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Prioritization of EFQM Excellence Model Criteria Using a Fuzzy AHP Approach with Triangular Fuzzy Numbers in the Manufacturing Sector

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Abstract: In an increasingly dynamic and complex industrial landscape, the continuous enhancement of organizational performance has emerged as a critical imperative. To this end, structured quality assessment frameworks, such as the European Foundation for Quality Management (EFQM) Excellence Model, have been widely adopted as integrative tools for diagnosing, monitoring, and improving business performance. Despite its comprehensive nature, the EFQM model often requires the incorporation of additional quantitative methods to refine the evaluation of the relative significance of its criteria. In this study, the Analytic Hierarchy Process (AHP) method, extended with triangular fuzzy numbers, has been employed to determine the weighted importance of the EFQM model's criteria under conditions of uncertainty and expert subjectivity. This fuzzy extension of AHP allows for a more nuanced capture of linguistic judgments, thereby enhancing the robustness of decision-making in ambiguous environments. Expert assessments were elicited through structured interviews with quality managers from three manufacturing companies, enabling the construction of pairwise comparison matrices for each criterion. These matrices were then aggregated and analyzed to derive consensus-based priority weights. The findings reveal significant variations in the perceived importance of enabler and result criteria, underscoring the context-dependent applicability of the EFQM model. Furthermore, the results offer a more granular understanding of the internal structure of the model, providing a foundation for its adaptive use in quality management systems across the manufacturing sector. The integration of fuzzy logic into the hierarchical decision-making process is demonstrated to yield improved precision and flexibility, making it a valuable methodological enhancement for organizations pursuing excellence under uncertainty. The proposed approach also contributes to the broader discourse on multi-criteria decision analysis in quality management by addressing limitations in conventional crisp AHP applications.

Keywords: Business excellence; European Foundation for Quality Management (EFQM); Fuzzy Analytic Hierarchy Process (AHP); Triangular fuzzy numbers

1 Introduction

Achieving sustainable development and competitive advantage requires a continuous improvement of organizational performance and quality. In this context, quality management frameworks such as the EFQM model play a crucial role in helping organizations identify their strengths and areas for improvement. The EFQM model has been widely adopted across Europe and beyond as a structured framework for pursuing organizational excellence. One of the practical challenges in implementing the EFQM model lies in determining the relative importance of its criteria, which significantly influences evaluation outcomes and strategic decision-making.

While the EFQM model provides qualitative guidance, there is a growing need for robust quantitative methods that can offer more precise insights and support objective assessments. Among such methods, the AHP is a highly useful and widely used decision-making tool based on structuring problems hierarchically and prioritizing alternatives through pairwise comparisons. However, traditional AHP has certain limitations when dealing with uncertainty and the inherent subjectivity of human judgment—especially relevant when evaluating qualitative criteria. To address these limitations, fuzzy extensions of AHP have been introduced, incorporating fuzzy logic—particularly triangular fuzzy numbers —as a means to model imprecise and ambiguous expert input.

Building on these premises, the objective of this paper is to determine the weights of EFQM model criteria using an AHP methodology enhanced with triangular fuzzy numbers. Expert evaluations were collected through interviews with quality managers from three companies operating in production sector, aiming to provide a comprehensive and nuanced assessment of the EFQM quality criteria.

2 Literature Review

The original weights from the EFQM model are straightforward and fixed, with the following point distribution across the criteria: 1. Purpose, Vision & Strategy (200 points), 2. Organizational Culture & Leadership (200 points), 3. Engaging Stakeholders (100 points), 4. Creating Sustainable Value (100 points), 5. Driving Performance & Transformation (100 points), 6. Stakeholder Perceptions (200 points), 7. Organizational Performance (100 points), totaling 1000 points [1]. These points can also be seen as weights, reflecting the relative importance of each criterion and providing a standardized approach for assessing various quality criteria across organizations. Some authors argue that evaluation scores should be modified by industry [2] and/or recommend using linguistic statements to address this issue and to reduce the subjectivity in the evaluation process [3–6]. Due to this feature, some authors in the literature emphasize the suitability of FAHP for adjustment of these weights according to the specific context and subjective judgments of decision-makers [7–12] and others [13] propose integrated fuzzy multi-attribute decision-making (MADM) methods.

