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Developing a New Approach for Assessing and Improving Business Excellence: Integrating Fuzzy Analytic Hierarchical Process and Constraint Programming Model

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Abstract: This study introduces a novel two-stage model for assessing and enhancing business excellence based on the EFQM framework. The Fuzzy Analytic Hierarchy Process (FAHP) is used in the first stage to calculate the weight vectors of criteria and sub-criteria, incorporating uncertainty through triangular fuzzy numbers (TFNs). In the second stage, the OR-Tools CP-SAT solver is used to solve the selection and improvement of sub-criteria as a multidimensional knapsack problem with mixed min/max constraints. In this way, a new and enhanced model for evaluating business excellence is presented—one that takes into account the company's current capabilities and circumstances while also providing management with a starting point for enhancing business performance. The model is validated using data from a manufacturing company in central Serbia. The findings suggest that improvement efforts should not be symmetrically distributed across all EFQM criteria and sub-criteria. Instead, an asymmetric approach provides efficient resource allocation while maximizing business excellence improvements. This study emphasizes the balance or symmetry between subjective decision-makers' assessments and mathematically based optimization, demonstrating the practical applicability of the proposed method in strategic decision-making under resource constraints.

Keywords: business excellence; EFQM; Fuzzy Analytic Hierarchical Process; constraint programming

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1. Introduction

1.1. EFQM Model

The European Foundation for Quality Management (EFQM 2020) [1] serves as a framework for quality management practices as well as for business improvement for organizations. It uses a systematic approach by determining the excellence in leadership, policies and strategies, partnerships and resources, processes, and learning and employee satisfaction. The process consists of analyzing the current situation, determining excellence objectives, scheduling tasks, carrying out changes, monitoring and measuring, adjusting, and promoting constant learning and improvement. The objective is to build an organization that is oriented towards excellence through defined actions such as diagnosing problems and focusing on achieving results.

Achieving the required level of business excellence involves simultaneous and continuous investment in a variety of resources. The purpose of manufacturing company management is to achieve balance and symmetry across several aspects of business models, such as human, financial, and technological resources. Ensuring symmetry through appropriate resource allocation enables businesses to improve performance while maintaining system stability. In this context, the EFQM model provides a systematic framework to ensure that no area of business operations is overlooked and that all elements evolve concurrently. Such a strategy promotes long-term success and enhances competitive advantage.

Organizations identify areas for improvement through the systematic use of defined criteria and sub-criteria in accordance with the EFQM model. Conducting internal self-assessment involves analyzing each of the seven criteria and their corresponding sub-criteria to determine the organization's standing in relation to excellence standards. The utilization of these criteria and sub-criteria enables organizations to systematically evaluate their operations, pinpoint areas in need of improvement, and direct efforts toward achieving excellence.

Providing specific recommendations on whether all criteria/sub-criteria should be improved simultaneously is beyond the scope of the EFQM model. It emphasizes a continual improvement approach, to enable organizations to take their own situation, requirements, and goals into account. The result of self-assessment enables organizations to identify priorities for improvement. Focusing on key aspects that contribute the most to achieving strategic goals or where there is the greatest potential for improvement can be an acceptable and recommended strategy. Sometimes, organizations will focus on a particular area until they gain substantial results, then tackle other areas. An organization must determine its own needs, so the approach needs to be flexible. Improvement should be seen as a continuous and adaptive process that reflects the organization's strategy, with priorities aligned with resources and organizational strategy.

1.2. Fuzzy Analytic Hierarchy Process

Decision-making is an integral part of every business system, including manufacturing enterprises. Generally speaking, in the context of decision-making, the principle of symmetry in this research can be observed through the application of two opposing approaches. The first approach is based on the subjective assessments of decision-makers (DMs), which are always grounded in knowledge, experience, and personal viewpoints. On the other hand, mathematically based methods represent an objective approach to decision-making. Therefore, the combination of these two approaches enables the achievement of a balance between subjectivity and objectivity. The integration of these two concepts—i.e., DMs' assessments and a precise mathematical approach—allows for balanced and efficient decision-making that supports long-term business success.

The development of the fuzzy sets theory [2,3] has enabled the quantitative description of uncertain and imprecise data at a satisfactory level. Many authors [4–6] suggest that triangular fuzzy numbers (TFNs) adequately capture uncertainties. On the other hand, the use of TFNs does not require complex mathematical calculations, making them easy to use. In this research, all uncertainties in the relative importance of sub-criteria and their values, as well as the relative importance of criteria, are modeled using TFNs.

In this research, the two-stage model for assessing and improving the business excellence of companies is proposed. Firstly, determining criteria weights is stated as a fuzzy group decision-making problem as in [7]. The weights vector of criteria is based on applying the proposed Fuzzy Analytic Hierarchy Process (FAHP). The fuzzy rating of the relative importance of sub-criteria under each criterion as well as their values are performed by quality managers. The weight vector of sub-criteria under each criterion is determined by using the proposed FAHP.

An important feature of the AHP method is that it includes a consistency check of DMs' assessments, ensuring that illogical and contradictory evaluations are not taken into consideration and require correction. This approach enhances the objectivity of the conducted analysis.

1.3. Constraint Programming

In the literature, there are papers where business improvement is based on the application of exact methods [8] as in this research. Improving business performance, among other things, can be achieved by enhancing the values of all quality sub-criteria. Ideally, all sub-criteria values should be improved to their maximum potential. However, in practice, such comprehensive improvement is not feasible due to resource constraints. Acknowledging this fact, determining which sub-criteria under each criterion should be enhanced, as well as by how much, is framed as a multidimensional knapsack problem with mixed min/max constraints. The considered problem is a single-criterion, constrained problem belonging to the class of NP optimization problems. The fitness function is defined as the distance from the highest weighted fuzzy criteria values. The aggregated weighted criteria values are calculated using fuzzy algebra rules. The problem addressed in this study is a constrained optimization problem. The optimal solution, free from subjective DMs' influence, is obtained using the OR-Tools (https://developers.google.com/optimization/cp/cp_solver, accessed on 10 November 2024). CP-SAT solver [9] is a constraint programming solver software that uses SAT (satisfiability) methods.

Constraint Programming (CP) is a branch of mathematical programming focusing on the discovery of viable solutions within specified constraints. CP problems are prevalent in various scientific and engineering areas. CP and Boolean satisfactory solutions (B-SAT or SAR) represent two successful logic approaches used in several application domains, from operational research to artificial intelligence. CP provides a robust modeling paradigm, allowing applications to be naturally expressed with a diverse set of constraints. Boolean satisfiability problems include determining the existence of an interpretation that satisfies a given boiler formula. B-SAT holds the distinction of being the first problem proven to be NP complete by the Cook–Levin theorem [10]. The Cook–Levin theorem suggests that any problem can be translated into a form in the realm of NP. Over the years, the B-SAT has been given considerable attention, resulting in progress that has enabled the use of B-SAT solvers in many applications [11–13]. CP-SAT is a versatile portfolio solver, centered around a Lazy Clause Generation (LCG) [14] based Constraint Programming Solver. CP-SAT uses Branch and Cut techniques, linear relaxations, and cutting planes also as part of its toolkit. The concept of lazy clause generation involves incrementally transforming the problem into an SAT formula, after which a solver is used to search for a solution.

1.4. Research Motivation and Objectives

In the context of the EFQM model, symmetry can reflect an equal distribution of resources across all criteria/sub-criteria; however, this is not always the best option. There is reasonable doubt that the optimal solution can be attained by allocating available resources and time asymmetrically. CP allows for the identification of asymmetric structures in data and resources, as well as directing resources towards key aspects of the business with greater potential for improvement. In other words, while a symmetric approach implies equal treatment of all criteria, CP enables the recognition of where asymmetric allocation yields better results.

The motivation for this research comes from the scarcity of literature addressing the evaluation of business excellence in enterprises within a fuzzy environment, particularly regarding the new 2020 EFQM model.

The main aim of this research is to integrate the following methods: (a) modeling of the relative importance of criteria and sub-criteria from the EFQM model, as well as their values by the TFNs, (b) criteria weights and sub-criteria weights under each criterion are determined by using the proposed FAHP, (c) determination of the aggregated weighted criteria values by applying fuzzy algebra rules and (d) determination of the business excellence improvement strategy by applying OR-Tools CP-SAT solver [9] which is a constraint programming solver software that uses SAT (satisfiability) methods.

The rest of the paper is organized as follows: Section 2 provides a literature review of EFQM and FAHP. Section 3 outlines the proposed methodology. Section 4 examines the proposed model using real-life data. Finally, Section 5 presents the conclusion.

2. Literature Review

In this section, an overview of the literature models used in this manuscript is provided. Therefore, the section is divided into two parts. In the first part, papers that have modified the EFQM model are analyzed. In the second part, a detailed analysis of the FAHP models found in the relevant literature is presented, along with a comparative analysis of these FAHP models and the proposed FAHP in this research.

2.1. Application of the EFQM Model in the Relevant Literature

The EFQM 2020 [1] model is essentially an evolution of the 2013 framework [15], updated to tackle the challenges and opportunities that today's organizations face. In the earlier version from 2013, the model was built around nine criteria and 29 sub-criteria, covering different dimensions of organizational excellence. The 2020 version simplifies this approach by reducing the framework to seven main criteria and 28 sub-criteria, aiming for a clearer and more adaptable structure. A comparison of the criteria and sub-criteria between the 2020 and 2013 models is presented in Table 1.

