EFQM Excellence Model Based On Multi-Criteria Processes Fuzzy AHP, Fuzzy DEMATEL, Fuzzy TOPSIS, And Fuzzy VIKOR; A Comparative Survey

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Abstract: In this study, a brief description of European Foundation for Quality Management (EFQM) excellence model of business was introduced based on Total Quality Management (TQM) concept. Then, an adaptation of EFQM excellence model of business with implementation of multi-criteria decision making processes including Fuzzy Analytic Hierarchical Process (F-AHP), Fuzzy Decision Making Trial and Evaluation Laboratory (F-DEMATEL), Fuzzy Technique for Order Preference Similarity to Ideal Solution (F-TOPSIS), and Fuzzy VIse Kriterijumska Optimizacija Kompromisno Resenje (F-VIKOR) was investigated as a survey on the literatures. Detailed differences of these methods and their influences on the quality assessment policies were studied analytically. Such modified version of EFQM model based on such fuzzy processes was compared with the routine strategies of EFQM. Some different types of fuzzy numbers, defuzzification methods and the way of comparison among them were also discussed in this study. Finally by comparing the advantages and disadvantages of each method, hybrid approaches were found as the most effective method of organizational assessment.

Index Terms: European Foundation for Quality Management (EFQM), Fuzzy Analytic Hierarchical Process (F-AHP), Fuzzy Decision Making Trial and Evaluation Laboratory (F-DEMATEL), Fuzzy Technique for Order Preference Similarity to Ideal Solution (F-TOPSIS), Fuzzy VIse Kriterijumska Optimizacija Kompromisno Resenje (F-VIKOR), Quality Management

1 INTRODUCTION

Quality is everyone's responsibility; a famous quotation from William Edwards Deming which is the compendium of the quality management policies [1]. Starting point of total quality management (TQM) was created from 1940s in Japan by Deming, Shewart and Juran [2]. TQM is a system management for value enhancement to the customers by designing and improving the organizational processes [3]. As a result of exceptional economic growth of Japanese corporations and business sectors from the last century, Americans and European business managers decided to plan a strategy to be able to compete and cope with such developments on purpose of competition surveillance against Japanese corporations. In this respect, an award similar to Deming Award which was introduced in 1951 was officially dedicated to the successful business managers in America in 1987 as Baldrige Award; called after Malcolm Baldrige [4]. Similar approach was started in Europe in 1989 by 14 leading European organizations to persuade and promote the application of TQM principles [2]. By confirmation of European Commission, European Foundation for Quality Management (EFQM) model was established in 1991 followed by European award dedication in 1992.

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Since then, EFQM Exchange Award as the most prestigious award in Europe for the organizations has been dedicated for promotion and persuasion of such business experiences, knowledge and guidelines exchanges [5]. Training the business leaders through practice-based learning among worldwide organizations is the mission of this model [5]. So, EFQM is a measurement method for the organizations based on self-assessment which is actually established based on TQM framework focused on the organization empowerment more than the results [3, 6]. Self-assessment beside the total quality improvement, is an organizational technique for quality management by which strengths and possibilities for improvement are focused and non-satisfactory results are analyzed so as to reveal the areas proper for improvement [7, 8]. This means that EFQM excellence model has a retrospective vision from the results to the leadership policies due to the assumption of causal relationship between these elements [9]. Companies, especially those with strong focus on continuous improvements experience a lot of benefits and gains from the self-assessment process of this model [9, 10]. After 1992, EFQM excellence model was used as the most popular tool for organizational self-assessment in Europe in such way that 69% of European organizations had used this model for self-assessment [9, 11].

Excellence model contains 9 criteria as the following [6].

1) Enablers criteria: Leadership, Policy and Strategy, Employee, Participations and Resource, Process
2) Results criteria: Customer Results, People Results, Social Results, Key Performance Results

Organization quality assessment is accomplished by scoring and ranking the organizations according to the above mentioned criteria for each of which there are some sub-criteria. Each criterion and sub-criterion has its own weight and importance level. By consideration of the criteria and sub-criteria weights, the recognition levels of the organizations are determined according to their scores. In this manner, organizations can be divided into 3-star (300+ points out of 1000), 4-star (400+ points out of 1000), and 5-star (500+ points out of 1000). Organizations, receiving scores of 600 and over, are considered as the “prize winner”. The best organization is entitled to be “award winner” [2]. The most important profit of this method is recognition of strong and weakness points of organization and employees of organization by assessment of internal facts and processes and results. Therefore, it accelerates the organizational development and provides an opportunity to use all of the employees experiences [6]. So due to all of these advantages, EFQM is used world widely among many organizations for the strategic quality managerial policy makings. However in spite of these benefits, there are also some drawbacks in EFQM due to the lack of comprehensive and inclusive strategies especially in definition of importance levels among the criteria and sub-criteria. Consequently, some studies have focused their attention on this matter to develop new evaluation methods for this model [5]. For example, many researches have investigated effectiveness of implementation of multi-criteria decision making (MCDM) processes instead of routine criteria weights assigned by EFQM model [12-16]. MCDM was first suggested in 1975 by Zeleny, and was explained by Zionts in 1979 since then gained universal recognition [17]. Since 1990, MCDM methods have rapidly developed and have been applied to support strategic decisions in different areas. A group of decision-makers is more confident in the results of decision making when MCDM is applied, especially in cases of increasing variety and complexity of information as well as the cases interacting with challenging problems. Such multi-criteria methods are either multi-layer or single layer decision processes of which Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Decision Making Trial and Evaluation Laboratory model (DEMATEL), Technique for Preference Similarity to Ideal Solution (TOPSIS), and Serbian model of VIse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR) are the most known and the most frequently applied methods [17]. AHP is a mathematical approach proposed by Saaty for ranking some alternatives (choices) based on some criteria. In this method, alternatives are compared and scored quantitatively pairwise according to each criterion. Criteria are also ranked among each other and by implementation of some mathematic approach, it is possible to sort the choices by their importance as well as to evaluate the consistency of pairwise comparisons [18]. Analytic Network Process (ANP) was also developed by Saaty which was based on AHP to cope with its restrictions as well as to deal with the problems where interrelationships and feedback among the criteria or alternatives are taken into consideration [18, 19]. There was some deficiency in ANP for which DEMATEL method was introduced by Yang and Tzeng to overcome the its limitations [19]. DEMATEL procedure provides meaningful structural relationships between the criteria through a causal diagram. So it is frequently used in strategic analysis, performance evaluation, cost of quality model development and brand marketing [19-21]. TOPSIS method was introduced by Chen and Hwang. TOPSIS is a multiple criteria method to identify the ideal solutions from a finite set of alternatives by measuring the shortest and the longest distance of the alternatives from the positive and negative criteria, respectively [22]. VIKOR method developed by Opricovic and Tzeng focuses on the selection of the most appropriate alternative by ranking the alternatives among conflicting criteria [23, 24]. The Serbian acronym VIKOR means "benchmark optimization and reconciliation" [25]. Similar to TOPSIS, this method is not a hierarchical process such as AHP or DEMATEL. In the EFQM, measures are in linguistic-vague forms expressed in linguistic parameters, implying so many doubts. Owning to this vagueness, the crisp values can’t convey the real measures properly. Fuzzy logic allows assignment of different meanings we give to the same linguistic expressions. As a matter of fact, this is why the fuzzy approach has been so widely adopted in different research fields [26, 27]. Professor Lotfi-Aliaskar Zadeh has introduced fuzzy logic and fuzzy sets in his paper for the first time in 1965. So afterwards, there has been a great interest among scientists to apply fuzzy logic in human decision making processes because of its capability in demonstration of human uncertainty in decision making processes [28]. Exactly alongside of this fact, fuzzy MCDM processes have been developed for all of above mentioned methods. Purpose of this research is to survey the prioritization methods of decision making based on fuzzy logic suitable for EFQM excellence model as well as to investigate their corresponding strengths and limitations. The current research also discusses the advantages of hybrid decision making processes over individual methods and its application in EFQM model.