The AHP represents one of the most prominent and extensively applied MADM methods. In its classical form [14], the AHP method relies on pairwise comparisons, where decision makers express their judgments using a standardized scale ranging from 1 to 9. A rating of 1 signifies equal importance between two elements, whereas higher values indicate a stronger preference or greater importance of one element over another. To ensure logical consistency in these judgments, AHP employs the eigenvector method for consistency assessment, where the principal eigenvalue and its corresponding eigenvector are used to derive the final weightings.

Table 1. The FAHP approach as addressed in the existing literature

Source	Number and Type of Linguistic Terms / Scale Range	Method of Aggregating Expert Judgments / Consistency Verification of Fuzzy Pairwise Matrix	Derivation of Weight Vector
[15]	9 TFNs, scale [1–3]	Fuzzy arithmetic mean; defuzzification via center of gravity; eigenvector method	Geometric mean; TFNs
[16]	5 TFNs, scale [1–2.5]	Conventional defuzzification; eigenvector approach	Extended analysis; crisp values
[17]	9 TFNs, scale [1–9]	Fuzzy geometric mean; consistency check not performed	Geometric mean; crisp; center of gravity method
[18]	9 TFNs, scale [1–10]	Defuzzification using left and right endpoints; eigenvector	Geometric mean; TFNs
[19]	9 TFNs, scale [1–10]	Fuzzy geometric mean; eigenvector method	Center of gravity method; TFNs
[20]	9 TFNs, scale [1–10]	Fuzzy geometric mean and eigenvector	Geometric mean; crisp
[21]	9 TFNs, scale [1–9]	Fuzzy geometric mean; center of gravity; eigenvector	Center of gravity method; TFNs
[22]	6 TFNs, scale [1–9]	Defuzzification formula (see [23]); eigenvector	Geometric mean; crisp
[24]	5 TFNs, scale [1–9]	Extended analysis; eigenvector method	Extended analysis; TFNs
[25]	5 TFNs, scale [1–5]	Fuzzy arithmetic mean; standard defuzzification; eigenvector	Arithmetic mean; crisp
Proposed model	5 TFNs, scale [1–9]	Fuzzy geometric mean; simplified center of gravity; eigenvector	Geometric mean; TFN

Given the inherent subjectivity in evaluating criteria, many researchers have proposed extensions to the traditional

AHP model by incorporating fuzzy logic, most commonly through the use of triangular fuzzy numbers (TFNs). The fuzzy AHP (FAHP) approach provides a better representation of the uncertainties involved in the considered problem compared to the standard AHP method. Table 1 provides a comparative overview of recent FAHP methodologies proposed in the past five years. It includes references to the original studies, the types of fuzzy number domains used (e.g., TFNs or trapezoidal), the number and structure of linguistic variables applied, as well as the defuzzification techniques employed to convert fuzzy judgments into crisp values. This synthesis offers valuable insight into current trends and methodological variations in the application of FAHP.

The studies presented in Table 1 have been analyzed and presented in two graphical illustrations. Figure 1 illustrates the granulation of fuzzy numbers and the domains over which these fuzzy numbers are defined. It should be noted that white pillars in the following figures represent the approach used in this research paper.

