EI
B	1/EI	1	MI	EI	EI	EI	EI
C	1/EI	1/MI	1	EI	EI	EI	EI
D	1/EI	1/EI	1/EI	1	EI	EI	EI
E	1/EI	1/EI	1/EI	1/EI	1	EI	EI
F	1/EI	1/EI	1/EI	1/EI	1/EI	1	EI
G	1/EI	1/EI	1/EI	1/EI	1/EI	1/EI	1

Table 8: The fuzzy decision matrix of criteria using DM's opinion [Decision Maker 1 (E1)] for FAHP.

	A			B			C			D			E			F			G		
A	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B	1	1	1	1	1	1	1	3	5	1	1	1	1	1	1	1	1	1	1	1	1
C	1	1	1	1/5	1/3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
E	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
G	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 9: Linguistic variables of criteria using DM's opinion [Decision Maker 1 (E1)] for FDEMATEL.

	A	B	C	D	E	F	G
A	NO	L	NO	VH	VH	NO	VL
B	H	VH	NO	VH	VH	L	NO
C	VH	NO	VH	NO	VH	VL	VH
D	L	VH	L	NO	NO	VH	VH
E	VH	NO	H	H	VH	VH	VH
F	VH	NO	NO	VH	VH	VH	NO
G	VL	VL	NO	VH	L	VH	NO

Table 10: The fuzzy decision matrix of criteria using DM's opinion [Decision Maker 1 (E1)] for FDEMATEL.

	A			B			C			D			E			F			G		
A	0.00	0.00	0.25	0.25	0.50	0.75	0.00	0.00	0.25	0.75	1.00	1.00	0.75	1.00	1.00	0.00	0.00	0.25	0.00	0.25	0.50
B	0.50	0.75	1.00	0.75	1.00	1.00	0.00	0.00	0.25	0.75	1.00	1.00	0.75	1.00	1.00	0.25	0.50	0.75	0.00	0.00	0.25
C	0.75	1.00	1.00	0.00	0.00	0.25	0.75	1.00	1.00	0.00	0.00	0.25	0.75	1.00	1.00	0.00	0.25	0.50	0.75	1.00	1.00
D	0.25	0.50	0.75	0.75	1.00	1.00	0.25	0.50	0.75	0.00	0.00	0.25	0.00	0.00	0.25	0.75	1.00	1.00	0.75	1.00	1.00
E	0.75	1.00	1.00	0.00	0.00	0.25	0.50	0.75	1.00	0.50	0.75	1.00	0.75	1.00	1.00	0.75	1.00	1.00	0.75	1.00	1.00
F	0.75	1.00	1.00	0.00	0.00	0.25	0.00	0.00	0.25	0.75	1.00	1.00	0.75	1.00	1.00	0.75	1.00	1.00	0.00	0.00	0.25
G	0.00	0.25	0.50	0.00	0.25	0.50	0.00	0.00	0.25	0.75	1.00	1.00	0.25	0.50	0.75	0.75	1.00	1.00	0.00	0.00	0.25

Table 11: The linguistic variables of alternatives for criteria to DM's opinions for FVIKOR.

	A	B	C	D	E	F	G
A1	VP	MP	VG	VG	VG	MP	MP
A2	VP	F	VG	VG	G	F	VG
A3	VP	F	VP	P	VP	F	VG
A4	G	VP	VG	VG	VP	VG	VG
A5	MG	VP	MP	VG	MP	VP	VG
A6	VG	G	P	VG	P	VG	VG
A7	VG	VG	P	G	MP	G	G
A8	VG	VG	G	MP	VG	MP	G
A9	VG	VP	MP	VG	F	P	G
A10	MG	P	VG	P	P	VG	P

Table 12: The fuzzy decision matrix of alternatives for the main criteria.

	A			B			C			D			E			F			G		
A1	0	1	1	1	3	5	9	9	10	9	9	10	9	9	10	1	3	5	1	3	5
A2	0	1	1	3	5	7	9	9	10	9	9	10	7	9	10	3	5	7	9	9	10
A3	0	1	1	3	5	7	0	1	1	0	1	3	0	1	1	3	5	7	9	9	10
A4	7	9	10	0	1	1	9	9	10	9	9	10	0	1	1	9	9	10	9	9	10
A5	5	7	9	0	1	1	1	3	5	9	9	10	1	3	5	0	1	1	9	9	10
A6	9	9	10	7	9	10	0	1	3	9	9	10	0	1	3	9	9	10	9	9	10
A7	9	9	10	9	9	10	0	1	3	7	9	10	1	3	5	7	9	10	7	9	10
A8	9	9	10	9	9	10	7	9	10	1	3	5	9	9	10	1	3	5	7	9	10
A9	9	9	10	0	1	1	1	3	5	9	9	10	3	5	7	0	1	3	7	9	10
A10	5	7	9	0	1	3	9	9	10	0	1	3	0	1	3	9	9	10	0	1	3

Table 13: The final fuzzy average and normalized weights (w_j^{FA}) of main criteria by FAHP.

Criteria		Fuzzy weights		Average weights	Normalized weights
A	0.129	0.158	0.196	0.159	0.161
B	0.129	0.158	0.196	0.159	0.161
C	0.081	0.118	0.156	0.117	0.118
D	0.129	0.140	0.156	0.140	0.141
E	0.129	0.140	0.156	0.140	0.141
F	0.129	0.151	0.196	0.156	0.158
G	0.102	0.135	0.156	0.129	0.131

Table 14: The final fuzzy values of $D+R$ and $D-R$ of the main criteria by FDEMATEL.