Table 1. Comparison of criteria and sub-criteria, EFQM 2013 and 2020 version.

EFQM 2013 [1]		EFQM 2020 [15]	
Criterion	**Sub-Criterion**	**Criterion**	**Sub-Criterion**
1. Leadership	1.1 Leadership 1.2 Attributes 1.3 Policy and Strategy 1.4 People Development 1.5 Organizational Culture	1. Purpose, Vision, and Strategy	1.1 Define Purpose and Vision 1.2 Identify and Understand Stakeholders Needs 1.3 Understand the Ecosystem, own Capabilities and Major Challenges 1.4 Develop Strategy 1.5 Design and Implement a Governance and Performance Management System
2. Strategy	2.1 Strategic Analysis 2.2 Strategic Objectives 2.3 Strategy Implementation	2. Organizational Culture and Leadership	2.1 Steer the Organization's Culture and Nurture Values 2.2 Create the Conditions for Realizing Change 2.3 Enable Creativity and Innovation 2.4 Unite Behind and Engage in Purpose, Vision, and Strategy

3. People	3.1 Employee Engagement 3.2 Employee Well-being and Satisfaction 3.3 Learning, Development, and Recognition	3. Engaging Stakeholders	3.1 Customers: Build Sustainable Relationships 3.2 People: Attract, Engage, Develop, and Retain 3.3 Business and Governing Stakeholders—Secure and Sustain Ongoing Support 3.4 Society: Contribute to Development, Well-Being, and Prosperity 3.5 Partners and Suppliers: Build Relationships and Ensure Support for Creating Sustainable Value
4. Partnerships and Resources	4.1 Partnerships 4.2 Resource Management 4.3 Process Management	4. Driving Performance and Transformation	4.1 Design the Value and How it is Created 4.2 Communicate and Sell the Value 4.3 Deliver the Value 4.4 Define and Implement the Overall Experience
5. Processes, Products, and Services	5.1 Process Management 5.2 Product and Service Design and Delivery 5.3 Quality of Products and Services	5. Creating Sustainable Value	5.1 Drive Performance and Manage Risk 5.2 Transform the Organization for the Future 5.3 Drive Innovation and Utilize Technology 5.4 Leverage Data, Information and Knowledge 5.5 Manage Assets and Resources
6. Customer Results	6.1 Customer Satisfaction 6.2 Customer Loyalty 6.3 Customer Retention	6. Stakeholder Perceptions	6.1 Customer Perception Results 6.2 People's Perception Results 6.3 Business and Governing Stakeholders' Perception Results 6.4 Society Perception Results 6.5 Partners and Suppliers Perception Results
7. People Results	7.1 People Satisfaction 7.2 People Engagement 7.3 People Development	7. Strategic and Operational Performance	7.1 Strategic and Operational Performance
8. Society Results	8.1 Contribution to the Local Community 8.3 Contribution to Society		
9. Key Performance Results	9.1 Achievement of Strategic Objectives 9.2 Financial Performance 9.3 Operational Performance		

In Table 1, the main differences between the two versions of the EFQM model—EFQM 2013 and EFQM 2020—can be observed. The key change in the EFQM 2020 model compared to the previous version lies in the modification of the categorization and structure of the criteria and sub-criteria. One important change is the inclusion of the Engaging Stakeholders criterion, indicating that the new model places greater importance on stakeholders. This is most evident through the criteria Engaging Stakeholders, Stakeholder Perceptions, and Creating Sustainable Value.

Stakeholder groups are also considered more broadly in the new model. This model addresses groups such as employees, customers, society, and partners. Furthermore, the EFQM 2020 model places more emphasis on innovation and continuous organizational development, as reflected in the sub-criteria such as Drive Performance and Manage Risk and Transform the Organization for the Future.

In addition to all the aforementioned points, an important change is reflected in the reduction of the number of criteria. From nine criteria in the 2013 model, the number has now been reduced to seven criteria. This change places a focus on key aspects of the business, which are later further broken down and analyzed through sub-criteria. The reduction in the number of criteria directly impacts the assessment, making the application of the new model significantly simpler, with the company's management now focused only on the important criteria for improving and sustaining the business. As previously mentioned, the focus is on stakeholders, particularly customers and employees.

In the EFQM Excellence Model, the weighting of criteria is crucial for evaluating organizational performance and overall excellence. It is generally recommended to adjust these weights based on the specific needs and priorities of each industry, especially for self-assessment purposes. As business trends have evolved over time, the criteria weights have also been adapted to stay aligned with these changing dynamics. Concurrently, both practitioners and academics have endeavored to refine the EFQM model to suit diverse fields of study. Numerous adaptations of the EFQM model, originating from its inception in 1992 and subsequent revisions up to 2021, have been explored in literature utilizing Multi-Criteria Decision-Making (MCDM) techniques and artificial intelligence approaches (Table 2).

Table 2. EFQM combined with MCDM techniques and artificial intelligence approaches.

Reference	*MCDM/AI or Optimization Approach*	*Industry*	*EFQM Version*
Hosseini Ezzabadi et al., 2015 [16]	FAHP/	any	2013
Liu and Ko, 2018 [17]	FAHP/	Service	2013
Daniel et al., 2019 [18]	/FIS	Production/Service	2013
Uygun et al., 2020 [19]	DEMATEL, FANP, VIKOR/	any	2013
Yanginlar and Gül, 2022 [20]	IF-AHP/	Railway	2013
Petrović et al., 2022 [21]	FBWM, FMOORA/	Production	2020
Petrović et al., 2023 [22]	FSAW	Production	2020
Proposed model	FAHP/CP	Production	2020

2.2. Application of the FAHP Method in the Relevant Literature

In the relevant literature, various approaches are used for determining criteria weights. In addition to direct assessment by DMs (see [23,24]), different MCDM methods are frequently applied. One of the oldest and most widely used methods is the Analytic Hierarchy Process (AHP) [25,26]. Its application is very broad, and it has been utilized in the relevant literature for determining criteria weights in supplier selection problems [27], site selection problems [28], production capacity planning issues [29], and others.

Besides the AHP method, other methods commonly used in the literature for determining criteria weights include the Best-Worst Method (BWM) [30], CRiteria Importance Through Intercriteria Correlation (CRITIC) [31], Defining Interrelationships between Ranked Criteria (DIBR) [32], DIBR II [33], Stochastic Identification of Weights (SITW) [34], Decision-Making Trial and Evaluation Laboratory (DEMATEL) [35], and others. Their application is also very broad and can be found in studies in the fields of reliability engineering [36,37], circular economy [32], lean organization systems management [33], mining [38], aviation [39], and others.

Many authors in the literature suggest that the AHP method is highly suitable for determining weight vectors. In conventional AHP [26], decision-makers express their assessments using a standard scale of measures [1–9]. A rating of 1 indicates that the relative importance of attributes is equal, while higher values denote greater importance of attributes. The consistency assessment of decision-makers' assessments is performed using the method of the eigenvalue vector [26,40]. Given the subjective nature of criteria and belonging to sub-criteria, numerous authors have expanded traditional AHP with TFNs (FAHP). Table 3 provides an analysis of recent literature on proposed FAHP methodologies within the last 7 years.

Table 3. The FAHP in the relevant literature.

Papers	Number/Type/ Domain	Aggregation of Decision-Maker Assessments/Consistency Check of the Aggregated Fuzzy Pair-wise Comparison Matrix	Weight Vector
Banduka et al., 2018 [41]	5/TFNs/[1–5]	-/Moment method and Eigenvector	Extended analysis/Crisp
Leśniak and Kubek, 2018 [42]	9/TFNs/[1/3–3]	-/Averaging method	Extended analysis/Crisp
Mallick et al., 2018 [43]	9/TFNs/[1–9]	-/Defuzzification method proposed by [43]	Geometric mean/TFNs
Calabrese et al., 2019 [44]	5/TFNs/[1–3.5]	-/The standard method of defuzzification and Eigenvector	Extended analysis/Crisp
Chou et al., 2019 [45]	9/TFNs/[1–9]	Fuzzy Arithmetic mean/-	Geometric mean/Crisp
Mittal et al., 2019 [46]	5/TFNs/[1–9]	-/α-cut [47]	Geometric mean/Crisp
Boral et al., 2020 [48]	9/TFNs/[1/3–3]	Fuzzy Arithmetic mean/The center-of-gravity method and Eigenvector	Geometric mean/TFNs
Ban et al., 2020 [49]	5/TFNs/[1–2.5]	-/The standard method of defuzzification and Eigenvector	Extended analysis/Crisp
Bakır and Atalık, 2021 [50]	9/TFNs/[1–9]	Fuzzy geometric mean/-	Geometric mean/Crisp
Wang et al., 2021 [6]	9/TFNs/[1–10]	-/The left and right endpoints method for defuzzification [6] and Eigenvector	Geometric mean/TFNs
Pham et al., 2021 [51]	9/TFNs/[1–10]	-/Center-of-gravity method and Eigenvector	Geometric mean/TFNs
Boonmee and Thoenburin, 2024 [52]	5/TFNs/[1–5]	Fuzzy arithmetic mean/The standard method of defuzzification and Eigenvector	Arithmetic mean/Crisp
Marković et al., 2024 [53]	7/TFNs/[1–9]	Fuzzy geometric mean/Center-of-gravity method and Eigenvector	Geometric mean/TFNs
The proposed model	5/TFNs/[1–9]	Fuzzy harmonic mean/Center-of-gravity method/Eigenvector	Geometric mean/TFNs

Based on the analysis of the literature, it is evident that the strengths and weaknesses of the proposed FAHP and FAHP found in the relevant literature can be clearly observed.