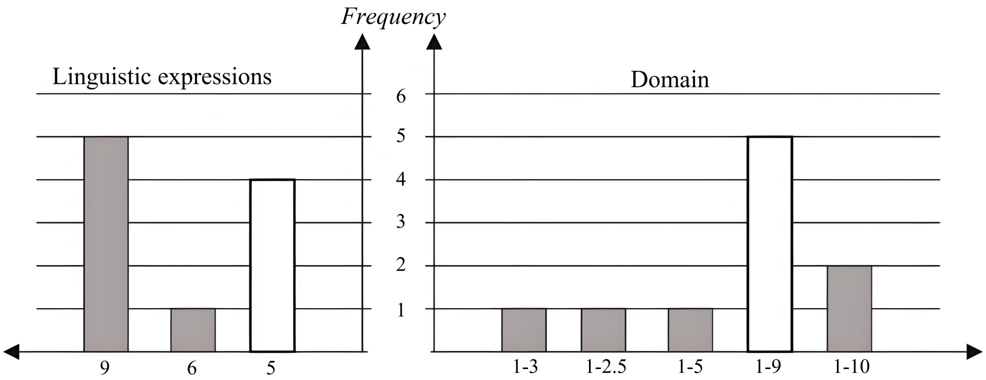

Figure 1. Number of linguistic expressions and domain of TFN in literature

The literature does not provide a universal recommendation for determining the number of linguistic terms used to describe the relative importance of elements in a fuzzy pairwise comparison matrix. As shown in Figure 1, the majority of authors in the analyzed studies suggest that it is sufficient to use either 5 or 9 linguistic terms. According to the literature review shown in Table 1, the majority of authors in the analyzed studies defined the domains of fuzzy numbers using the standard measurement scale, analogous to the conventional AHP approach. It should be noted that many authors consider the use of the [1–9] measurement scale to be appropriate. It is important to emphasize that the authors defined the domains over the set of positive real numbers, excluding zero. In doing so, the axioms established in the conventional AHP method were respected.

The transformation of decision-makers' assessments into a unified evaluation is achieved through the application of various aggregation operators, and the transformation of the fuzzy pairwise comparison matrix of relative importance can be carried out using various defuzzification procedures. Figure 2 illustrates the frequency of use of different operators as suggested by the authors of the analyzed studies.

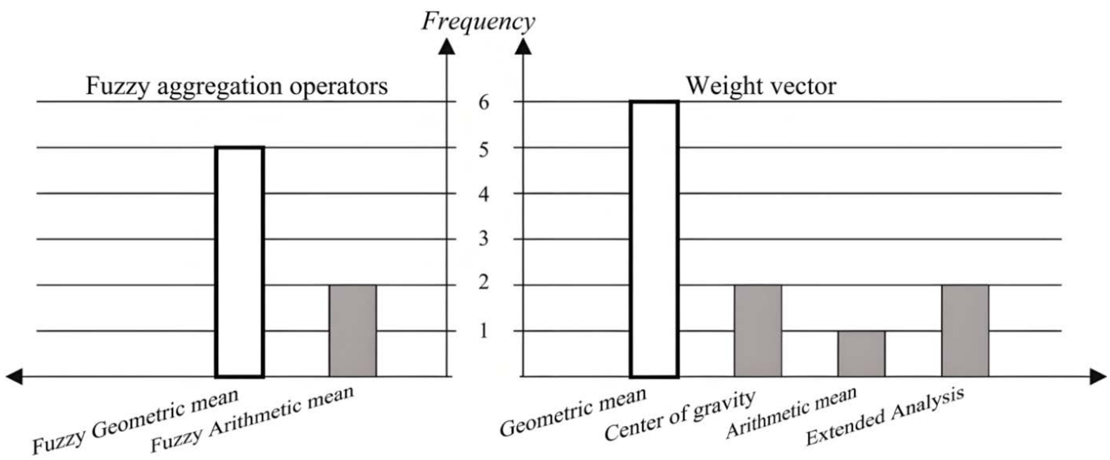

Figure 2. Fuzzy aggregation operators and weight vectors in literature

As shown in Figure 3, the majority of authors in the analyzed studies apply the method developed by Buckley [26] both for handling the uncertainty in the fuzzy pairwise comparison matrix and as an aggregation operator.