		$D+R$			$D-R$	
A	3.575	18.44252711	79.2	−3.575	−0.113705437	0
B	4.6	16.8004771	75.05185185	−1.6	−0.416278831	−1.348148148
C	2.8125	17.12086642	79.2	0.8125	−0.156277183	0
D	6.3	19.38028713	79.2	1.5	0.076018181	0
E	1.125	16.81473005	77.8	0.125	0.55116775	1.4
F	4.6625	17.66558816	76.4	1.2625	1.540353015	2.8
G	5.875	15.9093305	73.54814815	1.475	−1.481277495	−2.851851852

Table 15: Crisp values of $E(D+R)$ and $E(D-R)$ of main criteria by FAHP/FDEMATEL.

	$D+R$		D − R	
	Average weights	Normalized weights	Average weights	Normalized weights
A	7.166634775	0.023270489	−0.146524593	$-8.4601E+12$
B	6.812574398	0.022120834	−0.187195254	$-1.08084E+13$
C	5.214882639	0.016933034	0.019189482	$1.10797E+12$
D	6.429442154	0.020876781	0.055046186	$3.17828E+12$
E	6.06128811	0.019681363	0.121413432	$7.01022E+12$
F	6.84960454	0.022241073	0.328652136	$1.89759E+13$
G	5.462603904	0.0177374	−0.184694753	$-1.0664E+13$

Table 16: The final aggregated and normalized combining weights (w_j^c) of main criteria by FAHP/FDEMATEL.

	Aggregated weights	Normalized weights
A	0.162861808	0.162861808
B	0.154841859	0.154841859
C	0.118484272	0.118484272
D	0.146083928	0.146083928
E	0.137741645	0.137741645
F	0.155803807	0.155803807
G	0.124182681	0.124182681

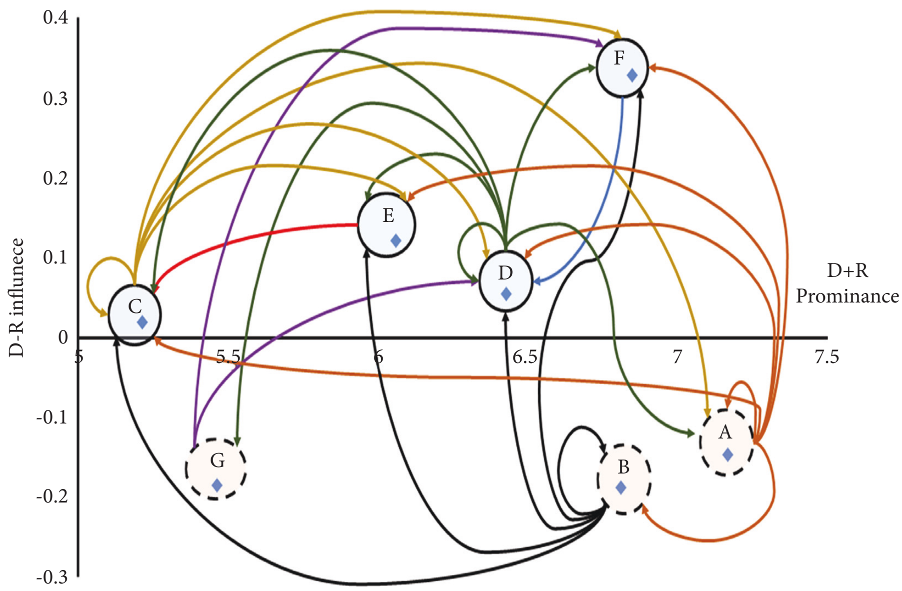

FIGURE 3: Causal diagram and influence relation map (IRM) of criteria.

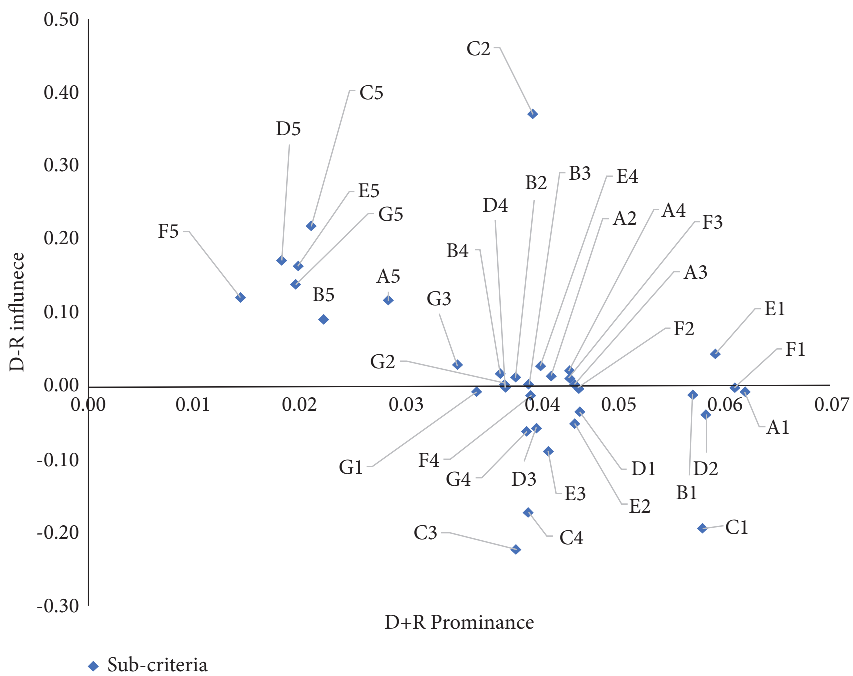

FIGURE 4: Causal diagram of subcriteria.