2. Evaluation Methods

The EFQM excellence model consists of nine criteria divided into two main categories; enablers and results criteria. These criteria are also divided into 32 sub-criteria [29]. These nine criteria and their corresponding weights are shown in Fig. 1 [30].

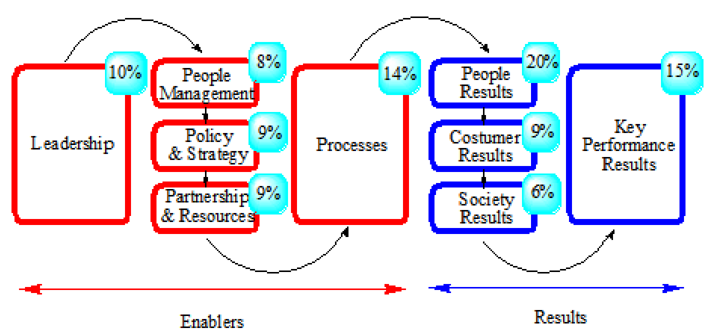

Fig. 1. *EFQM model criteria and their weight factors.*

Enablers embrace the processes and structures so that they are concerned with how the organization performs its activities [27, 29]. The results concentrate on achievements relating to organizational stakeholders; so deal with organizational accomplishments [27, 31]. For each criterion, there are several sub-criteria illustrated with various ‘guidance points’ clarifying necessary acts the organization has to do in order to fulfill the corresponding criteria [27]. A brief description for all criteria and their corresponding sub-criteria is provided in Table 1 [27, 30]. A questionnaire is prepared based on these criteria and sub-criteria to let some expert examiners assess the organizations quantitatively. Such quantitative assessment can be applied for comparison with all or parts of any kind of organizations. The algorithm of this assessment is based on RADAR logic which stands for Results, Approach, Deployment, Assessment and Review. It states that any organization should determine the Results aiming for and plan an integrated set of Approaches to deliver these results and consequently Deploy the approaches in a systematic way and finally, Assess and Review the approaches by monitoring the achieved results. Therefore, the questions in the questionnaire are prepared based on this algorithm [32]. At first, EFQM assessors are selected as auditors to fill in such qualitative questionnaire. Then, organizational qualitative assessment is converted to quantitative evaluation by taking the corresponding linguistic scoring values into account. Each question has its own specific weight as do the EFQM criteria and sub-criteria as well. Considering all of the evaluation scores as well as questions, criteria and sub-criteria weights, the summation of all scores is calculated. Finally in this manner, the total organization quality score is obtained [27]. All of the criteria and sub-criteria weights are represented in Table 2. However, these weights may vary according to different versions of EFQM model or even based on different organizations [4, 30]. However as mentioned above, there are some limitations in this scoring method by which organizations encounter some problems. These problems are attributed to scoring system of this model. So, the EFQM questions, criteria and sub-criteria weights and scoring method is modified by considering prioritization methods discussed below [14].

TABLE 8

EFQM EXCELLENCE MODEL CRITERIA AND SUB-CRITERIA

Criterion	Sub-criterion
1 Leadership	1a) Leaders develop the mission, vision, values and ethics, and act as role models 1b) Leaders define, monitor, review, and drive the improvement of the organization's management system and performance. 1c) Leaders engage with external stakeholders 1d) Leaders reinforce a culture of excellence with the organization's people 1e) Leaders ensure that the organization is flexible and manages change effectively
2 Policy & Strategy	2a) Strategy is based on understanding the needs and expectations of both stakeholders and the external environment 2b) Strategy is based on understanding internal performance and capabilities 2c) Strategy and supporting policies are developed, reviewed, and updated 2d) Strategy and supporting policies are communicated, implemented, and monitored
3 People	3a) People plans support the organization's strategy 3b) People's knowledge and capabilities are developed. 3c) People are aligned, involved, and empowered 3d) People communicate effectively throughout the organization. 3e) People are rewarded, recognized, and cared for
4 Partnership & Resources	4a) Partners and suppliers are managed for sustainable benefit. 4b) Finances are managed to secure sustained success 4c) Buildings, equipment, materials, and natural resources are managed in a sustainable way 4d) Technology is managed to support the delivery of strategy 4e) Information and knowledge are managed to support effective decision making and to build the organization's capability
5 Processes	5a) Processes are designed and managed to optimize stakeholder value 5b) Products and services are developed to create optimum value for customers. 5c) Products and services are effectively promoted and marketed 5d) Products and services are produced, delivered and managed 5e) Customer relationships are managed and enhanced
6 Customer Results	6a, 7a, 8a, 9a) Perception measures are used to give a clear understanding of the effectiveness, from the customers' perspective 6b, 7b, 8b, 9b) Performance indicators are used by the organization to monitor, understand, predict and improve its performance.