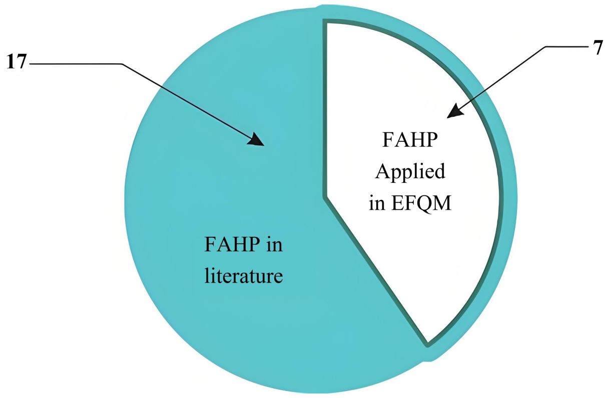

Figure 3. FAHP and EFQM in literature

During the literature review, a total of 17 research papers were identified that explore the application of the FAHP in various contexts. Of these, 7 studies specifically utilize FAHP as a methodological approach to determine the weights of EFQM criteria, demonstrating its utility in addressing the complexities of decision-making under uncertainty and subjectivity. These papers contribute to the growing body of knowledge on the application of FAHP for quantitative assessment and prioritization of areas of improvement in the EFQM framework due to resource availability and/or type of industry.

3 Methodology

The determination of criterion weights was carried out using FAHP, which was extended with TFNs. The evaluation of the relative importance of the criteria was performed by quality managers from three companies operating in the production sector. These decision-makers used pre-defined linguistic statements to assess the relative importance of the criteria. The aggregated weight values were obtained by applying the geometric mean method.

3.1 Identification of Relevant Criteria

The set of criteria $\{1, .., c, .., C\}$ used in the proposed model are adopted from the EFQM model from 2025 [1] and are presented as follows:

- Organizational culture and leadership ($c = 1$),
- Purpose, vision, and strategy ($c = 2$),
- Stakeholder perceptions ($c = 3$),
- Strategic and operational performance ($c = 4$),
- Stakeholder engagement ($c = 5$),
- Creating sustainable value ($c = 6$),
- Performance and transformation management ($c = 7$).

In this case, C represents the total number of quality criteria and the index of each quality criterion is denoted as c, $c = 1$,..,C.

3.2 Selection and Definition of Decision Makers

The decision-makers can be denoted by the set $\{1, .., d, .., D\}$, where D denotes the total number of decision-makers. The index of a decision-maker is represented as d, where $d = 1$,..,D. The set of decision-makers responsible for evaluating the relative importance of the quality criteria consists of three quality managers from three different companies engaged in manufacturing activities. This research proposes that the decision-makers have equal relative significance, as is the case when solving similar problems in the literature [27, 28].

3.3 Handling Uncertainties in the Model

The relative importance of the considered quality criteria can be described through linguistic terms rather than precise numerical values. The domains of fuzzy numbers used to describe the relative importance of the examined criteria in this study are defined based on the standard measurement scale [1–9] proposed by Saaty [14]. In this scale, the number 1 represents the lowest, and the number 9 represents the highest value.

The relative importance of the quality criteria is described using five linguistic terms modeled with triangular fuzzy numbers (TFNs):

- Of equal importance ($L1$): $(1, 1, 1)$
- Slightly greater importance ($L2$): $(1, 2.5, 4)$
- Moderately higher significance ($L3$): $(3, 5, 7)$

- Considerably more significant ($L4$): $(6, 7.5, 9)$
- Absolutely dominant in importance ($L5$): $(9, 9, 9)$

3.4 The Proposed FAHP Approach

The weight vector of the quality criteria was determined by applying the proposed FAHP model. The implementation of this model is conducted through the following five structured steps:

Step 1. For each decision-maker, an individual fuzzy pairwise comparison matrix of the relative importance of quality criteria is constructed, denoted as:

$$\left[\widetilde{W}^{d}_{cc'}\right]$$

where, $\widetilde{W}^{d}_{cc'}$ represents the fuzzy evaluation of the relative importance of criterion c compared to criterion c', for all $c, c' = 1, \ldots, C$.