weights of the main criteria and subcriteria. Due to the importance levels by FAHP, it shows that the main seven criteria, leadership (A), policy & strategy (B), people (C), partnership & resources (D), technology (E), mega online distance learning (F), and scoring & ranking (G), are ranked as follows: $A = 15.89\%$, $B = 15.89\%$, $C = 11.7\%$, $D = 13.97\%$, $\mathrm{E} = 13.97\%$, $F = 15.64\%$, and $G = 12.94\%$, respectively. While by FAHP/FDEMATEL, they are ranked as follows: $A = 16.29\%$, $B = 15.48\%$, $C = 11.85\%$, $D = 14.61\%$, $\mathrm{E} = 13.77\%$, $F = 15.57\%$, and $G = 12.42\%$ due to importance and influence levels together.

Here, ten alternatives of TQM-KPIs self-assessment are proposed and denoted as A, A2, A3, A4, A5, A6, A7, A8, A9, and A10, respectively. These alternatives can be considered as a set of strategies that mega university wants to select one of them for enhancing its plans, policies, activities, partnerships, and other resources and satisfying its goals and objectives. The alternatives are rated by DMs considering the evaluation of 7 criteria including A, B, C, D, E, F, and G in the case of the main criteria. While in the case of subcriteria, they are rated by considering 5 subcriteria of each main criterion.

By applying Steps 12 and 13 in Phase 3, the proposed model will determine the final alternatives ranking based on the benefit value (Si), the unfortunate value (Ri), and the FVIKOR index

Table 17: TQM-SAHFM model main and subcriteria weights.

Main criteria	Subcriteria	Global NWs		NW of subcriteria		Relative NW of subcriteria		AVERAGE relative NW of subcriteria	
		FAHP	FAHP/ FDEMATEL	FAHP	FAHP/ FDEMATEL	FAHP	FAHP/ FDEMATEL	FAHP	FAHP/ FDEMATEL
A	A1	15.89%	16.29%	0.18074	0.18317	0.02872	0.02984	0.03178	0.03258
	A2			0.22738	0.21831	0.03613	0.03556		
	A3			0.22738	0.22958	0.03613	0.0374		
	A4			0.22738	0.22718	0.03613	0.03701		
	A5			0.1371	0.14176	0.02179	0.02309		
B	B1	15.89%	15.48%	0.28159	0.28513	0.04474	0.04414	0.031778	0.030962
	B2			0.21044	0.20187	0.03344	0.03125		
	B3			0.20556	0.20737	0.03266	0.0321		
	B4			0.19464	0.1943	0.03093	0.03008		
	B5			0.10777	0.11134	0.01712	0.01724		
C	C1	11.7%	11.85%	0.2784	0.28558	0.03257	0.03384	0.023398	0.0237
	C2			0.20642	0.20707	0.02415	0.02454		
	C3			0.20642	0.1989	0.02415	0.02357		
	C4			0.19085	0.20463	0.02233	0.02425		
	C5			0.1179	0.10382	0.01379	0.0123		
D	D1	13.97%	14.61%	0.27805	0.28372	0.03884	0.04145	0.02794	0.02922
	D2			0.21483	0.22579	0.03001	0.03299		
	D3			0.20615	0.20583	0.0288	0.03007		
	D4			0.19059	0.19157	0.02663	0.02799		
	D5			0.11038	0.09308	0.01542	0.0136		
E	E1	13.97%	13.77%	0.28897	0.28978	0.04037	0.0399	0.027942	0.027538
	E2			0.21538	0.22471	0.03009	0.03094		
	E3			0.21538	0.21316	0.03009	0.02935		
	E4			0.15217	0.17058	0.02126	0.02349		
	E5			0.1281	0.10177	0.0179	0.01401		
F	F1	15.64%	15.57%	0.27331	0.28567	0.04275	0.04448	0.031282	0.031138
	F2			0.20695	0.21628	0.03237	0.03367		
	F3			0.20695	0.21268	0.03237	0.03311		
	F4			0.19135	0.19545	0.02993	0.03043		
	F5			0.12143	0.08992	0.01899	0.014		
G	G1	12.94%	12.42%	0.2784	0.30012	0.03602	0.03727	0.02588	0.02484
	G2			0.20642	0.19023	0.02671	0.02363		
	G3			0.20642	0.20665	0.02671	0.02567		
	G4			0.19085	0.20104	0.0247	0.02497		
	G5			0.1179	0.10197	0.01526	0.01266		

Table 18: The final alternatives ranking due to benefit value (Si), unfortunate value(Ri), and FVIKOR index(Qi) for main criteria A, B, C, D, E, F, and G.

	Si	Ri	Qi	Rank
A1	0.49	0.16	0.76	9
A2	0.33	0.16	0.59	5
A3	0.72	0.16	1.00	10
A4	0.31	0.15	0.49	4
A5	0.54	0.16	0.75	8
A6	0.25	0.13	0.17	3
A7	0.24	0.11	0.00	1
A8	0.25	0.12	0.06	2
A9	0.46	0.15	0.66	6
A10	0.58	0.15	0.70	7

(Qi) for main criteria A, B, C, D, E, F, and G. According to conditions 1 and 2 in Step 13, alternatives 7, 8, 6, 4, and 2 are selected as the best five alternatives, and the ranking results concerning the main seven criteria are shown in Table 18.