TABLE 2

EFQM CRITERIA AND SUB-CRITERIA WEIGHTS

Criteria	Criteria Weight	Sub-criteria	Sub-criteria Weight
1	10%	1a	20%
		1b	20%
		1c	20%
		1d	20%
		1e	20%
2	8%	2a	25%
		2b	25%
		2c	25%
		2d	25%
3	9%	3a	20%
		3b	20%
		3c	20%
		3d	20%
		3e	20%
4	9%	4a	20%
		4b	20%
		4c	20%
		4d	20%
		4e	20%
5	14%	5a	20%
		5b	20%
		5c	20%
		5d	20%
		5e	20%
6	20%	6a	0.75%
		6b	0.25%
7	9%	7a	0.75%
		7b	0.25%
8	6%	8a	0.75%
		8b	0.25%
9	15%	9a	50%
		9b	50%

2.1 EFQM Model Based on Fuzzy AHP

A fuzzy set is a class of objects with a continuum of grades of membership. Such set is characterized by a membership function which assigns a grade of membership ranging between 0 and 1 to each object [27]. Grade 1 denotes complete membership and grade 0 stands for exclusion from the set. The other grades between 0 and 1 describe fuzzy and vague nature of the elements. If l , m and u denote the lower limit (the smallest possible value), mean of the number (the most promising value) and the upper limit (the largest possible value) of the fuzzy number, respectively; the triangular fuzzy number as shown in Fig. 2 can be denoted as a triplet , in which . can be denoted as a triplet (l, m, u), in which $l \le m \le u$. So, the membership function can be defined as bellow [33].

$$\mu(x) = \begin{cases} \dfrac{x-l}{m-l} & x \in [l, m] \\ \dfrac{u-x}{u-m} & x \in [m, u] \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

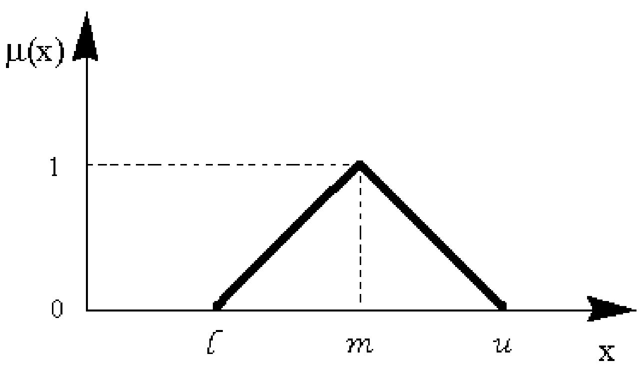

Fig. 2. *Triangular fuzzy number illustration.*

If let the $M = (l_1, m_1, u_1)$ and $N = (l_2, m_2, u_2)$ be two fuzzy numbers and suppose r as a natural crisp number, the basic fuzzy calculations rules are as below [34].

$$M \oplus N = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \qquad (2)$$

$$M \otimes N = (l_1.l_2, m_1.m_2, u_1.u_2) \qquad (3)$$

$$\frac{1}{M} = (\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}) \qquad (4)$$

$$r \otimes M = (r.l_1, r.m_1, r.u_1) \qquad (5)$$

So prioritization and scoring the alternatives (EFQM criteria or questions) for the self-assessment process is done by implementation of such fuzzy numbers in fuzzy AHP. Each EFQM question, criterion or sub-criterion is compared separately by the other items via a questionnaire by some qualified assessors. Evaluation of importance ranking from linguistic values to quantitative scale is made by formation of AHP pairwise comparison matrix (as matrix A in Eq.(6)) with fuzzy scales presented in Table 3 [35].

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \cdots & A_n \end{array} \\ \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{pmatrix} \end{array}. \qquad (6)$$

where superscripts A_1 to A_n stand for comparison matrix for all alternatives (EFQM questions or criteria).

TABLE 3
QUNATITATIVE SCALES FOR IMPORTANCE LEVELS IN F-AHP METHOD

Linguistic Variables	**Fuzzy Scales**
Extremely Important	(7, 9, 9)
Strongly Important	(5, 7, 9)
Moderately Important	(3, 5, 7)
Slightly Important	(1, 3, 5)
Equally Important	(1, 1, 1)

At first, geometric average of the elements of the comparison matrix is calculated by considering all assessors matrices. It is important to check whether the resultant matrix is consistent or not. In a consistent matrix, $A_{pl} * A_{lq} = A_{pq}$, for $p, q, l = 1, \dots, n$. Then, synthetic matrix is calculated as Eq.(7) [35].

$$S = (\sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij})^{-1} . \begin{pmatrix} \sum_{j=1}^{n} A_{1j} \\ \sum_{j=1}^{n} A_{2j} \\ \vdots \\ \sum_{j=1}^{n} A_{nj} \end{pmatrix}. \qquad (11)$$

Then, weights matrix W is obtained by calculating the fuzzy degree by the following equation.

$$W = \left. \begin{pmatrix} Min\{\deg(S_1, S_k)\} \\ Min\{\deg(S_2, S_k)\} \\ \vdots \\ Min\{\deg(S_n, S_k)\} \end{pmatrix} \right|_{k = 1, 2, \ldots, n} . \qquad (8)$$

in which fuzzy degree function is defined for two fuzzy numbers M and N as below [35].

$$\deg(M \geq N) = \begin{cases} 1 & m_1 \geq m_2 \\ 0 & u_1 \leq l_2 \\ \dfrac{u_1 - l_2}{u_1 - l_2 + m_2 - m_1} & \text{otherwise} \end{cases} \quad (9)$$

Finally by normalization of the obtained weights, EFQM questions or criteria (or even sub-criteria) ranking is performed separately by the extent of the corresponding value in each row of matrix W [35]. Although it is possible to apply this method for the EFQM questions, criteria and sub-criteria weights determination, it is so much better to use it only for the questions or criteria weight ranking because of their fewer items compared to the sub-criteria. Moreover the triangular fuzzy numbers, there are other types of fuzzy numbers including singleton, trapezoidal, s-shaped or z-shaped (sigmoid), and bell shaped numbers [36, 37]. For example, trapezoidal fuzzy number can be defined by membership function according to Eq.(10) which is shown in Fig. 3.