Step 2. The aggregated fuzzy pairwise comparison matrix of the quality criteria is obtained as:

$$\left[\widetilde{W}_{cc'}\right]$$

where, aggregation is performed using the fuzzy geometric mean as follows:

$$\widetilde{W}_{cc'} = \sqrt{\prod_{c'=1,\ldots,c} \widetilde{W}_{cc'}}$$

Step 3. The aggregated fuzzy pairwise comparison matrix is defuzzified into a crisp pairwise comparison matrix by applying the simple gravity center method, resulting in the matrix:

$$[W_{cc'}]$$

Step 4. The consistency chck of the pairwise comparisons is performed by applying the eigenvector method, as suggested by Saaty [14].

Step 5. Finally, the weight vector of the quality criteria is derived using the fuzzy geometric mean approach, ensuring a consistent and reliable representation of the priority of each criterion.

Step 6. The crisp value of the weight vector was derived through the application of the Center of Area method [29].

$$\text{Defuzz } \widetilde{\omega} = \omega = \frac{(u-l)+(m-l)}{3} + l$$

4 Results

The fuzzy pairwise comparison matrices of the relative importance of the quality criteria at the level of each decision-maker are presented below (Step 1):

(a) Evaluations provided by the first decision-maker:

$$\begin{bmatrix} L1 & 1/L2 & 1/L3 & 1/L4 & 1/L4 & 1/L4 & 1/L5 \\ & L1 & 1/L2 & 1/L3 & 1/L3 & 1/L3 & 1/L4 \\ & & L1 & 1/L2 & 1/L2 & 1/L2 & 1/L3 \\ & & & L1 & L1 & L1 & 1/L2 \\ & & & & L1 & L1 & 1/L2 \\ & & & & & L1 & 1/L2 \\ & & & & & & L1 \end{bmatrix}$$

(b) Evaluations provided by the second decision-maker:

$$\begin{bmatrix} L1 & 1/L3 & 1/L3 & 1/L4 & L2 & 1/L2 & 1/L3 \\ & L1 & L1 & 1/L3 & L4 & L2 & L1 \\ & & L1 & 1/L2 & L4 & L2 & L1 \\ & & & L1 & L5 & L3 & L2 \\ & & & & L1 & 1/L3 & 1/L3 \\ & & & & & L1 & 1/L2 \\ & & & & & & L1 \end{bmatrix}$$

(c) Evaluations provided by the third decision-maker:

$$\begin{bmatrix} L1 & L2 & 1/L4 & 1/L3 & 1/L2 & L1 & 1/L3 \\ & L1 & 1/L5 & 1/L4 & 1/L3 & 1/L2 & 1/L4 \\ & & L1 & L2 & 1/L3 & 1/L4 & 1/L2 \\ & & & L1 & L2 & L3 & L1 \\ & & & & L1 & L2 & 1/L2 \\ & & & & & L1 & 1/L3 \\ & & & & & & L1 \end{bmatrix}$$

The following is the aggregated fuzzy pairwise comparison matrix of the quality criteria's relative importance:

$$\begin{bmatrix} (1,1,1) & (0.33,0.58,1.10) & (0.13,0.17,0.26) & (0.12,0.15,0.21) & (0.30,0.51,0.87) & (0.30,0.38,0.55) & (0.13,0.16,0.23) \\ & (1,1,1) & (0.35,0.35,0.48) & (0.13,0.17,0.26) & (0.50,0.67,1) & (0.33,0.58,1.10) & (0.23,0.26,0.30) \\ & & (1,1,1) & (0.40,0.74,1.59) & (0.60,0.84,1.44) & (0.30,0.51,0.87) & (0.33,0.43,0.69) \\ & & & (1,1,1) & (1.82,2.82,3.30) & (2.08,2.92,3.66) & (0.63,1,1.59) \\ & & & & (1,1,1) & (0.52,0.79,1.10) & (0.21,0.32,0.69) \\ & & & & & (1,1,1) & (0.21,0.32,0.69) \\ & & & & & & (1,1,1) \end{bmatrix}$$