Many authors [41,44,46,49,52] suggest using five linguistic expressions for describing existing uncertainties, as in this research.

Linguistic variables are modeled by TFNs in all analyzed papers, as in this research.

The domain of TFNs is defined into a common measurement scale in [43,45,46,50,53], as in this research.

Assessment of the relative importance of considered items is stated as a fuzzy group decision-making problem in [45,48,52,53], as in this research.

The aggregation of assessments from decision-makers into a single evaluation is executed using various operators, for instance: (i) fuzzy arithmetic mean [45,48,52], and (ii) fuzzy geometric mean [50,53]. In this research, aggregation is conducted using the fuzzy harmonic mean, which represents one of the main differences between this paper and the papers presented in Table 3.

Transformation of fuzzy pair-wise comparison matrix into pair-wise comparison matrix is performed by using different defuzzification procedures, for instance: (i) standard defuzzification method [44,49,52] (ii) moment method [41], (iii) average method [42], (iv) the proposed defuzzification method [43], (v) center-of-gravity method [48], (vi) α-cut [46], (vii) left and right side method [6], and (viii) simple center area method [51,53]. In this research, the center-of-gravity method is used, which can be marked as one of the differences between our research and the analyzed papers.

A consistency check of decision-makers' assessments in all analyzed papers is performed using the method of the eigenvalue vector [26].

The weights vector is given by applying: (i) the extent analysis method by [54] in [41,42,44,49,52] and (ii) the method based on fuzzy geometric mean by [55] in [6,43,45,46,48,50,51,53], as in this research.

In this research, five linguistic expressions modeled using Triangular Fuzzy Numbers (TFNs) were employed. The authors' intention was to reduce DMs' indecisiveness and facilitate more intuitive reasoning, as also suggested in several previous studies [41,44,46,49,52]. Additionally, the domain of fuzzy numbers used in this study is [1–9], which corresponds to the measurement scale of the standard AHP method.

For the aggregation of values, the fuzzy harmonic mean was applied. Compared to arithmetic and geometric means, it is less sensitive to the influence of extreme values, which helps to mitigate the potential impact of significant deviations in assessments provided by individual decision-makers.

3. Methodology

The proposed model that combines the FFQM, FAHP, and OR-Tools CP-SAT solver [9] for assessment and improvement of business excellence is presented in Figure 1.

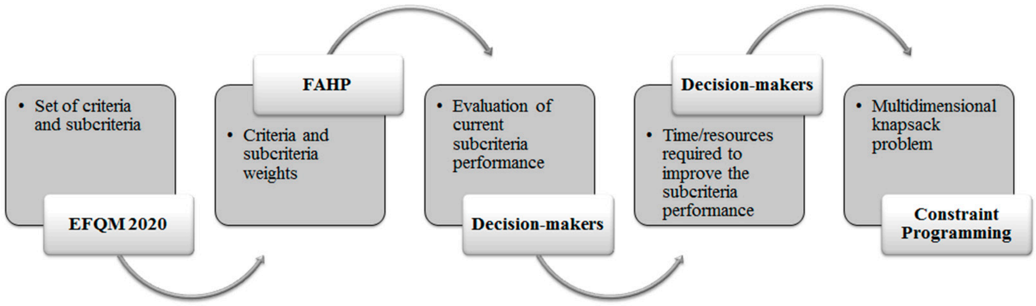

Figure 1. The proposed model for assessing and improving business excellence within the enterprise.

3.1. Basic Definitions of Fuzzy Sets Theory

This section offers fundamental definitions of fuzzy set theory and fuzzy algebra [2,3].

Definition 1. *A linguistic variable is a variable where values are described using language-based terms [3].*

Definition 2. *Fuzzy set* $\widetilde{A}$ *consists of ordered pairs:*

$$\tilde{A} = \{x, \mu_{\tilde{A}}(x) | x \epsilon X, 0 \leq \mu_{\tilde{A}}(x) \leq 1\} \quad (1)$$

where the fuzzy set $\widetilde{A}$ *is defined over the set of real numbers* $x \epsilon R$*. The membership function is denoted as* $\mu_{\tilde{A}}(x)$*.*

Definition 3. *A fuzzy number* $\widetilde{A}$ *is a convex, normalized version of fuzzy set* $\widetilde{A}$*, that is defined over the real number set R such that:*

If there exists $x_0 \in R$ *such that* $\mu_{\tilde{A}}(x_0) = 1$

$\mu_{\tilde{A}}(x)$ *is continuous over the entire domain of definition.*

Definition 4. *A fuzzy number* $\widetilde{A}$ *on the real number set R is a triangular fuzzy number if its membership function* $\mu_{\tilde{A}}(x) \in R \rightarrow [0,1]$ *can be expressed as:*

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x-l}{m-l} & x \in [l,m] \\ \dfrac{x-u}{m-u} & x \in [m,u] \\ 0 & other \end{cases} \quad (2)$$

where:

$l \leq m \leq u$, l and u are the minimum and maximum values belonging to the domain X, respectively. The modal value is represented as m. A triangular fuzzy number is then denoted as (l, m, u). The domain on which the fuzzy number is defined X is a set of elements.

Definition 5. *Let us examine two triangular fuzzy numbers TFNs $\tilde{A} = (l_1, m_1, u_1)$ and $\tilde{B} = (l_2, m_2, u_2)$. Algebraic operations on these numbers are further illustrated as follows:*

$$(l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{3}$$

$$(l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \tag{4}$$

$$(l_1, m_1, u_1) \cdot (l_2, m_2, u_2) = (l_1 \cdot l_2, m_1 \cdot m_2, u_1 \cdot u_2) \tag{5}$$

$$(l_1, m_1, u_1) : (l_2, m_2, u_2) = (l_1 : u_2, m_1 : m_2, u_1 : l_2) \tag{6}$$

$$\varphi \cdot (l_1, m_1, u_1) = (\varphi \cdot l_1, \varphi \cdot m_1, \varphi \cdot u_1) \tag{7}$$

$$(l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \tag{8}$$

Definition 6. *Defuzzification is the process by which a fuzzy number is transformed into a corresponding scalar value. The center-of-gravity method [56] was used in this research.*

For a TFN $\tilde{A} = (l, m, u)$, the corresponding scalar is obtained according to the expression:

$$\frac{(u - l) + (m - l)}{3} + l \tag{9}$$

Definition 7. *The Hamming distance between these two TFNs [57] is*

$$d = \frac{1}{4} \cdot (|l_1 - l_2| + 2 \cdot |m_1 - m_2| + |u_1 - u_2|) \tag{10}$$

3.2. Definition of a Finite Set of Criteria and Sub-Criteria

The evaluation criteria for assessing a company's business excellence, as outlined in the EFQM 2020 model, follow a hierarchical structure. These criteria can be formally represented by the indices set $\{1, \ldots, k, \ldots, K\}$, where K is the total number of quality criteria, and each quality criterion is denoted by indices $k, k = 1, \ldots, K$. Sub-criteria under criterion $k, k = 1, \ldots, K$ are represented by set of indices $\{1, \ldots, j, \ldots, J_k\}$. Total number of sub-criteria under criterion $k, k = 1, \ldots, K$ is denoted as J_k. The index of the sub-criterion is marked as $j, j = 1, \ldots, J_k$. These criteria and their sub-criteria are presented in Table 1.

3.3. Introduction to the Group of Decision-Makers

The evaluation of the relative importance of quality criteria is approached as a fuzzy group decision-making issue. DMs involved in the decision-making process are formally indicated by indices set $\{1, \ldots, e, \ldots, E\}$, where E represents the total number of DMs. The index of DM is stated by the index $e, e = 1 \ldots, E$. In this study, the evaluation of the level of excellence of a medium-sized enterprise operating in the production economic sector is examined. The assessment of the relative importance of criteria is performed by a quality inspector, a representative from the chamber of commerce, and a university professor. The quality manager evaluates the values of the sub-criteria.

3.4. Modeling of the Existing Uncertainties

In this study, the fuzzy sets theory is employed to model linguistic variables that describe the relative importance of criteria, sub-criteria, and their respective values using TFNs. A fuzzy number, which represents a special form of fuzzy sets, is presented through its membership function, whose parameters are form, granularity, and domain [2].

In the literature, the majority of authors argue that uncertain and imprecise data can be adequately modeled using TFNs [4–6], as in this research. With the triangular possibility distribution function, the maximum value of the belief measure is achieved only at one point. The use of TFNs reduces computational complexity while still achieving sufficiently accurate results.

Granularity can be defined as the number of linguistic expressions used to assess the values of uncertain and imprecise data. The granularity depends on the estimation of DMs. They base their estimations on experience as well as the magnitude and complexity of the problem. In this research, the authors believe that existing uncertainties can be adequately assessed using five pre-defined linguistic expressions, as suggested in [57,58].

The relative importance of criteria, sub-criteria, and their values is described using the following linguistic expressions which have been modeled using corresponding TFNs:

- Very small importance/value (V1): $(1, 1, 2.5)$
- Low importance/values (V2): $(1.5, 3, 4.5)$
- Medium importance/value (V3): $(3, 5, 7)$
- High importance/value (V4): $(5.5, 7, 8.5)$
- Extremely high importance/value (V5): $(7.5, 9, 9)$

In the literature, there is no rule or recommendation on how to choose the domain on which fuzzy numbers are defined. Many authors use a common measurement scale defined by [26], as in this research.