Similarly, the final alternative rankings due to benefit value (Si), unfortunate value (Ri), and FVIKOR index (Qi) for subcriteria of each main criterion are shown in Table 19. According to conditions 1 and 2 in Step 13, for the main

Table 19: The final alternatives ranking due to benefit value (Si), unfortunate value (Ri), and FVIKOR index (Qi) for all subcriteria of each main criteria A, B, C, D, E, F, and G, separately.

	A				B				C			
	Si	Ri	Qi	Rank	Si	Ri	Qi	Rank	Si	Ri	Qi	Rank
A1	0.69	0.23	0.94	10	0.60	0.20	0.60	7	0.57	0.26	0.74	10
A2	0.24	0.17	0.00	1	0.23	0.15	0.00	1	0.46	0.20	0.44	5
A3	0.55	0.23	0.82	7	0.48	0.21	0.49	6	0.50	0.26	0.69	8
A4	0.62	0.22	0.80	6	0.61	0.20	0.60	8	0.42	0.18	0.33	3
A5	0.51	0.20	0.55	4	0.46	0.19	0.39	5	0.36	0.29	0.66	7
A6	0.26	0.20	0.29	3	0.24	0.19	0.15	2	0.54	0.20	0.50	6
A7	0.73	0.22	0.91	9	0.64	0.20	0.64	9	0.37	0.20	0.36	4
A8	0.51	0.17	0.27	2	0.48	0.15	0.28	3	0.80	0.21	0.71	9
A9	0.63	0.23	0.88	8	0.68	0.29	1.00	10	0.31	0.19	0.27	2
A10	0.39	0.22	0.56	5	0.35	0.20	0.33	4	0.15	0.15	0.00	1
	D				E				F			
	Si	Ri	Qi	Rank	Si	Ri	Qi	Rank	Si	Ri	Qi	Rank
A1	0.35	0.26	0.60	5	0.33	0.22	0.62	7	0.45	0.22	0.47	6
A2	0.32	0.19	0.41	3	0.39	0.21	0.63	8	0.40	0.21	0.38	4
A3	0.29	0.17	0.32	2	0.23	0.22	0.55	6	0.32	0.18	0.17	2
A4	0.40	0.26	0.63	7	0.71	0.29	1.00	10	0.55	0.26	0.77	9
A5	0.28	0.21	0.41	4	0.09	0.09	0.21	3	0.44	0.21	0.44	5
A6	0.68	0.28	0.89	9	0.16	0.16	0.38	4	0.29	0.15	0.00	1
A7	0.60	0.19	0.62	6	0.10	0.06	0.17	2	0.38	0.22	0.37	3
A8	0.82	0.28	1.00	10	0.00	0.00	0.00	1	0.45	0.29	0.72	7
A9	0.16	0.07	0.00	1	0.31	0.16	0.49	5	0.55	0.26	0.76	8
A10	0.54	0.28	0.79	8	0.44	0.21	0.68	9	0.66	0.29	1.00	10
	G											
	Si	Ri	Qi	Rank								
A1	0.43	0.11	0.24	3								
A2	0.43	0.28	0.62	6								
A3	0.21	0.16	0.22	2								
A4	0.27	0.22	0.38	5								
A5	0.93	0.28	0.95	10								
A6	0.56	0.30	0.75	8								
A7	0.74	0.30	0.87	9								
A8	0.17	0.08	0.00	1								
A9	0.30	0.16	0.27	4								
A10	0.73	0.22	0.68	7								

criterion A, alternatives 2, 8, 6, 5, and 10 are selected as the best alternatives. For the main criterion B, alternatives 2, 6, 8, 10, and 5 are selected as the best alternatives. For the main criterion C, alternatives 10, 9, 4, 7, and 2 are selected as the best alternatives. For the main criterion D, alternatives 9, 3, 2, 5, and 1 are selected as the best alternatives. For the main criterion E, alternatives 8, 7, 5, 6, and 9 are selected as the best alternatives. For the main criterion F, alternatives 6, 3, 7, 2, and 5 are selected as the best alternatives. For the main criterion G, alternatives 8, 3, 1, 9, and 4 are selected as the best alternatives.

Based on the previous ranking results of the main criteria and subcriteria, the proposed model can give the best guideline to the mega university experts for selecting the best alternatives and strategies based on the most important criteria and their related subcriteria.

5. Findings and Discussions

Ranked results by FAHP are shown in Figure 5, which indicate that the subcriteria for the proposed model that occupied the first ten positions are as follows:

(1) Policy and strategy are based on the present and future needs and expectations of stakeholders (B1)

(2) Distance-learning sources and materials are managed and improved (F1)

(3) Processes are systematically designed and managed (E1)

(4) Internal and external partnerships are managed (D1)

(5) Leaders are personally involved in ensuring the university's management system is developed, implemented, and continually improved (A2)

(6) Leaders are involved with and interact with customers, partners, and representatives of Society (A3)

(7) Leaders motivate, support, and recognize the university's people and nurture a culture of excellence (A4)

(8) Teaching quality is managed and enhanced (G1)

(9) Policy and strategy are based on information from performance measurement, research, learning, and externally related activities (B2)