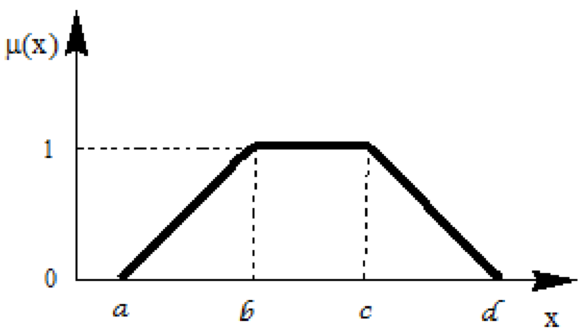

Fig. 3. *Trapezoidal membership function.*

$$\mu(x) = \begin{cases} \dfrac{x - a}{b - a} & x \in [a, b] \\ 1 & x \in [b, c] \\ \dfrac{d - x}{d - c} & x \in [c, d] \end{cases} \quad (10)$$

Verbal fuzzy phrases are corresponded with these numbers as Table 4 [38].

TABLE 4
VERBAL AND FUZZY VALUES FOR TRAPEZOIDAL FUZZY NUMBERS

Linguistic Variables	Fuzzy Scales
Very Good	(9, 9, 10)
Good	(7, 9, 10)
Slightly Good	(5, 7, 9)
Fair	(3, 5, 7)
Slightly Poor	(1, 3, 5)
Poor	(0, 1, 3)
Very Poor	(0, 1, 1)

In this case, instead of using degree function as Eq.(8) and (9), fuzzy weights in weight matrix are defuzzified as X as below.

$$X = \frac{a + 2b + 2c + d}{6} \quad (11)$$

Some other fuzzy numbers can be considered as bell shaped membership function as below [30].

$$\mu(x) = \frac{1}{1 + s(x - m)^2} \quad (12)$$

in which m is the standard value for assessment of the criteria which corresponds to m value in triangular fuzzy number and s value is a shape factor which is usually 0.02 [30]. These factors define the shape of the membership function which is illustrated schematically in Fig. 4. Quantitative scales for such numbers are shown in Table 5 [39].

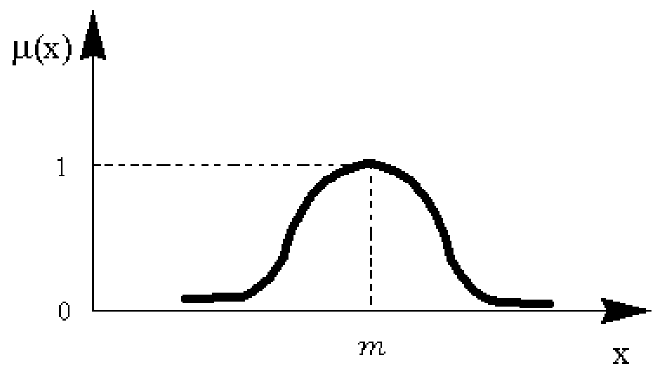

Fig. 4. *Bell-shaped membership function for a fuzzy number.*

In such cases, defuzzification process is also performed by using some other functions instead of degree function. For example, there are defined many defuzzification functions among which centroid function defined in Mamdani model is the most known [39]. So in these cases, center of gravity (Z) is employed as the following equation [39-41].

$$Z = \frac{\sum_{i=1}^{n} \mu(x_i) x_i}{\sum_{i=1}^{n} \mu(x_i)} \quad (13)$$

Therefore, corresponding defuzzified numbers of every criterion and sub-criterion are obtained and summed regarding their own crisp weights factors. As a result, weighted sum of all defuzzified numbers makes the total organizational quality score.

TABLE 5
VERBAL AND FUZZY VALUES FOR BELL SHAPED FUZZY NUMBERS

Linguistic Variables	Fuzzy Scales
Extremely Higher	(0.07, 0.09, 0.12, 0.17, 0.24, 0.36, 0.55, 0.83, 1)
Very Higher	(0.09, 0.12, 0.17, 0.24, 0.36, 0.55, 0.83, 1, 0.83)
Higher	(0.12, 0.17, 0.24, 0.36, 0.55, 0.83, 1, 0.83, 0.55)
Slightly Higher	(0.17, 0.24, 0.36, 0.55, 0.83, 1, 0.83, 0.55, 0.36)
Medium	(0.24, 0.36, 0.55, 0.83, 1, 0.83, 0.55, 0.36, 0.24)
Slightly Lower	(0.36, 0.55, 0.83, 1, 0.83, 0.55, 0.36, 0.24, 0.17)
Lower	(0.55, 0.83, 1, 0.83, 0.55, 0.36, 0.24, 0.17, 0.12)
Very Lower	(0.83, 1, 0.83, 0.55, 0.36, 0.24, 0.17, 0.12, 0.09)
Extremely Lower	(0.83, 0.55, 0.36, 0.24, 0.17, 0.12, 0.09, 0.07)

2.2 EFQM Model Based on Fuzzy DEMATEL

Similar to AHP, each EFQM question, criterion or sub-criterion is compared pair-wisely by the evaluating experts in this method. Pairwise comparison matrix (similar to Eq.(1)) with fuzzy scales presented in Table 6 is formed. Unlike AHP, total effect of all experts evaluation is considered by arithmetic averaging instead of geometric averaging. Then, the initial data can be obtained as the direct-relation matrix which is an $n \times n$ matrix A where each element of A_{ij} is denoted as the degree in which the criterion i affects the criterion j [42].

Then, the obtained matrix A is divided by scalar value s as below to calculate the initial direct-relation matrix D [25, 42].

$$s = \max_{1 \le i \le n} \{ \sum_{j=1}^{n} A_{ij} \} \quad (14)$$

$$D = A / s \quad (15)$$

Afterwards, in condition that $\lim_{m \to \infty} D^m = 0$, the total relation matrix T is calculated as below. If each element of T is assumed as $T_{ij} = (l_{ij}^T, m_{ij}^T, u_{ij}^T)$, then it is

$$[l_{ij}^T] = D_l \times (I - D_l)^{-1} \quad (16.1)$$

$$[m_{ij}^T] = D_m \times (I - D_m)^{-1} \quad (16.2)$$

$$[u_{ij}^T] = D_u \times (I - D_u)^{-1} \quad (16.3)$$

in which I is identity matrix [25].