3.5. The Proposed FAHP

Determining the weighted values of criteria for decision-making regarding business excellence improvement is based on the proposed FAHP, which is implemented through the following steps:

Step 1. Let us construct a fuzzy pair-wise comparison matrix for criteria for every DM separately:

$$\left[\widetilde{W}^{e}_{kk'}\right]_{KxK} \tag{11}$$

where:

$$\widetilde{W}^{e}_{kk'} = \left(l^{e}_{kk'}, m^{e}_{kk'}, u^{e}_{kk'},\right) \tag{12}$$

Step 2. Let us construct the aggregated fuzzy pair-wise comparison matrix of the relative importance of criteria using the harmonic mean:

$$\left[\widetilde{W}_{kk'}\right]_{KxK} \tag{13}$$

where:

$$\widetilde{W}_{kk'} = \frac{K}{\sum_{e=1,\ldots,E}\frac{1}{\widetilde{W}^{e}_{kk'}}} = \frac{K}{\sum_{e=1,\ldots,E}\left(\frac{1}{u^{e}_{kk'}}, \frac{1}{m^{e}_{kk'}}, \frac{1}{l^{e}_{kk'}}\right)} \tag{14}$$

$$\widetilde{W}_{kk'} = \frac{K}{\left(\sum_{e=1,\ldots,E}\frac{1}{u^{e}_{kk'}}, \sum_{e=1,\ldots,E}\frac{1}{m^{e}_{kk'}}, \sum_{e=1,\ldots,E}\frac{1}{l^{e}_{kk'}}\right)} \tag{15}$$

$$\widetilde{W}_{kk'} = \left(\frac{K}{\sum_{e=1,\dots,E} \frac{1}{l_{kk'}^{e}}}, \frac{K}{\sum_{e=1,\dots,E} \frac{1}{m_{kk'}^{e}}}, \frac{K}{\sum_{e=1,\dots,E} \frac{1}{u_{kk'}^{e}}} \right) = (l_{kk'}, m_{kk'}, u_{kk'}) \tag{16}$$

Step 3. Let us transform the fuzzy pair-wise comparison matrix of the relative importance criteria into a pair-wise comparison matrix of the relative importance of criteria, $[W_{kk'}]_{KxK}$ by using the center-of-gravity method.

Step 4. Let us examine the consistency of the evaluations provided by DMs using the eigenvector method. A consistency index (CI) of 0.1 or less suggests that the mistakes made by DMs are within an acceptable range.

Step 5. Let us determine the weight of the criteria by applying the fuzzy geometric mean:

$$[\widetilde{\omega}_k]_{Kx1} \tag{17}$$

where:

$$\widetilde{\omega}_k = \frac{\prod_{k'=1,\dots,K} \widetilde{W}_{kk'}}{\sum_{k=1,\dots,K}\left(\prod_{k'=1,\dots,K} \widetilde{W}_{kk'}\right)} = \frac{\left(\prod_{k'=1,\dots,K} \sqrt[K]{l_{kk'}}, \prod_{k'=1,\dots,K} \sqrt[K]{m_{kk'}}, \prod_{k'=1,\dots,K} \sqrt[K]{u_{kk'}}\right)}{\sum_{k=1,\dots,K} \prod_{k'=1,\dots,K} \sqrt[K]{l_{kk'}}, \sum_{k=1,\dots,K} \prod_{k'=1,\dots,K} \sqrt[K]{m_{kk'}}, \sum_{k=1,\dots,K} \prod_{k'=1,\dots,K} \sqrt[K]{u_{kk'}}} \tag{18}$$

$$\widetilde{\omega}_k = \left(\frac{\prod_{k'=1,\dots,K} \sqrt[K]{l_{kk'}}}{\sum_{k=1,\dots,K} \prod_{k'=1,\dots,K} \sqrt[K]{u_{kk'}}}, \frac{\prod_{k'=1,\dots,K} \sqrt[K]{m_{kk'}}}{\sum_{k=1,\dots,K} \prod_{k'=1,\dots,K} \sqrt[K]{m_{kk'}}}, \frac{\prod_{k'=1,\dots,K} \sqrt[K]{u_{kk'}}}{\sum_{k=1,\dots,K} \prod_{k'=1,\dots,K} \sqrt[K]{l_{kk'}}} \right) = (l_k, m_k, u_k) \tag{19}$$

Step 6. The weights of sub-criteria under criterion $k, k = 1, \dots, K$, $\left[\widetilde{\omega}_j^k\right]_{J_k x1}$ are determined using the proposed approach (Step 1 to Step 6).

3.6. The Proposed Constraint Programming Model

Enhancing the criteria values can be accomplished by improving the sub-criteria values for each criterion. Given the company's resource constraints and the outcomes of best practices, this study assumes that sub-criteria values can be enhanced by up to two ratings. Furthermore, it is assumed that enhancing business excellence in the company is realized through improving each criterion.

Determining the sub-criteria at the level of each criterion that needs improvement, as well as the extent of improvement needed, is performed precisely using the proposed model, which can be realized through the following steps:

Step 1. Fuzzy rating of sub-criteria values, $\tilde{x}_j^k$ as well as the time required to improve the sub-criteria by one or two ratings and t_j^k is performed by the quality manager. They base their assessments on the available number of trained workers and the available resources for improvement, which are defined by strategic management.

Step 2. Let us determine the maximum values of the criteria:

$$z_k^{max} = \widetilde{\omega}_k \cdot V_5 \tag{20}$$

Step 3. Let us determine the various combinations of improved values for sub-criteria at the level of each criterion. The number of combinations within each criterion is different and depends on the initial estimated values of the sub-criteria.

Step 4. Let us determine the weighted fuzzy value of each criterion for each defined combination $c, c = 1, \dots, C_k$:

$$\tilde{z}_{ck} = \widetilde{\omega}_k \cdot \sum_{j=1,\dots,J_k}\left(\widetilde{\omega}_j^k \cdot \tilde{x}_{ij}^k\right) \tag{21}$$

where:

$\tilde{x}_{ij}^k$ is the improved value of the sub-criteria

C_k is the total number of combinations (possible ways of improvement) of criteria $k, k = 1, \ldots, K$

Step 5. Determining the set of sub-criteria that need improvement and by how much they need to be improved is formulated as a multidimensional knapsack problem with combined min/max constraints

The fitness function

$$\max_{j=1,\ldots,J_k} d_{ij}^k, k = 1, \ldots, K \tag{22}$$

Subject to

$$\sum_{j=1,\ldots,J_k} t_{ij}^k \leq T, k = 1, \ldots, K \tag{23}$$

where:

$d_{ij}^k = d\left(\tilde{z}_{ij}^k, z_k^{min}\right)$ is Hamming distance

T is the total time needed to improve the values of criteria in order to enhance business excellence.

Step 6. The crisp values of criteria before and after improvement are shown in Figure 2. The representative scalars of the given TFNs are obtained using the center-of-gravity method.

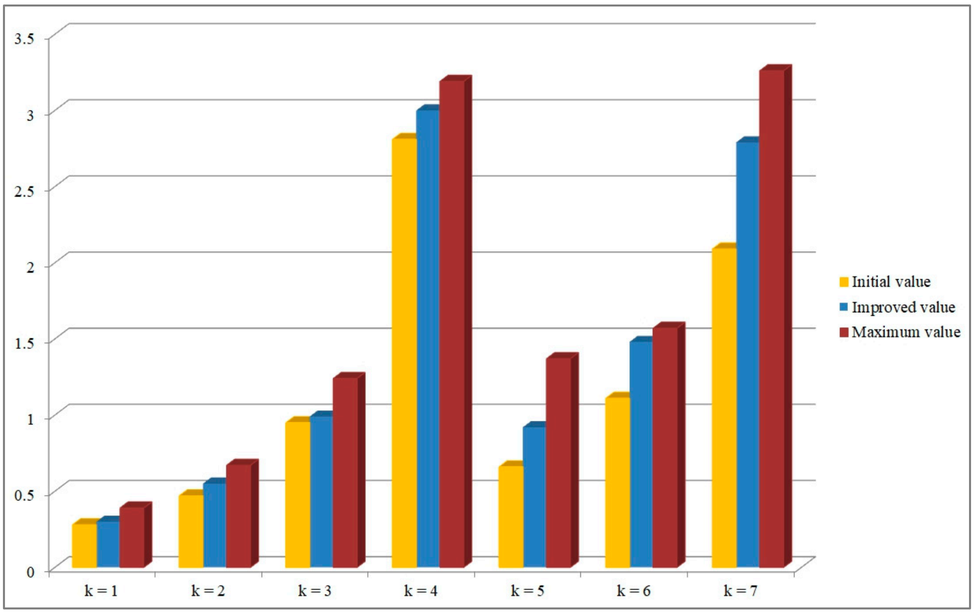

Figure 2. The crisp criteria values before and after improvement.

4. Case Study

Based on the EFQM 2020 paradigm, this study examines the relative importance of criteria and sub-criteria. Interviews with a university professor, a quality inspector, and a chamber of commerce official were used to ascertain the relative relevance of the criteria. Additionally, data on the relative importance and values of sub-criteria are collected from the quality manager of a manufacturing enterprise. The observed enterprise is part of a group of Small and midsize enterprises (SMEs) that play a significant role in the gross national income of the Republic of Serbia.