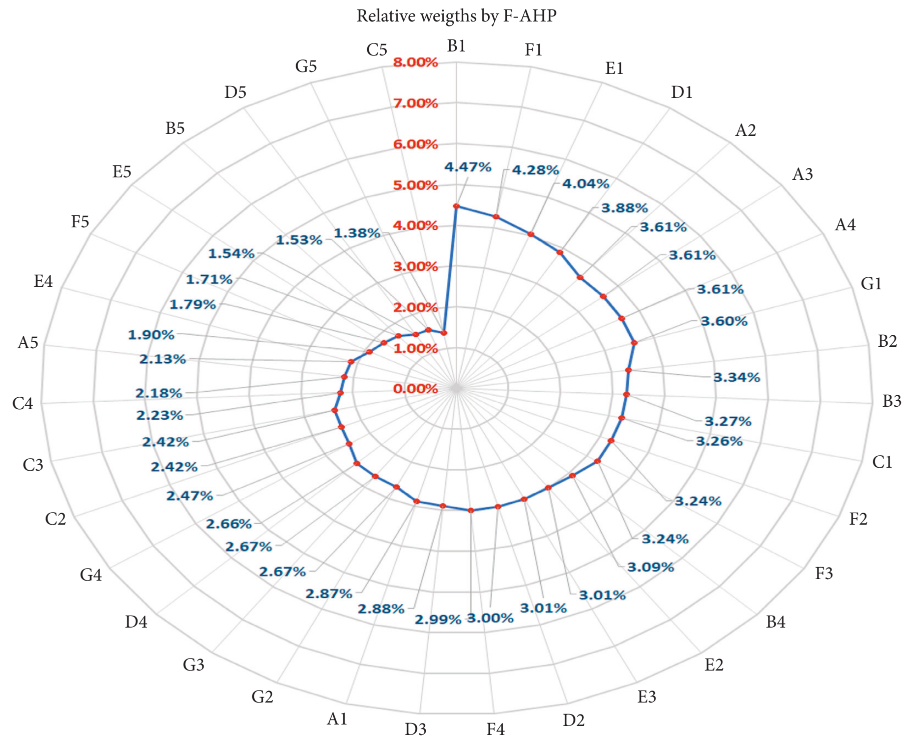

Figure 5: TQM-SAHFM model weights related to each criterion by FAHP.

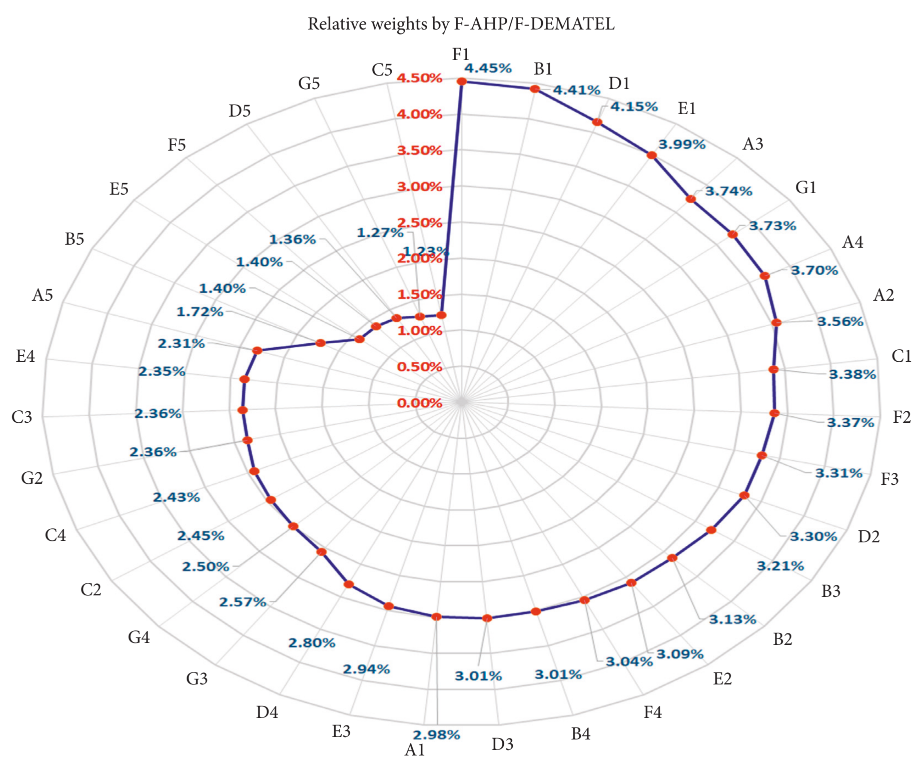

Figure 6: TQM-SAHFM model weights related to each criterion by FAHP/FDEMATEL.

(10) Policy and strategy are developed and reviewed (B3)
(11) People's resources are planned, managed, and improved (C1)
(12) Distance-learning systems and frameworks are designed and developed based on customer needs and expectations (F2)

Moreover, the ranked results by FAHP/FDEMATEL shown in Figure 6 indicate that the subcriteria for the proposed model that occupied the first ten positions are as follows.