TABLE 6
LINGUISTIC VARIABLES FOR RATING THE EFQM CRITERIA OR SUB-CRITERIA IN F-DEMATEL METHOD

Linguistic Variables	**Fuzzy Scales**
Very Good	(8, 10, 10)
Good	(7, 8, 9)
Slightly Good	(5, 6.5, 8)
Fair	(4, 5, 6)
Slightly Poor	(2, 3.5, 5)
Poor	(1, 2, 3)
Very Poor	(0, 0, 2)

Supposing r and c as $n \times 1$ vectors indicating the sum of rows and sum of columns of matrix T, respectively as below.

$$r = [r_i]_{n \times 1} = [\sum_{j=1}^{n} T_{ij}]_{n \times 1} \quad (17.1)$$

$$c = [c_j]_{n \times 1} = [\sum_{i=1}^{n} T_{ij}]_{n \times 1} \quad (17.2)$$

Based on the last expressions, r_i, the row sum of the i[th] row of matrix T, represents the sum of direct and indirect effects of element i on the other criteria, and c_j, the column sum of the j[th] column of matrix T, represents the sum of direct and indirect effects of element j has received from other elements. Hence, when $i = j$, $r_i + c_i$ indicates the total influences given and received by element i. In fact, the total sum of influences $r_i + c_i$ gives us the degree of importance that criterion i plays in the problem. Furthermore, the difference $r_i - c_i$ represents the net effect that element i contributes to the problem. Based on the last index, when $r_i - c_i$ is positive, element i is called a net causer. It means that it has a significant impact on the other elements. In the contrary, when $r_i - c_i$ is negative, element i is called a net receiver. It means that it is influenced by the other criteria. Finally, Defuzzification process of fuzzy numbers $r + c$ and $r - c$ is done by the following formula [19, 25, 42, 43].

$$X = \frac{a_1 + 2a_2 + a_3}{4} \quad (18)$$

in which X is the deffuzified value of fuzzy number

$\tilde{X} = (a_1, a_2, a_3)$.

.

However, other researches have proposed other formulas as below [44-47].

$$X = \frac{a_1 + a_2 + a_3}{3} \quad (19)$$

$$X = \frac{a_1 + 4a_2 + a_3}{6} \quad (20)$$

$$X = \begin{cases} a_3 - \sqrt{\dfrac{(a_3 - a_1)(a_3 - a_2)}{2}} & a_2 \prec \dfrac{a_1 + a_3}{2} \\ \sqrt{\dfrac{(a_3 - a_1)(a_3 - a_2)}{2}} - a_1 & a_2 \succ \dfrac{a_1 + a_3}{2} \\ a_2 & \text{otherwise} \end{cases} \quad (21)$$

This method can be applied for the EFQM questions, criteria and sub-criteria weights ranking. However it is more beneficial to use it for the EFQM questions or sub-criteria because of the interconnections among them.

2.3 EFQM Model Based on Fuzzy TOPSIS

The basic principle of TOPSIS is sorting the alternatives according to the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [48]. The procedure of TOPSIS can be expressed in a series of steps as below [49]. For fuzzy TOPSIS method, evaluation matrix for the EFQM criteria are as Table 7 [50].

TABLE 7
LINGUISTIC VARIABLES FOR RATING THE ALTERNATIVES IN F-TOPSIS METHOD

Linguistic Variables	**Fuzzy Scales**
Very Good	(8, 10, 10)
Good	(7, 8, 9)
Slightly Good	(5, 6.5, 8)
Fair	(4, 5, 6)
Slightly Poor	(2, 3.5, 5)
Poor	(1, 2, 3)
Very Poor	(0, 0, 2)

Supposing the aggregated fuzzy rating obtained by K decision makers as $\tilde{X} = (a, b, c)$, it can be determined as below.

$$a = \min\{a_k\},\ b = \frac{1}{K}\sum_{k=1}^{K} b_k,\ c = \max\{c_k\} \quad (22)$$

The effective matrix of comparison as matrix X in Eq.(23) is formed by these numbers as below. The columns indicate the ranking criteria (attributes or TQM criteria) and rows list the competing alternatives (EFQM questions, criteria or sub-criteria). For a problem with m alternatives evaluated by n criteria, a $m \times n$ matrix is formed.

$$X = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} & \multicolumn{4}{l}{\begin{pmatrix} \tilde{X}_{11} & \tilde{X}_{12} & \cdots & \tilde{X}_{1n} \\ \tilde{X}_{21} & \tilde{X}_{22} & \cdots & \tilde{X}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{X}_{m1} & \tilde{X}_{m2} & \cdots & \tilde{X}_{mn} \end{pmatrix}} \end{matrix} . \quad (23)$$

Matrix will be normalized as matrix by the following equation.

$$\tilde{R}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \quad (24)$$

in which $c_j^* = \max\{c_{ij}\}$.

Similarly, the aggregated fuzzy weights of each TQM criterion are calculated as follow.

$$w_1 = \min\{w_k\}, w_2 = \frac{1}{K}\sum_{k=1}^{K} w_k, w_3 = \max\{w_k\} \quad (25)$$

where $\tilde{w} = (w_1, w_2, w_3)$ is the fuzzy weight of each TQM criterion. These weights can be simply obtained by a column sum for each column of the main matrix followed by a vector normalization. Then, the weighted normalized decision matrix is constructed as below.

$$V = R \times W = \begin{pmatrix} \tilde{V}_{11} & \tilde{V}_{12} & \cdots & \tilde{V}_{1n} \\ \tilde{V}_{21} & \tilde{V}_{22} & \cdots & \tilde{V}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{V}_{m1} & \tilde{V}_{m2} & \cdots & \tilde{V}_{mn} \end{pmatrix} . \quad (26)$$

in which $W = \begin{pmatrix} \tilde{w}_1 & 0 & \cdots & 0 \\ 0 & \tilde{w}_2 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & \tilde{w}_n \end{pmatrix}$.