SMEs account for around 97% of all registered and operational businesses in Serbia, making them a significant contributor to the country's economy, job generation, and community development, according to data from 2021. These enterprises are essential to preserving the stability and prosperity of the national economy, even though the precise proportion of their contributions may differ.

The Case Study chapter is divided into two sections. In the first section, the application of the FAHP method is presented based on the evaluations provided by the DMs. The second section includes the input data, including constraints and potential combinations for improving the criteria and sub-criteria within the domain of the considered constraints.

4.1. Application of FAHP

By applying Step 1 of the proposed FAHP algorithm, the DMs express their assessments using pre-defined linguistic expressions modeled by triangular fuzzy numbers (TFNs). The assessments are presented below:

The quality inspector evaluates the relative importance of criteria ($e = 1$):

$$\begin{bmatrix} (1,1,1) & (1,1,1) & 1/V1 & 1/V4 & 1/V4 & 1/V4 & 1/V5 \\ & (1,1,1) & 1/V1 & 1/V3 & 1/V3 & 1/V4 & 1/V4 \\ & & (1,1,1) & 1/V3 & 1/V3 & 1/V3 & 1/V4 \\ & & & (1,1,1) & (1,1,1) & (1,1,1) & 1/V3 \\ & & & & (1,1,1) & (1,1,1) & 1/V3 \\ & & & & & (1,1,1) & (1,1,1) \\ & & & & & & (1,1,1) \end{bmatrix}$$

Assessment of the relative importance of criteria by the Chamber of Commerce representative ($e = 2$):

$$\begin{bmatrix} (1,1,1) & 1/V4 & 1/V4 & 1/V5 & V1 & 1/V1 & 1/V4 \\ & (1,1,1) & (1,1,1) & 1/V3 & V4 & V3 & (1,1,1) \\ & & (1,1,1) & 1/V3 & V4 & V3 & 1/V3 \\ & & & (1,1,1) & V5 & V4 & V3 \\ & & & & (1,1,1) & 1/V2 & 1/V4 \\ & & & & & (1,1,1) & 1/V4 \\ & & & & & & (1,1,1) \end{bmatrix}$$

Assessment of the importance of criteria by the university professor ($e = 3$):

$$\begin{bmatrix} (1,1,1) & V1 & 1/V4 & 1/V3 & 1/V1 & (1,1,1) & 1/V3 \\ & (1,1,1) & 1/V5 & 1/V4 & 1/V2 & 1/V1 & 1/V4 \\ & & (1,1,1) & V3 & V4 & V4 & V5 \\ & & & (1,1,1) & V3 & V4 & (1,1,1) \\ & & & & (1,1,1) & V1 & 1/V3 \\ & & & & & (1,1,1) & V1 \\ & & & & & & (1,1,1) \end{bmatrix}$$

By applying Step 2 of the proposed algorithm, the evaluations were aggregated. The aggregated matrix of the relative importance of criteria:

$$\begin{bmatrix} (1,1,1) & (0.29,0.33,0.43) & (0.150.20,0.25) & (0.12,0.14,0.19) & (0.25,0.33,0.42) & (0.25,0.33,0.40) & (0.12,0.14,0.19) \\ & (1,1,1) & (0.24,0.27,0.32) & (0.13,0.18,0.26) & (0.26,0.37,0.65) & (0.26,0.37,0.45) & (0.17,0.20,0.25) \\ & & (1,1,1) & (0.21,0.29,0.49) & (0.41,0.57,0.93) & (0.40,0.56,0.92) & (0.19,0.25,0.35) \\ & & & (1,1,1) & (2.05,2.27,2.40) & (2.21,2.34,2.42) & (0.36,0,0.48,0.72) \\ & & & & (1,1,1) & (0.46,0.60,1.03) & (0.13,0.18,0.26) \\ & & & & & (1,1,1) & (0.29,0.33,0.43) \\ & & & & & & (1,1,1) \end{bmatrix}$$

By applying Step 3 of the proposed algorithm, the fuzzy values of the aggregated matrix were transformed into crisp values in order to determine the consistency index using the Eigenvector method (Step 4):

$$\begin{bmatrix} 1 & 0.35 & 0.20 & 0.15 & 0.33 & 0.33 & 0.15 \\ & 1 & 0.28 & 0.19 & 0.43 & 0.36 & 0.21 \\ & & 1 & 0.33 & 0.64 & 0.63 & 0.26 \\ & & & 1 & 2.24 & 2.32 & 0.52 \\ & & & & 1 & 0.70 & 0.19 \\ & & & & & 1 & 0.35 \\ & & & & & & 1 \end{bmatrix}, CI = 0.06$$

The criteria weights were determined according to Step 5 of the proposed algorithm:

$\widetilde{\omega}_1 = (0.02,0.03,0.05)$ $\widetilde{\omega}_2 = (0.03,0.05,0.08)$
$\widetilde{\omega}_3 = (0.06,0.09,0.17)$ $\widetilde{\omega}_4 = (0.16,0.24,0.38)$
$\widetilde{\omega}_5 = (0.06,0.10,0.17)$ $\widetilde{\omega}_6 = (0.08,0.13,0.20)$
$\widetilde{\omega}_7 = (0.21,0.36,0.55)$

The fuzzy ratings of sub-criteria within each criterion, along with the weight vector of sub-criteria, are provided below (the procedure is the same as for the criteria weights):

The fuzzy pair-wise matrix of the sub-criteria under criterion $k = 1$:

$$\begin{bmatrix} (1,1,1) & 1/V1 & 1/V1 & 1/V1 & 1/V3 \\ & (1,1,1) & (1,1,1) & V1 & 1/V1 \\ & & (1,1,1) & (1,1,1) & 1/V1 \\ & & & (1,1,1) & 1/V1 \\ & & & & (1,1,1) \end{bmatrix}, C.I. = 0.07$$

The weights vector of sub-criteria under criterion $k = 1$:

$\widetilde{\omega}_1^1 = (0.05,0.14,0.20)$ $\widetilde{\omega}_2^1 = (0.12,0.20,0.36)$
$\widetilde{\omega}_3^1 = (0.12,0.20,0.30)$ $\widetilde{\omega}_4^1 = (0.10,0.20,0.30)$
$\widetilde{\omega}_5^1 = (0.17,0.27,0.64)$

The fuzzy pair-wise matrix of the sub-criteria under criterion $k = 2$:

$$\begin{bmatrix} (1,1,1) & 1/V2 & 1/V3 & (1,1,1) \\ & (1,1,1) & 1/V1 & V2 \\ & & (1,1,1) & V3 \\ & & & (1,1,1) \end{bmatrix}, C.I. = 0.01$$

The weights vector of sub-criteria under criterion $k = 2$:

$\widetilde{\omega}_1^2 = (0.06,0.10,0.20)$ $\widetilde{\omega}_2^2 = (0.14,0.37,0.67)$
$\widetilde{\omega}_3^2 = (0.25,0.44,0.95)$ $\widetilde{\omega}_4^2 = (0.06,0.10,0.20)$

The fuzzy pair-wise matrix of the sub-criteria under criterion $k = 3$:

$$\begin{bmatrix} (1,1,1) & V2 & (1,1,1) & (1,1,1) & V1 \\ & (1,1,1) & 1/V3 & 1/V3 & 1/V2 \\ & & (1,1,1) & (1,1,1) & V1 \\ & & & (1,1,1) & V1 \\ & & & & (1,1,1) \end{bmatrix}, C.I. = 0.00$$

The weights vector of sub-criteria under criterion $k = 3$:

$\widetilde{\omega}_1^3 = (0.15,0.23,0.41)$ $\widetilde{\omega}_2^3 = (0.04,0.07,0.14)$
$\widetilde{\omega}_3^3 = (0.15,0.23,0.42)$ $\widetilde{\omega}_4^3 = (0.15,0.23,0.42)$
$\widetilde{\omega}_5^3 = (0.09,0.23,0.34)$

The fuzzy pair-wise matrix of the sub-criteria under criterion $k = 4$:

$$\begin{bmatrix} (1,1,1) & V2 & V2 & V4 \\ & (1,1,1) & (1,1,1) & V3 \\ & & (1,1,1) & V1 \\ & & & (1,1,1) \end{bmatrix}, C.I. = 0.08$$

The weights vector of sub-criteria under criterion $k = 4$:

$\widetilde{\omega}_1^4 = (0.25,0.57,1.11)$ $\widetilde{\omega}_2^4 = (0.12,0.21,0.41)$
$\widetilde{\omega}_3^4 = (0.09,0.14,0.32)$ $\widetilde{\omega}_4^4 = (0.04,0.08,0.15)$

The fuzzy pair-wise matrix of the sub-criteria under criterion $k = 5$:

$$\begin{bmatrix} (1,1,1) & (1,1,1) & V1 & V2 & 1/V1 \\ & (1,1,1) & V1 & V2 & 1/V2 \\ & & (1,1,1) & 1/V1 & 1/V2 \\ & & & (1,1,1) & 1/V2 \\ & & & & (1,1,1) \end{bmatrix}, C.I. = 0.06$$

The weights vector of sub-criteria under criterion $k = 5$:

$\tilde{\omega}_1^5 = (0.11,0.22,0.39)$ $\tilde{\omega}_2^5 = (0.10,0.18,0.36)$

$\tilde{\omega}_3^5 = (0.10,0.18,0.28)$ $\tilde{\omega}_4^5 = (0.05,0.09,0.22)$

$\tilde{\omega}_5^5 = (0.15,0.34,0.70)$

The fuzzy pair-wise matrix of the sub-criteria under criterion $k = 6$:

$$\begin{bmatrix} (1,1,1) & V3 & V4 & V4 & V3 \\ & (1,1,1) & V1 & V1 & (1,1,1) \\ & & (1,1,1) & (1,1,1) & 1/V1 \\ & & & (1,1,1) & 1/V1 \\ & & & & (1,1,1) \end{bmatrix}, C.I. = 0.00$$

The weights vector of sub-criteria under criterion $k = 6$:

$\tilde{\omega}_1^6 = (0.32,0.59,1)$ $\tilde{\omega}_2^6 = (0.08,0.11,0.23)$

$\tilde{\omega}_3^6 = (0.05,0.10,0.15)$ $\tilde{\omega}_4^6 = (0.05,0.11,0.23)$

$\tilde{\omega}_5^6 = (0.08,0.10,0.15)$

4.2. The Application of the Proposed Constraint Programming Model

The fuzzy ratings of sub-criteria values and the time needed for their enhancement (Step 1 of the proposed Algorithm) are displayed in Table 4. The data presented in this table represent the input data for the CP.