(1) Distance-learning sources and materials are managed and improved (F1)
(2) Policy and strategy are based on the present and future needs and expectations of stakeholders (B1)
(3) Internal and external partnerships are managed (D1)
(4) Processes are systematically designed and managed (E1)
(5) Leaders are involved with and interact with customers, partners, and representatives of Society (A3)
(6) Teaching quality is managed and enhanced (G1)
(7) Leaders motivate, support, and recognize the university's people and nurture a culture of excellence (A4)
(8) Leaders are personally involved in ensuring the university's management system is developed, implemented, and continually improved (A2)
(9) People's resources are planned, managed, and improved (C1)
(10) Distance-learning systems and frameworks are designed and developed based on customer needs and expectations (F2)
(11) The credibility of the institution is satisfied according to national/international standards of distance learning (F3)
(12) Finances and managed (D2)

The findings indicate that FAHP criteria and subcriteria that have achieved the highest score are "leadership (A2, A3, A4)," "policy and strategy (B1, B2, B3)," "people (C1)," "partnership & resources (D1)," "product, service, & process (E1)," "mega online distance learning (F1, F2)," and "scoring & ranking (G1)" concerning others subcriteria that are analyzed based on FAHP by considering the importance level only among criteria and subcriteria. While in the case of FAHP/FDEMATEL, by considering the importance level and influence level among criteria and subcriteria, the findings indicate that "leadership (A2, A3, A4)," "policy and strategy (B1)," "people (C1)," "partnership & resources (D1, D2)", "product, service, & process (E1)," "mega online distance learning (F1, F2, F3)," and "scoring & ranking (G1)" have achieved the highest score concerning others subcriteria.

6. Conclusions

In this paper, a new "TQM Hybrid MCDM Fuzzy Model" for self-assessment TQM-KPIs in mega universities was proposed. It consists of a hierarchical structure for solving the TQM-KPIs problem in mega universities. It uses seven main criteria, among which are five enabler criteria of EFQM and two additional proposed criteria. The "TQM Hybrid MCDM Fuzzy Model" integrates three fuzzy MCDM methods including FAHP, FDEMATEL, and FVIKOR, treating ambiguity and uncertainty in the evaluation of higher education institutions and universities. The "TQM Hybrid MCDM Fuzzy Model" was evaluated and analyzed by developing questionnaires to collect data about the current situation of mega university quality criteria at KAU as a case study example. Three questionnaires were designed including academic leaders and experts, academic staff, and students, respectively. The questionnaires were developed based on the results from surveys. The criteria and subcriteria of the "TQM Hybrid MCDM Fuzzy Model" are then identified. Considering the importance level among criteria and subcriteria, the "TQM Hybrid Fuzzy Model" indicated that the criteria that have achieved the highest score include "leadership (A2, A3, A4)," "policy and strategy (B1, B2, B3)," "people (C1)," "partnership & resources (D1)," "product, service, & process (E1)," "mega online distance learning (F1, F2)," and "scoring & ranking (G1)," respectively. By considering the importance level and influence level among criteria and subcriteria, it indicated that "leadership (A2, A3, A4)," "policy and strategy (B1)," "people (C1)," "partnership & resources (D1, D2)," "product, service, & process (E1)," "mega online distance learning (F1, F2, F3)," and "scoring & ranking (G1)," respectively, have achieved the highest score. These results prove that the "TQM Hybrid MCDM Fuzzy Model" can enhance TQM-KPIs and can help in identifying strategic opportunities aiming to raise the level of quality services efficiently in mega universities. In future work, the complete software of the model will be embedded inside the KAU database library.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This project was funded by the Deanship of Scientific Research (DSR), King Abdul-Aziz University, Jeddah, under grant no. (G: 189-611-1440). The authors, therefore, acknowledge with thanks to DSR's technical and financial support. This project was funded by the Deanship of Scientific Research (DSR), King Abdul-Aziz University, Jeddah, under grant no. (G: 189-611-1440).

References

[1] M. Venable, "Online education and Mega-Universities: factors to consider," 2019, https://www.bestcolleges.com/blog/online-education-and-mega-universities/.

[2] WSIS Stocktaking 2020 Global Report: ZERO DRAFT, https://www.itu.int/net4/wsis/forum/2020/Files/outcomes/draft/GlobalWSISStocktakingReport%202020_DRAFT.pdf.

[3] E. Ossiannilsson, K. Williams, A. F. Camilleri, and M. Brown, "International council for open and distance education: quality models in online and open education around the globe: state of the art and recommendations," 2015, https://files.eric.ed.gov/fulltext/ED557055.pdf.

[4] I. Jung, "Quality assurance survey of mega universities," *Perspectives on Distance Education Lifelong Learning & Distance Higher Education*, UNESCO Publishing, Paris, France, 2005.

[5] P. Ordenes, "Higher education KPIs-most commonly used KPIs in 2021," 2021, https://www.cascade.app/blog/higher-education-kpis.

[6] Z. Lazic, A. Dordevic, and A. Gazizulina, "Improvement of quality of higher education institutions as a basis for improvement of quality of life," *Sustainability*, vol. 13, p. 4149, 2021.

[7] 2021 TRENDS, https://download.hlcommission.org/HLCTrends2021.pdf.

[8] B. Alzahrani, H. Bahaitham, M. Andejany, and A. Elshennawy, "How ready is higher education for quality 4.0 transformation according to the LNS research framework?" *Sustainability*, vol. 13, no. 9, p. 5169, 2021.

[9] N. Karadağ and A. Z. Özgür, "Assessment and evaluation in mega universities," *TOJET: The Turkish Online Journal of Educational Technology – October*, vol. 19, 2020.

[10] UNISCO, *Higher Education for All: Report on the Futures of Higher Education Envisions Collective and Holistic Responses to Global Challenges*, UNISCO, 2021.

[11] F. O. Iyoha, D. E. Gberevbie, and C. K. Ayo, "Enhancing the quality of higher education in Africa: exploring the Covenant University business model," in *Proceedings of the 8th International Conference of Education*, Seville, Spain, November 2015.