The ideal and negative-ideal solutions are formed as below.

$$V^+ = \{v_1^+, v_2^+, \ldots, v_n^+\} = \{(\max v_{ij} \mid i \in I), (\min v_{ij} \mid j \in J)\} \quad (27.1)$$

$$V^- = \{v_1^-, v_2^-, \ldots, v_n^-\} = \{(\min v_{ij} \mid i \in I), (\max v_{ij} \mid j \in J)\} \quad (27.2)$$

Calculating the distances between two fuzzy numbers are obtained by vertex method as below.

$$d(\tilde{M}, \tilde{N}) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]} \quad (28)$$

So, the separation measure is calculated as

$$d_i^+ = \sum_{j=1}^{n} d(v_{ij}, v_j^+) \qquad i = 1, 2, \ldots, m \qquad (29.1)$$

$$d_i^- = \sum_{j=1}^{n} d(v_{ij}, v_j^-) \qquad i = 1, 2, \ldots, m \qquad (29.2)$$

Finally, the relative closeness for the ideal solution is calculated by

$$CL_i = \frac{d_i^-}{d_i^- + d_i^+}, \qquad i = 1, 2, \ldots, m \qquad (30)$$

So we can rank the alternatives in decreasing order of the relative closeness. Such closeness index defines the alternatives weights. This method can be applied for all of the EFQM questions, criteria or sub-criteria. However due to it seems to be more suitable for sub-criteria weight determination, because of their large number of items.

2.4 EFQM Model Based on Fuzzy VIKOR

A comparison matrix as matrix A similar to Eq.(23) is formed in this method. An element x_{ij} of the matrix indicates the performance rating of the i[th] alternative A_i, with respect to the j[th] criterion C_j [51]. Fuzzy numbers equivalent to linguistic variables are shown in Table 8. Then, the weight importance of the criteria is multiplied by the normalized values of the first matrix in Eq.(23) to obtain a matrix like Eq.(26) [25]. These steps are similar to the initial steps of TOPSIS method.

TABLE 8

LINGUISTIC VARIABLES FOR RATING THE ALTERNATIVES IN F-VIKOR METHOD

Linguistic Variables	Fuzzy Scales
Very Good	(9, 9, 10)
Good	(7, 9, 10)
Slightly Good	(5, 7, 9)
Fair	(3, 5, 7)
Slightly Poor	(1, 3, 5)
Poor	(0, 1, 3)
Very Poor	(0, 1, 1)

Then, ranking alternatives can be described as the following steps [51]. The best x_j^+ and the worst x_j^- values of all criterion functions are determined, where $j = 1, 2, \ldots, n$. If the j[th] criterion represents a benefit, $x_j^+ = \max\{f_{ij}\}$, and $x_j^- = \min\{f_{ij}\}$; while if it is a loss, $x_j^+ = \min\{f_{ij}\}$, and $x_j^- = \max\{f_{ij}\}$. f_{ij} values are the normalized x_{ij} values. This step is almost the same as Eq.(27). Afterwards, S_i (the maximum group utility) and R_i (the minimum individual regret of the opponent) values are computed by the below relations where $i = 1, 2, \ldots, m$.

$$S_i = \sum_{j=1}^{n} (w_j \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-}) \qquad (31)$$

$$R_i = \max\{\sum_{j=1}^{n} (w_j \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-})\} \qquad (32)$$

in which w_i is the weight of the j[th] criterion and is obtained similar to F-TOPSIS method. The value Q_i, for $i = 1, 2, \ldots, m$ is computed by the relation (33).

$$Q_i = v(\frac{S_i - S^-}{S^+ - S^-}) + (1-v)(\frac{R_i - R^-}{R^+ - R^-}) \qquad (33)$$

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

The alternatives, sorting by the S, R, and Q values, are ranked in decreasing order. So the results are three ranking lists [25]. Finally, the alternative (A') which is ranked the best by the minimum Q is proposed as a compromise solution, if the following two conditions are satisfied:

1) $Q(A'') - Q(A') \geq \frac{1}{m-1}$, where A'' is the alternative with second position in the ranking list by Q, and m is the number of alternative.

2) Alternative A' must also be the best ranked by S or/and R.

Similar to TOPSIS, this method can be applied for all of the EFQM questions, criteria and sub-criteria. However for its quick procedure compared to the above mentioned methods, it is better to use it for determination of multiple EFQM sub-criteria or criteria weights.

3 RESULTS AND DISCUSSION

As a survey on the literatures, organizational overall evaluation according to the final results of EFQM assessments is the basis of many major decision makings in the organizations. However, many organizations, especially public sectors, tend to magnify or exaggerate their performance. In this case, integration of fuzzy logic into the EFQM excellence model prevents such magnifications; so they might refuse to measure and evaluate their performance by the integrated model of fuzzy EFQM [27]. This fact might be one of the limiting factors for fuzzy methods implemented with EFQM model. On the other hand, the efficiency of the classic approach to EFQM assessment cannot be improved by considering the available data or expert knowledge. So, decision makers and assessors are not generally satisfied with its results. Moreover, the knowledge and experience of the assessors that is prescribed in the EFQM model is often vague and uncertain. Therefore, application of fuzzy methods makes decision making easier by means of linguistic terms [39]. So it is considered as a promising strength point for implementation of fuzzy methods in EFQM model. The RADAR logic provides a standardized scoring to determine how the organizations performs their mission to implement a sustainable strategy [27]. However, weight factors of the EFQM criteria and sub-criteria and their interconnections which varies in different organizations need to be defined wisely based on some prioritization or decision making processes. In this manner, implementation of decision making processes is widely studied in the literatures. MCDM methods can be useful to support evaluation and selection processes and to help improve the overall sustainability of the organizations [17]. Among many MCDM processes suitable for this case, fuzzy logic and hybrid fuzzy methods are observed to be the most applicable methods; especially for the supplier selection according to the literature [52]. By the way, detailed analysis of implementation of such fuzzy methods in EFQM model is discussed as follow.

3.1 Fuzzy MCDM Methods Comparison

As a comparison between two main fuzzy decision making processes; i.e., F-AHP and F-TOPSIS, there are some differences and similarities which are discussed in the literatures summarized as follow [50].