Table 4. The estimated values of sub-criteria and the time required for their improvement.

Criteria	Sub-Criteria	Sub-Criteria Values	The Time Required to Improve the Sub-Criterion Value by One Rating	The Time Required to Improve the Sub-Criterion Value by Two Ratings
$k = 1$	$j = 1$	$V2$	20	25
	$j = 2$	$V5$	80	110
	$j = 3$	$V4$	50	70
	$j = 4$	$V2$	40	70
	$j = 5$	$V3$	60	95
$k = 2$	$j = 1$	$V2$	15	25
	$j = 2$	$V4$	20	25
	$j = 3$	$V3$	15	30
	$j = 4$	$V1$	5	10
$k = 3$	$j = 1$	$V5$	120	180
	$j = 2$	$V4$	20	30
	$j = 3$	$V4$	30	60
	$j = 4$	$V2$	70	120
	$j = 5$	$V3$	60	80
$k = 4$	$j = 1$	$V4$	180	260
	$j = 2$	$V5$	20	40
	$j = 3$	$V4$	80	190
	$j = 4$	$V2$	20	25
$k = 5$	$j = 1$	$V3$	60	100
	$j = 2$	$V1$	210	340

	$j = 3$	$V4$	250	390
	$j = 4$	$V3$	60	110
	$j = 5$	$V1$	30	80
$k = 6$	$j = 1$	$V3$	20	40
	$j = 2$	$V2$	10	30
	$j = 3$	$V4$	60	90
	$j = 4$	$V3$	60	100
	$j = 5$	$V5$	20	25
$k = 7$	$j = 1$	$V3$	25	30

The maximum value for each criterion is determined based on the proposed algorithm (Step 2) and is illustrated in the following example:

$$\tilde{z}_2^{max} = (7.5,9,9) \cdot (0.03,0.05,0.08) = (0.11,0.45,1.45)$$

In a similar manner, the maximum values of the other criteria are determined, so that:

$\tilde{z}_1^{max} = (0.08,0.27,0.81)$ $\tilde{z}_2^{max} = (0.11,0.45,1.45)$
$\tilde{z}_3^{max} = (0.26,0.80,2.65)$ $\tilde{z}_4^{max} = (0.60,2.16,6.81)$
$\tilde{z}_5^{max} = (0.23,0.91,2.98)$ $\tilde{z}_6^{max} = (0.35,1.18,3.17)$
$\tilde{z}_7^{max} = (1.58,3.24,4.95)$

Through the utilization of the OR-Tools CP-SAT solver, a collection of potential solutions aimed at enhancing the value of each criterion was derived, as illustrated in Table 5. The $i, i = 1, \dots, I$ denotes all potential and possible combinations for improvement within the given constraints, i.e., the combinations that are feasible within the given constraints (available resources).

Table 5. Possible solutions.

	Possible Solutions	$j = 1$	$j = 2$	$j = 3$	$j = 4$	$j = 5$
$k = 1$	$i = 1$	$V3$	$V5$	$V4$	$V2$	$V3$
	$i = 2$	$V4$	$V5$	$V4$	$V2$	$V3$
$k = 2$	$i = 1$	$V3$	$V5$	$V3$	$V1$	
	$i = 2$	$V4$	$V5$	$V3$	$V1$	
	$i = 3$	$V3$	$V4$	$V4$	$V1$	
	$i = 4$	$V3$	$V4$	$V3$	$V4$	
	$i = 5$	$V3$	$V4$	$V3$	$V5$	
	$i = 6$	$V4$	$V4$	$V3$	$V4$	
	$i = 7$	$V4$	$V4$	$V3$	$V5$	
	$i = 8$	$V2$	$V5$	$V3$	$V2$	
	$i = 9$	$V2$	$V5$	$V3$	$V3$	
	$i = 10$	$V3$	$V5$	$V3$	$V2$	
$k = 3$	$i = 1$	$V5$	$V5$	$V5$	$V2$	$V3$
$k = 4$	$i = 1$	$V4$	$V5$	$V5$	$V3$	
$k = 5$	$i = 1$	$V4$	$V1$	$V4$	$V4$	$V1$
	$i = 2$	$V4$	$V1$	$V4$	$V5$	$V1$
	$i = 3$	$V5$	$V1$	$V4$	$V4$	$V1$
	$i = 4$	$V4$	$V1$	$V4$	$V3$	$V2$
	$i = 5$	$V5$	$V1$	$V4$	$V3$	$V2$
	$i = 6$	$V3$	$V1$	$V4$	$V4$	$V2$
	$i = 7$	$V3$	$V1$	$V4$	$V4$	$V3$
	$i = 8$	$V3$	$V1$	$V4$	$V5$	$V2$
$k = 6$	$i = 1$	$V4$	$V3$	$V4$	$V3$	$V5$

	$i = 2$	$V4$	$V4$	$V4$	$V3$	$V5$
	$i = 3$	$V4$	$V2$	$V5$	$V3$	$V5$
	$i = 4$	$V4$	$V2$	$V4$	$V4$	$V5$
	$i = 5$	$V3$	$V3$	$V5$	$V3$	$V5$
	$i = 6$	$V3$	$V4$	$V5$	$V3$	$V5$
	$i = 7$	$V3$	$V3$	$V4$	$V4$	$V5$
	$i = 8$	$V3$	$V3$	$V4$	$V5$	$V5$
	$i = 9$	$V3$	$V4$	$V4$	$V4$	$V5$
	$i = 10$	$V3$	$V2$	$V5$	$V4$	$V5$
	$i = 11$	$V5$	$V3$	$V5$	$V4$	$V5$
$k = 7$	$i = 1$	$V4$				

The greatest improvement of business excellence is achieved for those possible solutions that lead to the greatest improvement of criteria ratings. In the considered problem, the improvement of business excellence should be executed as shown in Table 6.

Table 6. Optimal solutions.

Optimal Solutions	$j = 1$	$j = 2$	$j = 3$	$j = 4$	$j = 5$
$k = 1$	$V4$	$V5$	$V4$	$V2$	$V3$
$k = 2$	$V4$	$V4$	$V3$	$V5$	
$k = 3$	$V5$	$V5$	$V5$	$V2$	$V3$
$k = 4$	$V4$	$V5$	$V5$	$V3$	
$k = 5$	$V3$	$V1$	$V4$	$V4$	$V3$
$k = 6$	$V5$	$V3$	$V5$	$V4$	$V5$
$k = 7$	$V4$				

Figure 2 shows the initial, improved, and maximum values of the criteria.

Based on the results obtained, it can be inferred that applying the proposed solution results in a notable enhancement in the following criteria: Strategic and Operational Performance $(k = 7)$, Stakeholder Perceptions $(k = 6)$, Creating Sustainable Value $(k = 5)$ and Driving Performance and Transformation $(k = 4)$. These criteria can be improved by implementing the following quality management methods, e.g., Radar chart, PDCA, Balanced scorecard, Benchmarking, and Kaizen.

5. Conclusions

In this research, a novel approach for assessing and improving business excellence was developed through the integration of the EFQM model, FAHP, and CP, establishing symmetry and balance between the subjective evaluations of DMs and a mathematically grounded, objective approach. The proposed model was tested on data originating from a manufacturing SME based in central Serbia.

In order to discover sub-criteria sets for improvement and ascertain the level of improvement required to raise business excellence within organizations, this study presents a fuzzy two-stage model approach. The first stage employs the FAHP method to ascertain weight vectors for both criteria and sub-criteria under each criterion. In the second stage, the problem of selecting sub-criteria for enhancement and determining their upgraded values is framed as a multidimensional knapsack problem with combined min/max constraints. By employing the OR-Tools CP-SAT solver, the optimal solution to this formulated problem is achieved.

The proposed FAHP-CP approach results show that improvement efforts should not be allocated symmetrically (equally) across all of the EFQM model's criteria and sub-criteria. An asymmetric strategy produces superior upgrades while assuring more efficient deployment of available resources. Therefore, it can be stated that through the principle of symmetry, achieved by combining subjective and objective approaches, it has been determined that the principle of asymmetry should be followed when improving criteria and sub-criteria.