[12] C. U. Ogbulogo, T. O. George, and D. O. Olukanni, "Teaching Aids, Quality Delivery, and Effective Learning Outcomes in A Nigerian Private University," in *Proceedings of the 6th International Conference on Education and New Learning Technologies (EDULEARN)*, Barcelona, Spain, July 2014.

[13] A. Al-Bashir, "Applying total quality management tools using QFD at higher education institutions in gulf area (case study: ALHOSN university)," *International Journal of Production Management and Engineering*, vol. 4, no. 2, p. 87, 2016.

[14] D. Kucharova, "Internal quality assurance practices in czech public higher education," in *Proceedings of the Conference: 20th International Conference on Current Trends in Public Sector Research, Slapanice, Czech Republic Current Trends in Public Sector Research*, Brno, Czechia, January 2016.

[15] A. Basu, S. K. Banshal, K. Singhal, and V. K. Singh, "Designing a composite index for research performance evaluation at the national or regional level: ranking central universities in India," *Scientometrics*, vol. 107, no. 3, pp. 1171–1193, 2016.

[16] M. Gholamzadeh and M. Mojahed, "An improved TOPSIS/EFQM methodology for evaluating the performance of organizations," *Life Science Journal*, vol. 10, 2013.

[17] A. Ziaei, H. Alirezaee, A. Riyahi, and P. Shirazi, "Assess causal relationships of EFQM model criteria using fuzzy dematel (case study: tovseeh Taavon bank)," *International Business Management*, vol. 10, pp. 2185–2189, 2016.

[18] S. Mehrdad, *A New Framework Based on EFQM to Achieve Continuous Improvement In Higher Education Institutions (HEIs)*, Eastern Mediterranean University (EMU), Famagusta, Cyprus, 2015.

[19] K. Mohammed, B. Ali, and A. Abdulaziz, "Total quality management in Saudi higher education," *International Journal of Computers and Applications*, vol. 135, no. 4, pp. 6–12, 2016.

[20] A. Y. Noaman, A. H. M. Ragab, A. I. Madbouly, A. M. Khedra, and A. G. Fayoumi, "Higher education quality assessment model: towards achieving educational quality standard," *Studies in Higher Education*, vol. 42, no. 1, pp. 23–46, 2017.

[21] K. Nasim, A. Sikander, and X. Tian, "Twenty years of research on total quality management in higher education: a systematic literature review," *Higher Education Quarterly*, vol. 74, 2019.

[22] Y. A. Al-Turki, A. L. Bilgrami, and A. E. Said, "A case study of key performance indicators in scientific research in A Middle eastern university," *International Journal of Latest Research in Science and Technology*, vol. 4, no. 6, 2015.

[23] I. Jung (2016), http://portal.unesco.org/education/en/file_download.php/94e2bfdd4dddf7f9d342d32afa7457f4jung_study.pdf.

[24] A. Mohaghar, M. R. Fathi, M. K. Zarchi, and A. Omidian, "A combined VIKOR-fuzzy AHP approach to marketing strategy selection," *Business Management and Strategy*, vol. 3, no. 1, 1969.

[25] M. Taghvaei and M. Goodarzi, "Development and prioritization of medical tourism development strategies (case study: shiraz metropolis)," *Research Urban Planning*, vol. 7, no. 24, pp. 1–22, 2016.

[26] L. S. Chen and C. H. Cheng, "Selecting IS personnel use fuzzy GDSS based on metric distance method," *European Journal of Operational Research*, vol. 160, no. 3, pp. 803–820, 2005.

[27] A. Ozdagoglu and M. E. Guler, "E-service quality of Internet based banking using combined fuzzy AHP and fuzzy TOPSIS," *Tehnički Vjesnik*, vol. 23, no. 4, pp. 1109–1116, 2016.

[28] V. Jain, A. K. Sangaiah, S. Sakhuja, N. Thoduka, and R. Aggarwal, "Supplier selection using fuzzy AHP and TOPSIS: A case study in the indian automotive industry," *Neural Computing and Applications*, vol. 29, pp. 1–10, 2016.

[29] M. Asghari, P. Nassiri, M. R. Monazzam et al., "Weighting criteria and prioritizing of heat stress indices in surface mining using a delphi technique and fuzzy AHP-TOPSIS method," *Journal of Environmental Health Science and Engineering*, vol. 15, no. 1, 2017.

[30] A. Yazdani-Chamzini, S. Shariati, S. Haji Yakhchali, and E. Kazimieras Zavadskas, "Proposing a new methodology for prioritising the investment strategies in the private sector of Iran," *Economic Research-Ekonomska Istraživanja*, vol. 27, no. 1, pp. 320–345, 2014.

[31] E. Ali Mohammadian and M. Shafiei, "Fuzzy multi-criteria decision-making approach to rank and improve the gap between educational hospitals affiliated to Shiraz University of Medical Sciences and based on Balanced Scorecard approach," *Journal of Iran University of Medical Sciences*, vol. 22, no. 140, pp. 12–24, 2011.

[32] I. Petrovic and M. Kankaras, "A hybridized IT2FS-DEMATEL-AHP-TOPSIS multi-criteria decision making approach: case study of selection and evaluation of criteria for determination of air traffic control radar position," *Decision Making: Applications In Management And Engineering*, vol. 3, no. 1, pp. 134–152, 2020.