Differences can be mentioned as:

In calculation steps, F-AHP requires more complex computations than F-TOPSIS. Pairwise comparisons among the criteria and alternatives are made in F-AHP, while there is no pairwise comparison in F-TOPSIS [53]. So it makes F-TOPSIS a considerable quick method. On the other hand, F-AHP is preferable for widely spread hierarchies, where a few number of criteria are available and a few pairwise comparisons are required at lower level trees while F-TOPSIS works better for single layer decision trees with large number of criteria [54]. However, Kahraman et al. have also proposed F-TOPSIS method for the complex structures [53, 55]. F-TOPSIS is considered as one of the best methods when it comes to change in the ranking of the alternatives by introducing a non-optimal alternative [53]. In F-AHP, consistency check is available while in F-TOPSIS, there is no similar check for well-manner being [54]. In F-AHP when the number of alternatives and criteria grows, the pairwise comparison process becomes cumbersome, and the risk of inconsistencies grows [55]. Another disadvantage of F-AHP is revealed when the priority weights of criterion or alternative could be equal to zero [56].

On the other side, similarities are as below.

Linguistic variables are adopted in both F-AHP and F-TOPSIS. The ranking results of the F-AHP and F-TOPSIS are the same when the decision makers are consistent with themselves in determining the data [54]. Although both methods are equally suitable to deal with the fuzzy scores of alternatives as well as the relative importance of different criteria, it is worth mentioning that the F-AHP is more appropriate than the F-TOPSIS only when the purpose of study is replacing a supplier [57]. The F-AHP gives more sensitive results than the classic AHP method for evaluating the alternatives under a fuzzy environment. However, although the two methods have different steps for ordering the alternatives, they have the same performance results in ranking the emerging economies. The overall performance of the methods demonstrates that both methods produce coherent results in their rankings under the fuzzy environment [58]. As the F-TOPSIS method introduces the ranking index including the distances from the positive and negative ideal points, the highest ranked alternative is not necessarily always the closest to the ideal solution [59]. The simplest extension for this purpose is to change a fuzzy problem into a crisp one by applying the defuzzification method [60, 61]. However, this approach can cause some information loss and gives only a crisp point estimate for the relative closeness of each criteria. Although the extension gives a fuzzy relative closeness for each criteria, it was determined that the supports of the derived fuzzy relative closeness are over exaggerated [61, 62]. The extension principle is therefore not advisable either [61]. The F-DEMATEL method which can be considered as an advanced modified version of F-AHP, is a useful tool to solve the problems that need group decision-making in a fuzzy environment. This method is superior to conventional techniques; because of exposing the relationships between factors and ranking the criteria relating to the type of relationships. Due to these advantages, F-DEMATEL can be used to reveal the influences of the criteria and to increase the model applicability [43]. As a comparison between F-TOPSIS and F-VIKOR methods which are almost the same, some valuable features can be understood. Normalization is used in both methods to eliminate the units of criterion values. The difference appears in the aggregation approaches. The F-VIKOR method introduces an aggregating function representing the distance from the ideal solution. This ranking index is an aggregation of all criteria, the relative importance of the criteria, and a balance between total and individual satisfaction. The F-TOPSIS method introduces the ranking index, including the distances from the positive and negative ideal points. Both methods provide a ranking list. The highest ranked alternative by F-VIKOR is the closest to the ideal solution. However, the highest ranked alternative by F-TOPSIS is not always the closest to the ideal solution as mentioned above. In addition to ranking, the F-VIKOR method proposes a compromise solution with an advantage rate [59]. Regardless of the fuzzy MCDM methods, the form of fuzzy numbers can be an influential matter. Utilization of centroid function of defuzzification is better than the other methods in implementation of some more complicated forms of fuzzy numbers [63]. Hence, it is recommended to use this kind of defuzzification formula in these cases when some complicated fuzzy numbers such as trapezoidal, bell shaped or Gaussian numbers are used instead of triangular numbers, according to the literature [30]. However similar to the other fuzzy methods, there are different formulas for centroid function; namely, Yager, Cheng, Chen, Wang, etc. But as a matter of fact, it is shown that no single method in centroid concept is superior to the other methods in ranking fuzzy numbers [64]. A few studies have investigated the more complicated fuzzy numbers such as trapezoidal ones in F-AHP or F-TOPSIS methods as a generalized form concluding better results [38, 65, 66]. Mohamed Noor et al have shown that implementation of F-AHP with trapezoidal fuzzy numbers has shorter computational time compared to the case where triangular fuzzy numbers are used. Moreover, the level of complexity was also reported lower in this case [67]. According to all of these facts, it can be understood that none of these methods has all of the necessary and ideal conditions to be used for ranking the all of the EFQM questions, criteria and sub-criteria weights. Each of them seems to be powerful in prioritization of the parameters in different layers of a multi-layer EFQM model. Exactly due to this fact, hybrid methods are being studied.