In accordance with the proposed algorithm (Steps 3–5), the subsequent procedures are executed:

$$\begin{bmatrix} 1 & 0.67 & 0.19 & 0.16 & 0.56 & 0.41 & 0.17 \\ & 1 & 0.39 & 0.19 & 0.72 & 0.67 & 0.26 \\ & & 1 & 0.91 & 0.96 & 0.56 & 0.48 \\ & & & 1 & 2.65 & 2.89 & 1.07 \\ & & & & 1 & 0.80 & 0.41 \\ & & & & & 1 & 0.41 \\ & & & & & & 1 \end{bmatrix}, \text{C.I.} = 0.04$$

Considering the consistency ratio, it can be inferred that the errors made by the decision-makers in assessing the relative importance of the quality criteria are negligible.

The weight vectors of the quality criteria are as follows:

$$\tilde{\omega}_1 = (0.02, 0.04, 0.08)$$
$$\tilde{\omega}_2 = (0.03, 0.06, 0.12)$$
$$\tilde{\omega}_3 = (0.07, 0.13, 0.27)$$
$$\tilde{\omega}_4 = (0.13, 0.27, 0.53)$$
$$\tilde{\omega}_5 = (0.05, 0.10, 0.21)$$
$$\tilde{\omega}_6 = (0.06, 0.12, 0.26)$$
$$\tilde{\omega}_7 = (0.13, 0.28, 0.54)$$

The corresponding crisp values of the weight vectors, obtained through Step 6, are as follows:

$$\omega_1 = 0.05$$
$$\omega_2 = 0.07$$
$$\omega_3 = 0.16$$
$$\omega_4 = 0.31$$
$$\omega_5 = 0.12$$
$$\omega_6 = 0.15$$
$$\omega_7 = 0.32$$

5 Conclusions

The original weights from the EFQM model are straightforward and fixed, providing a standardized approach for assessing various quality criteria across organizations. By employing FAHP, it becomes possible to gain a more nuanced and detailed understanding of how different criteria are perceived within an organization. This approach enables a deeper insight into which factors are considered most crucial for a particular organization, accounting for both the unique characteristics of the organization and the inherent uncertainties in the decision-making process.

Criteria with Higher Weights:

In the EFQM model, "Driving Performance and Transformation," "Stakeholder Perceptions," and "Strategic and Operational Performance" are allocated the highest number of points (200 points each). This is consistent with the FAHP results, where Criterion 4 (Driving Performance & Transformation) and Criterion 7 (Strategic and Operational Performance) achieved the highest fuzzy weights (0.31 and 0.32, respectively). Criterion 6 (Stakeholder Perceptions) also maintains a relatively high FAHP weight (0.15), although slightly lower compared to its original point allocation. These findings suggest that organizations tend to prioritize operational transformation, performance outcomes, and stakeholder satisfaction, aligning with the EFQM framework's emphasis on results and sustainable performance.

Criteria with Lower Weights:

Criteria such as "Purpose, Vision and Strategy" (Criterion 1), "Organizational Culture and Leadership" (Criterion 2), "Engaging Stakeholders" (Criterion 3), and "Creating Sustainable Value" (Criterion 5) are originally allocated 100 points each in the EFQM model. In the FAHP analysis, the first two criteria also received comparatively lower fuzzy weights, with "Purpose, Vision and Strategy" (0.05) and "Organizational Culture and Leadership" (0.07) showing particularly low values. This suggests a relative de-emphasis on leadership and cultural aspects compared to performance-driven results within the analyzed context. Such differences may reflect specific organizational priorities captured during the FAHP evaluation, emphasizing tangible outputs over enabling factors.

It should be emphasized that the decision-makers involved in the FAHP evaluation were managers from manufacturing enterprises. Consequently, the resulting prioritization of criteria is strongly aligned with the specific needs and strategic focus of the manufacturing sector, where operational efficiency, performance outcomes, and stakeholder satisfaction are critical drivers of competitiveness and sustainability. This sectoral context provides an explanation for the observed emphasis on results-oriented criteria over enabler-related aspects.

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.

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