The methodological innovations of the proposed model are (1) determination of the weights of criteria/sub-criteria taken from the EFQM 2020 model using the FAHP method. In this way, the EFQM 2020 model is adapted to the needs and conditions of the considered enterprise; (2) application of the fuzzy harmonic mean for aggregating the evaluations of DMs; and (3) use of the OR-Tools CP-SAT solver to determine optimal improvements for criteria/sub-criteria in order to optimize the consumption of available resources.

The practical implications of the proposed model are (1) it provides management with a reliable mathematical tool that serves as a decision support system; (2) the decision-making process is sufficiently simplified, clear, and close to human thinking patterns; (3) the model is flexible enough to be applied in any industry; and (4) through the application of this model, companies can significantly improve their competitiveness and sustainability.

The proposed fuzzy two-stage model outperforms the standard EFQM model in three areas: (1) Recognizing that criteria and sub-criteria weights are unequal, aligning with best practice results; (2) Precisely determining sub-criteria sets for improvement and the extent of required enhancement, thereby eliminating ambiguity; and (3) Providing flexibility and adaptability by easily incorporating changes in criteria, sub-criteria, and their values into the model.

The main drawback of the proposed model lies in the subjectivity of DMs, which is almost inevitable when applying the FAHP method. However, by using the fuzzy harmonic mean to aggregate the DMs' evaluations, extreme values of the assessments are appropriately moderated and weighted towards an average value. In addition, a limitation of the study is the reliance on a relatively small number of DMs.

In future research, the proposed model could be tested in companies from other industry sectors, as well as companies from other regions. By using the EFQM 2020 framework, but through reassessing and determining the criteria weights that would match the considered case study, the model would be applicable and appropriate. Furthermore, advanced types of fuzzy numbers could be used for modeling uncertain values. Lastly, developing software to automate the decision-making process, with potential for commercialization, could be a key direction for future research.

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References

1. European Foundation for Quality Management. *EFQM 2020 Model*; European Foundation for Quality Management: Brussels, Belgium, 2020.
2. Dubois, D.; Prade, H. Systems of Linear Fuzzy Constraints. *Fuzzy Sets Syst.* **1980**, *3*, 37–48. https://doi.org/10.1016/0165-0114(80)90004-4.
3. Zimmermann, H.-J. Fuzzy Set Theory. *WIREs Comput. Stat.* **2010**, *2*, 317–332. https://doi.org/10.1002/wics.82.
4. Akkaya, G.; Turanoğlu, B.; Öztaş, S. An Integrated Fuzzy AHP and Fuzzy MOORA Approach to the Problem of Industrial Engineering Sector Choosing. *Expert Syst. Appl.* **2015**, *42*, 9565–9573. https://doi.org/10.1016/j.eswa.2015.07.061.
5. Mabrouk, N.B. Green Supplier Selection Using Fuzzy Delphi Method for Developing Sustainable Supply Chain. *Decis. Sci. Lett.* **2021**, *10*, 63–70. https://doi.org/10.5267/j.dsl.2020.10.003.
6. Wang, C.N.; Nguyen, N.A.T.; Dang, T.T.; Lu, C.-M. A Compromised Decision-Making Approach to Third-Party Logistics Selection in Sustainable Supply Chain Using Fuzzy AHP and Fuzzy VIKOR Methods. *Mathematics* **2021**, *9*, 886. https://doi.org/10.3390/math9080886.
7. Jami Pour, M.; Ebrahimi Delavar, F.; Taheri, G.; Kargaran, S. Developing a Scale of Social Commerce Service Quality: An Exploratory Study. *Kybernetes* **2021**, *50*, 2232–2263. https://doi.org/10.1108/K-06-2020-0373.
8. Daneshamooz, F.; Fattahi, P.; Hosseini, S.M.H. Mathematical Modeling and Two Efficient Branch and Bound Algorithms for Job Shop Scheduling Problem Followed by an Assembly Stage. *Kybernetes* **2021**, *50*, 3222–3245. https://doi.org/10.1108/K-08-2020-0521.
9. OR-Tools CP-SAT. Available online: https://developers.google.com/optimization/cp/cp_solver (accessed on 10 Novembar 2024).
10. Cook, S.A. The Complexity of Theorem-Proving Procedures. In Proceedings of the Third Annual ACM Symposium on Theory of Computing-STOC '71, Shaker Heights, OH, USA, 3–5 May 1971; ACM Press: New York, NY, USA, 1971; pp. 151–158.
11. Alouneh, S.; Abed, S.; Al Shayeji, M.H.; Mesleh, R. A Comprehensive Study and Analysis on SAT-Solvers: Advances, Usages and Achievements. *Artif. Intell. Rev.* **2019**, *52*, 2575–2601. https://doi.org/10.1007/s10462-018-9628-0.
12. MiniZinc. MiniZinc Challenge 2023 Results. Available online: https://www.minizinc.org/challenge/2023/results/ (accessed on 9 April 2025).
13. SAT Competition. The International SAT Competition Web Page. Available online: https://satcompetition.github.io (accessed on 9 April 2025).
14. Ohrimenko, O.; Stuckey, P.J.; Codish, M. Propagation = Lazy Clause Generation. In *Principles and Practice of Constraint Programming–CP 2007, Proceedings of the Lecture Notes in Computer Science*; Bessière, C., Eds.; Springer: Berlin/Heidelberg, Germany, 2007; Volume 4741, pp. 544–558, ISBN 978-3-540-74969-1.
15. European Foundation for Quality Management. *EFQM Excellence Model*; European Foundation for Quality Management: Brussels, Belgium, 2013.
16. Hosseini Ezzabadi, J.; Dehghani Saryazdi, M.; Mostafaeipour, A. Implementing Fuzzy Logic and AHP into the EFQM Model for Performance Improvement: A Case Study. *Appl. Soft Comput.* **2015**, *36*, 165–176. https://doi.org/10.1016/j.asoc.2015.06.051.
17. Liu, Y.-L.; Ko, P.-F. A Modified EFQM Excellence Model for Effective Evaluation in the Hotel Industry. *Total Qual. Manag. Bus. Excell.* **2018**, *29*, 1580–1593. https://doi.org/10.1080/14783363.2017.1279011.
18. Daniel, J.; Naderpour, M.; Lin, C.-T. A Fuzzy Multilayer Assessment Method for EFQM. *IEEE Trans. Fuzzy Syst.* **2019**, *27*, 1252–1262. https://doi.org/10.1109/TFUZZ.2018.2874019.
19. Uygun, O.; Yalcin, S.; Kiraz, A.; Erkan, E. A Novel Assessment Approach for EFQM Driven Institutionalization Using Integrated Fuzzy Multi-Criteria Decision Making Methods. *Sci. Iran.* **2020**, *27*, 880–892. https://doi.org/10.24200/sci.2018.5398.1259.
20. Yanginlar, G.; Gül, S. An EFQM-Based Self-Assessment Method for Railway Transportation Service Quality: An Application with Intuitionistic Fuzzy AHP. *Ege Acad. Rev.***2022,** *22*, 371–392. https://doi.org/10.21121/eab.1008669.
21. Petrović, T.; Vesić Vasović, J.; Komatina, N.; Tadić, D.; Klipa, Đ.; Đurić, G. A Two-Stage Model Based on EFQM, FBWM, and FMOORA for Business Excellence Evaluation in the Process of Manufacturing. *Axioms* **2022**, *11*, 704. https://doi.org/10.3390/axioms11120704.
22. Petrović, T.; Paunović, V.; Komatina, N. EFQM and Business Model Relation Effect on Performance of Manufacturing Enterprises. *Int. Rev.* **2023**, 39–47. https://doi.org/10.5937/intrev2302050P.
23. Komatina, N.; Marinković, D.; Tadić, D.; Pamučar, D. Advancing PFMEA Decision-Making: FRADAR Based Prioritization of Failure Modes Using AP, RPN, and Multi-Attribute Assessment in the Automotive Industry. *Teh. Glas./Tech. J.* **2025**, *19*, *accepted for publication*.