3.2 Hybrid Methods

Individual MCDM methods can yield different rankings. Thus, selecting an appropriate method could be a great challenge. During the last few years, combining two or more methods to solve the same multiple criteria problems has been used increasingly. It is therefore recommended to use a hybrid approach to benefit from the advantages and avoid the disadvantages of these methods and to integrate those results for final decision making [17]. In this respect, Zeydan, and Colpan have studied on F-AHP and F-TOPSIS. They have stated that there were some advantages and disadvantages when these techniques were compared with each other. It was claimed that the advantages of combined F-TOPSIS and F-AHP were far more than comparing the performance of these techniques [61, 68, 69]. In the combined methodology, the qualitative and quantitative data relating to the criteria were collected and used as inputs into F-TOPSIS approach [61, 68]. Another advantage of hybrid approaches is integration of subjective and objective criteria importance. Furthermore, fuzzy logic can also help to overcome uncertainties arising from human qualitative judgments so as to provide us with a more appropriate model for real-life assessments [17]. Classical MCDM methods are not efficient enough due to identification of many effective criteria in a qualitative way based on the experts' judgments according to the linguistic variables and uncertainty of the problem. These problems are solved by implementation of integrated F-DEMATEL, F-AHP, and F-VIKOR in Taati and Esmaili Dooki's research [25]. F-DEMATEL, F-AHP, and F-VIKOR are used to identify the effective criteria, determine the weight importance of the criteria, and to rank the alternatives, respectively [25]. Moreover, F- DEMATEL and F-AHP are used for weighing the criteria; while F-VIKOR is utilized for prioritizing the alternatives. The best ranking result is produced by integration of these fuzzy methods. According to this research, applying each method separately has some demerits. Results of that study have shown that integration of these three methods makes it possible to find out the weights of the criteria and prioritize the alternatives in the best way that the weaknesses of each method is eliminated [25]. Hacioglu and Dincer have conducted the evaluation of capital markets using the hybrid methods of AHP-VIKOR and AHP-TOPSIS under the fuzzy environment. By comparison of the results obtained for the F-AHP and VIKOR approach with those obtained by F-AHP and TOPSIS, it was demonstrated that the ranking of emerging capital markets for both methods was in the same order for both the F-AHP-VIKOR and F-AHP-TOPSIS methods [58]. It shows that in hybrid methods, there is no significant difference between F-TOPSIS and F-VIKOR. However in Noor's and his co-authors' study, it was revealed that hybrid F-AHP and F-VIKOR needs shorter time for the computations rather than hybrid F-AHP and F-TOPSIS. It is because of the lower complexity of F-AHP-F-VIKOR to the F-AHP-F-TOPSIS [67]. Another research has shown that integrated fuzzy methods including F-DEMATEL and ANP have no meaningful difference with the original EFQM model [2]. In other words, determining the criteria weights with both methods results in the same outcome. It reveals an interesting fact that interconnections between EFQM criteria have not anything important to be find out by F-DEMATEL. Therefore, it seems beneficial to apply F-DEMATEL for finding the weights of the EFQM sub-criteria or questions instead of the criteria. F-AHP method and VIKOR is also used together in another work. F-AHP has been used to determine the importance rate of each objective. At the end, these weights were applied in VIKOR method to find the best possible alternatives [70]. This work and the work of Taati et al show that F-AHP is better to be applied before the F-VIKOR on the lower layers of EFQM model in a hybrid method and the results of the F-AHP should be implemented as input of F-VIKOR for the higher layers of the EFQM model. It is a consistent finding according to the features of F-AHP and F-VIKOR discussed above. In the lower layers of EFQM model, there are a few criteria for each of sub-criteria questions, while in the higher layers, sub-criteria and criteria become complicated interconnected. So it is obvious to use F-AHP for the lower layers as a better choice. The most frequently applied MCDM methods in hybrid forms are ANP and DEMATEL, in both crisp and in fuzzy environments according to the literature [17]. Herat et al have used F-DEMATEL and ANP methods in EFQM excellence model for hospitals improvement guidelines. They drew the causal relations between nine areas of healthcare organization excellence model using F-DEMATEL and determined their effects on each other. Then, they have ranked the improvement projects using ANP based on these causal relations [71]. The F-DEMATEL method can be used to determine the interactions amongst the main criteria in the developed approach. Thus, relations amongst the criteria are determined via the experts opinions. The criteria relations obtained by the F-DEMATEL method can provide input to the F-ANP method [4]. In this study, the institutionalization levels of the some public institutions were ranked and the levels of excellence were evaluated with the help of VIKOR method. The proposed approach was compared with the weights of the EFQM model, and showed that there was no statistical difference between the EFQM weights and the criterion weights obtained as the result of implementation of such fuzzy methods [4]. Abdullah and Zulkifli developed a new study of integration of F-DEMATEL and F-AHP to overcome the problems of decision making process. After the collection of data from a group of decision makers using the defined linguistic scale, the F-AHP was applied to obtain the relative weights of the criteria. Finally, F-DEMATEL was used by applying trapezoidal fuzzy numbers so as to avoid inadequate reflection of the vagueness in the MCDM problems. This method was more flexible thanks to the introduction of trapezoidal fuzzy numbers in F-AHP and F-DEMATEL. It allowed to model imprecise, uncertain and ambiguous information that was commonly encountered in the real world problems. The method also incorporated the F-AHP and F-DEMATEL by applying the weights obtained from F-AHP into the expected value. In fact, this integration method was capable to handle fuzzy MCDM problems with more comprehensible approach thanks to the knowledge of fuzzy sets. It is believed that setting a new threshold value for F-DEMATEL will offer an alternative results [72]. This finding could explain the reason why hybrid method of Uygun et al had no significant difference with routine EFQM model. Because in the work of Uygun et al, F-DEMATEL was applied first and its results were input to F-ANP. While in the work of Abdullah et al, F-AHP was applied before F-DEMATEL. This can change that imminent threshold value for F-DEMATEL. Kuo et al have proposed a hybrid method of F-ANP and F-TOPSIS for carbon management of a green supplier selection system. It was due to the fact that the dependency between criteria in ANP makes the calculated weights have a better power of discrimination. While, F-TOPSIS is easy to apply; yet has the powerful efficiency of ranking alternatives [73]. In general, none of the fuzzy methods can be recommended to be used individually as the best method of self-assessment in EFQM model. But it is proposed to use hybrid methods of F-AHP (or DEMATEL)-F-TOPSIS (or F-VIKOR) for more efficient and real organizational assessment. According to the diverse researches in this field, it is recommended to apply F-AHP for the EFQM questions weight determination, F-DEMATEL or F-TOPSIS with triangular fuzzy numbers or F-VIKOR with trapezoidal fuzzy numbers for EFQM sub-criteria weight finding, and finally, F-VIKOR or F-TOPSIS for the definition of the EFQM criteria weights. After determination of all of the EFQM layers weight factors, the EFQM model is modified. So the assessors can evaluate the organizational overall quality by using this modified EFQM model as usual.

4 Conclusion

In brief we conclude that organizational quality management by using different prioritization and MCDM methods including fuzzy AHP, fuzzy DEMATEL, fuzzy TOPSIS, and fuzzy VIKOR can be used with more benefits than ordinary EFQM model. All of these methods have strong capabilities for decision making and strategy planning for the system optimization. However there are also some limitations for each method to be used individually. Regardless of advantages and disadvantages of each method, it is promising to utilize all of them in their proper situation for organizational self-assessment. In this respect as a hybrid method, F-AHP can be the best option for prioritization among the EFQM questions importance weights while F-DEMATEL is the best choice for finding the interconnections and relations among the sub-criteria. F-TOPSIS and F-VIKOR are both the best methods for ranking the final alternatives (EFQM nine criteria weights). VIKOR can be more quicker than TOPSIS with lower computational complexities when it is combined with F-AHP. Utilization of other complicated forms of fuzzy numbers such as trapezoidal fuzzy numbers instead of triangular ones can be also beneficial with faster and more reliable computational results.

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