[33] S. N. Taati and A. Esmaili Dooki, "A hybrid method of Fuzzy EMATEL/AHP/VIKOR approach to rank and select the best hospital nurses of a Years: a case study," *Journal of Applied Research on Industrial Engineering*, vol. 4, no. 2, pp. 116–132, 2017.

[34] U. T. Şenel, B. D. Rouyendegh, and S. Demir, "A multi-attribute approach to ranking departments based on performance: a balanced scorecard pilot study," *Complex & Intelligent Systems*, vol. 296, pp. 1–9, 2022.

[35] U. T. Şenel, B. D. Rouyendegh, and S. Tekin, "Integrated performance evaluation method study and performance-based department ranking: a case study," *SN Applied Sciences*, vol. 2, no. 2, p. 281, 2020.

[36] A. Mardani, A. Jusoh, and E. K. Zavadskas, "Fuzzy multiple criteria decision-making techniques and applications—two decades review from 1994 to 2014," *Expert Systems with Applications*, vol. 42, no. 8, pp. 4126–4148, 2015.

[37] King Abdulaziz University 2021-2022 Ranking, https://cwur.org/2021-22/King-Abdulaziz-University.php.

[38] E. Herrera-Viedma, I. Palomares, C. C. Li et al., "Revisiting fuzzy and linguistic decision making: scenarios and challenges for making wiser decisions in a better way," *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, vol. 51, no. 1, pp. 191–208, 2021.

[39] C. Bao, D. Wu, and J. Li, "A knowledge-based risk measure from the fuzzy multicriteria decision-making perspective," *IEEE Transactions on Fuzzy Systems*, vol. 27, no. 5, pp. 1126–1138, 2019.

[40] A. Hadi-Vencheh, M. Mirjaberi, and A. HAdi-Vencheh, "Seclusion-factor method to solve fuzzy-multiple criteria decision-making problems," *IEEE Transactions on Fuzzy Systems*, vol. 19, no. 2, pp. 201–209, 2011.

[41] S. Raziei, "EFQM excellence model based on multi-criteria processes fuzzy AHP, fuzzy dematel, fuzzy TOPSIS, and fuzzy VIKOR; A comparative survey," *International Journal of Scientific & Technology Research*, vol. 8, no. 04, 2019.

[42] S. K. Malik, "Generalized MCDM-based decision support system for personnel prioritization," in *Proceedings of the International Conference on ICT for Sustainable Development*, pp. 155–168, Springer, Singapore, February 2016.

[43] N. M. Yaghoubi, M. Bandeii, and J. Moloudi, "An empirical study of the EFQM excellence model in Iran," *International Journal of Business and Management*, vol. 6, no. 5, 2011.

[44] M. J. Paghaleh, "Performance measurement by EFQM excellence model with fuzzy approach," *Australian Journal of Basic and Applied Sciences*, vol. 5, pp. 1020–1024, 2001.

[45] J. C. Bou-Llusar, A. B. Escrig-Tena, V. Roca-Puig, and I. Beltrán-Martín, "An empirical assessment of the EFQM Excellence Model: evaluation as a TQM framework relative to the MBNQA Model," *Journal of Operations Management*, vol. 27, pp. 1–22, 2009.

[46] U. Nabitz and N. Klazinga, "EFQM approach and the Dutch quality award," *International Journal of Health Care Quality Assurance*, vol. 12, no. 2, pp. 65–71, 1999.

[47] J. J. Buckley, "Fuzzy hierarchical analysis," *Fuzzy Sets and Systems*, vol. 17, no. 3, pp. 233–247, 1985.

[48] S.-L. Si, X.-Y. You, H.-C. Liu, and P. Zhang, "DEMATEL Technique: a systematic review of the state-of-the-art literature on methodologies and applications," *Mathematical Problems in Engineering*, vol. 2018, Article ID 3696457, 33 pages, 2018.

[49] S. K. Patil and R. Kant, "A fuzzy DEMATEL method to identify critical success criteria of knowledge management adoption in the supply chain," *Journal of Information & Knowledge Management*, vol. 12, 2013.

[50] D. Dalalah, M. Hayajneh, and F. Batieha, "A fuzzy multi-criteria decision-making model for supplier selection," *Expert Systems with Applications*, vol. 38, pp. 8384–8391, 2011.

[51] M. Alimardani, M. Rabbani, and H. Rafiei, "A novel hybrid model based on DEMATEL, ANP and TOPSIS for supplier selection in agile supply chains," *International Journal of Services and Operations Management*, vol. 18, no. 2, p. 179, 2014.

[52] D. Gharakhani, "The evaluation of supplier selection criteria by fuzzy DEMATEL method," *Journal of Basic and Applied Scientific Research*, vol. 2, pp. 3215–3224, 2012.

[53] S. Seker and E. K. Zavadskas, "Application of fuzzy DEMATEL method for analyzing occupational risks on construction sites," *Sustainability*, vol. 9, no. 11, p. 2083, 2017.

[54] J. J. H. Liou, G. H. Tzeng, and H. C. Chang, "Airline safety measurement using a hybrid model," *Journal of Air Transport Management*, vol. 13, no. 4, pp. 243–249, 2007.

[55] M. Tamura, H. Nagata, and K. Akazawa, "Extraction and systems analysis of Criteria that prevent safety and security by structural models," in *Proceedings of the 41st SICE Annual Conference*, Osaka, Japan, September 2002.

[56] M. F. El-Santawy, "A VIKOR method for solving personnel training selection problem," *International Journal of Computing Science*, vol. 1, pp. 9–12, 2012.