24. Tadić, D.; Lukić, J.; Komatina, N.; Marinković, D.; Pamučar, D. A Fuzzy Decision-Making Approach to Electric Vehicle Evaluation and Ranking. *Teh. Vjesn./Tech. Gaz.* **2025**, *4*, *accepted for publication*.
25. Saaty, T.L. *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation (Decision Making Series)*. McGraw-Hill: New York, NY, USA, 1980.
26. Saaty, T.L. The Modern Science of Multicriteria Decision Making and Its Practical Applications: The AHP/ANP Approach. *Oper. Res.* **2013**, *61*, 1101–1118. https://doi.org/10.1287/opre.2013.1197.
27. Komatina, N.; Tadić, D.; Aleksić, A.; Jovanović, A.D. The Assessment and Selection of Suppliers Using AHP and MABAC with Type-2 Fuzzy Numbers in Automotive Industry. *Proc. Inst. Mech. Eng. Part O J. Risk Reliab.* **2023**, *237*, 836–852. https://doi.org/10.1177/1748006X221095359.
28. Biswas, A.; Gazi, K.H.; Sankar, P.M.; Ghosh, A. A Decision-Making Framework for Sustainable Highway Restaurant Site Selection: AHP-TOPSIS Approach Based on the Fuzzy Numbers. *Spec. Oper. Res.* **2025**, *2*, 1–26. https://doi.org/10.31181/sor2120256.
29. Milanovic, M.; Misita, M.; Komatina, N. Determination of the Optimal Production Plan by Using Fuzzy AHP and Fuzzy Linear Programming. *J. Intell. Fuzzy Syst.* **2020**, *38*, 4315–4325. https://doi.org/10.3233/JIFS-190913.
30. Rezaei, J. Best-Worst Multi-Criteria Decision-Making Method. *Omega* **2015**, *53*, 49–57. https://doi.org/10.1016/j.omega.2014.11.009.
31. Diakoulaki, D.; Mavrotas, G.; Papayannakis, L. Determining Objective Weights in Multiple Criteria Problems: The Critic Method. *Comput. Oper. Res.* **1995**, *22*, 763–770. https://doi.org/10.1016/0305-0548(94)00059-H.
32. Pamucar, D.; Deveci, M.; Gokasar, I.; Işık, M.; Zizovic, M. Circular Economy Concepts in Urban Mobility Alternatives Using Integrated DIBR Method and Fuzzy Dombi CoCoSo Model. *J. Clean. Prod.* **2021**, *323*, 129096. https://doi.org/10.1016/j.jclepro.2021.129096.
33. Božanić, D.; Epler, I.; Puška, A.; Biswas, S.; Marinković, D.; Koprivica, S. Application of the DIBR II–Rough MABAC Decision-Making Model for Ranking Methods and Techniques of Lean Organization Systems Management in the Process of Technical Maintenance. *Facta Univ. Ser. Mech. Eng.* **2024**, *22*, 101. https://doi.org/10.22190/FUME230614026B.
34. Kizielewicz, B.; Sałabun, W. SITW Method: A New Approach to Re-Identifying Multi-Criteria Weights in Complex Decision Analysis. *Spectr. Mech. Eng. Oper. Res.* **2024**, *1*, 215–226. https://doi.org/10.31181/smeor11202419.
35. Gazi, K.H.; Raisa, N.; Biswas, A.; Azizzadeh, F.; Mondal, S.P. Finding Most Important Criteria in Women's Empowerment for Sports Sector by Pentagonal Fuzzy DEMATEL Methodology. *Spec. Decis. Mak. Appl.* **2025**, *2*, 28–52. https://doi.org/10.31181/sdmap21202510.
36. Komatina, N. A Novel BWM-RADAR Approach for Multi-Attribute Selection of Equipment in the Automotive Industry. *Spectr. Mech. Eng. Oper. Res.* **2025**, *2*, 104–120. https://doi.org/10.31181/smeor21202531.
37. Tadić, D.; Komatina, N. A Hybrid Interval Type-2 Fuzzy DEMATEL-MABAC Approach for Strategic Failure Management in Automotive Manufacturing. *J. Eng. Manag. Syst. Eng.* **2025**, *4*, 21–38. https://doi.org/10.56578/jemse040102.
38. Xu, D.-Y.; Cui, H.-Q.; Wang, T.-Y.; Fu, J.-W.; Zhu, G.-B. Interactions and Influences on Coal Miners' Safety Attention: An Evaluation Using an Improved DEMATEL-ISM Approach. *Facta Univ. Ser. Mech. Eng.* **2024**, *22*, 139. https://doi.org/10.22190/FUME230726042X.
39. Radovanović, M.; Božanić, D.; Tešić, D.; Puška, A.; Hezam, I.M.; Jana, C. Application of Hybrid DIBR-FUCOM-LMAW-Bonferroni-Grey-EDAS Model in Multicriteria Decision-Making. *Facta Univ. Ser. Mech. Eng.* **2023**, *21*, 387. https://doi.org/10.22190/FUME230824036R.
40. Saaty, T.L. Decision-Making with the AHP: Why Is the Principal Eigenvector Necessary. *Eur. J. Oper. Res.* **2003**, *145*, 85–91. https://doi.org/10.1016/S0377-2217(02)00227-8.
41. Banduka, N.; Tadic, D.; Macuzic, I.; Crnjac, M. Extended Process Failure Mode and Effect Analysis (PFMEA) for the Automotive Industry: The FSQC-PFMEA. *Adv. Prod. Eng. Manag.* **2018**, *13*, 206–215. https://doi.org/10.14743/apem2018.2.285.
42. Leśniak, A.; Kubek, D.; Plebankiewicz, E.; Zima, K.; Belniak, S. Fuzzy AHP Application for Supporting Contractors' Bidding Decision. *Symmetry* **2018**, *10*, 642. https://doi.org/10.3390/sym10110642.
43. Mallick, J.; Singh, C.K.; AlMesfer, M.K.; Kumar, A.; Khan, R.A.; Islam, S.; Rahman, A. Hydro-Geochemical Assessment of Groundwater Quality in Aseer Region, Saudi Arabia. *Water* **2018**, *10*, 1847. https://doi.org/10.3390/w10121847.
44. Calabrese, A.; Costa, R.; Levialdi, N.; Menichini, T. Integrating Sustainability into Strategic Decision-Making: A Fuzzy AHP Method for the Selection of Relevant Sustainability Issues. *Technol. Forecast. Soc. Change* **2019**, *139*, 155–168. https://doi.org/10.1016/j.techfore.2018.11.005.

45. Chou, Y.-C.; Yen, H.-Y.; Dang, V.T.; Sun, C.-C. Assessing the Human Resource in Science and Technology for Asian Countries: Application of Fuzzy AHP and Fuzzy TOPSIS. *Symmetry* **2019**, *11*, 251. https://doi.org/10.3390/sym11020251.
46. Mittal, V.K.; Sindhwani, R.; Shekhar, H.; Singh, P.L. Fuzzy AHP Model for Challenges to Thermal Power Plant Establishment in India. *Int. J. Oper. Res.* **2019**, *34*, 562. https://doi.org/10.1504/IJOR.2019.099109.
47. Lee, A.H.I.; Chen, W.C.; Chang, C.J. A Fuzzy AHP and BSC Approach for Evaluating Performance of IT Department in the Manufacturing Industry in Taiwan. *Expert Syst. Appl.* **2008**, *34*, 96–107. https://doi.org/10.1016/j.eswa.2006.08.022.
48. Boral, S.; Howard, I.; Chaturvedi, S.K.; McKee, K.; Naikan, V.N.A. An Integrated Approach for Fuzzy Failure Modes and Effects Analysis Using Fuzzy AHP and Fuzzy MAIRCA. *Eng. Fail. Anal.* **2020**, *108*, 104195. https://doi.org/10.1016/j.engfailanal.2019.104195.
49. Ban, A.I.; Ban, O.I.; Bogdan, V.; Sabau Popa, D.C.; Tuse, D. Performance Evaluation Model of Romanian Manufacturing Listed Companies by Fuzzy AHP and TOPSIS. *Technol. Econ. Dev. Econ.* **2020**, *26*, 808–836. https://doi.org/10.3846/tede.2020.12367.
50. Bakır, M.; Atalık, Ö. Application of Fuzzy AHP and Fuzzy MARCOS Approach for the Evaluation of E-Service Quality in the Airline Industry. *Decis. Mak. Appl. Manag. Eng.* **2021**, *4*, 127–152. https://doi.org/10.31181/dmame2104127b.
51. Pham, N.T.; Do, A.D.; Nguyen, Q.V.; Ta, V.L.; Dao, T.T.B.; Ha, D.L.; Hoang, X.T. Research on Knowledge Management Models at Universities Using Fuzzy Analytic Hierarchy Process (FAHP). *Sustainability* **2021**, *13*, 809. https://doi.org/10.3390/su13020809.
52. Boonmee, C.; Thoenburin, P. Temporary Safety Zone Site Selection during Haze Pollution: An Integrated Approach with FAHP and FTOPSIS. *Expert Syst. Appl.* **2024**, *245*, 123002. https://doi.org/10.1016/j.eswa.2023.123002.
53. Marković, A.; Stojanović, B.; Komatina, N.; Ivanović, L. Multi-Attribute Approach for Selection of Polymeric Materials for Manufacturing Gears: A Case Study in the Automotive Industry. *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.* **2024**, *238*, 10744–10755. https://doi.org/10.1177/09544062241271690.
54. Chang, D.-Y. Applications of the Extent Analysis Method on Fuzzy AHP. *Eur. J. Oper. Res.* **1996**, *95*, 649–655. https://doi.org/10.1016/0377-2217(95)00300-2.
55. Buckley, J.J. Fuzzy Hierarchical Analysis. *Fuzzy Sets Syst.* **1985**, *17*, 233–247. https://doi.org/10.1016/0165-0114(85)90090-9.
56. Tzeng, G.; Teng, J. Transportation Investment Project Selection with Fuzzy Multiobjectives. *Transp. Plan. Technol.* **1993**, *17*, 91–112. https://doi.org/10.1080/03081069308717504.
57. Celik, E.; Erdogan, M.; Gumus, A.T. An Extended Fuzzy TOPSIS–GRA Method Based on Different Separation Measures for Green Logistics Service Provider Selection. *Int. J. Environ. Sci. Technol.* **2016**, *13*, 1377–1392. https://doi.org/10.1007/s13762-016-0977-4.
58. Tadic, D.; Aleksic, A.; Mimovic, P.; Puskaric, H.; Misita, M. A Model for Evaluation of Customer Satisfaction with Banking Service Quality in an Uncertain Environment. *Total Qual. Manag. Bus. Excell.* **2018**, *29*, 1342–1361. https://doi.org/10.1080/14783363.2016.1257905.