

Fuzzy Integrated Approach for Selecting Investment Projects in R&D Departments*

Research Article / Araştırma Makalesi

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ABSTRACT

Making sound decisions is essential for companies to sustain their operations profitably. In this context, the objective of this study is to develop an integrated quantitative approach to support decision-making processes by accounting for multiple, and often conflicting, criteria in the selection of investment projects within an R&D center. The proposed approach consists of three stages. In the first stage, project evaluation criteria are identified and weighted using the Full Consistency Method (FUCOM), which combines methodological simplicity with analytical reliability. Since experts also expressed their evaluations through linguistic variables, the weights of the criteria were additionally determined using the Fuzzy FUCOM and the results of these two methods were compared. In the second stage, projects were assessed according to the defined criteria using the Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) method. This method commonly used for multi-alternative decision-making problems in the literature, was used here to rank 17 alternative projects. The third stage involved selecting the optimal set of projects for investment. Knapsack algorithm was formulated under multiple constraints to identify the most beneficial combination of projects for the company. As a result, four main categories of criteria—economic, institutional, technological, and strategic—along with their sub-criteria, were defined. While some inconsistencies were observed between the weights derived from the FUCOM and Fuzzy FUCOM methods, the ranking of the main criteria remained unchanged. Furthermore, investment alternatives were ranked under various scenarios. The findings of this study provide a practical framework that can guide R&D centers in enhancing their decision-making processes and achieving a sustainable competitive advantage.

Keywords: FUCOM, Fuzzy FUCOM, MAIRCA, Knapsack Algorithm, Multi Criteria Decision Making.

1. INTRODUCTION

With the rapid evolution of living conditions and consumer preferences, the dynamics of the business world are also transforming swiftly. In this environment of constant change, companies must carefully determine their investment areas or projects. Project selection has become a critical factor for sustaining competitiveness and long-term viability in today's increasingly challenging business landscape. However, businesses do not have unlimited resources. They operate under various resource constraints such as financial, human, and technical ones. As such, project selection represents a complex and time-consuming decision-making process influenced by numerous criteria and performance metrics. Some of these criteria may conflict with one another, while others may involve uncertainty. This study focuses on project selection within the R&D center of a company engaged in the production of durable consumer goods. The objective is to ensure that the R&D activities are conducted efficiently and evaluated in a manner that will be most beneficial to the company. Within this scope, various equipment and

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machinery investments are being considered, each contributing to R&D operations to differing extents (Yıldız, 2014).

In order to study the project selection within the R&D center of a company engaged in the production of durable consumer goods, the study is organized as follows. First, a comprehensive literature review was conducted to identify the most frequently employed criteria in project selection problems. These criteria were then assessed in collaboration with experts in the domain to select the most critical criteria for the company. As a result, nine key criteria were established for this project. During the criteria-weighting stage, the **Full Consistency Method (FUCOM)** was applied. Additionally, linguistic variables were incorporated into the weighting procedure, and weights were determined using the **Fuzzy FUCOM** method. At the second stage, the **Multi-Attribute Ideal-Real Comparative Analysis (MAIRCA)** method was used to rank the 17 proposed projects taking into account the identified criteria. Finally, at the third stage, the projects that offered the greatest benefit to the company while satisfying budget constraints were selected using the **knapsack algorithm**. This study contributes to the existing literature by integrating novel multi-criteria decision-making approaches and optimization techniques, particularly in the context of **R&D project selection**, where empirical applications remain limited.

2. LITERATURE REVIEW

2.1. R&D project selection

The topic of R&D project selection began to gain popularity, especially in the 1950s and 1960s. Over time, as the number of models proposed in the literature has increased, user interest in these approaches has also grown. A review of studies on project selection in R&D centers reveals that a wide range of methods has been employed. According to an analysis of research articles published between 1977 and 2019 in the **ScienceDirect** and **Wiley** databases, the distribution of methods used across 86 studies on R&D project selection is illustrated in Figure 1 below (Türkmen and Topçu, 2021).

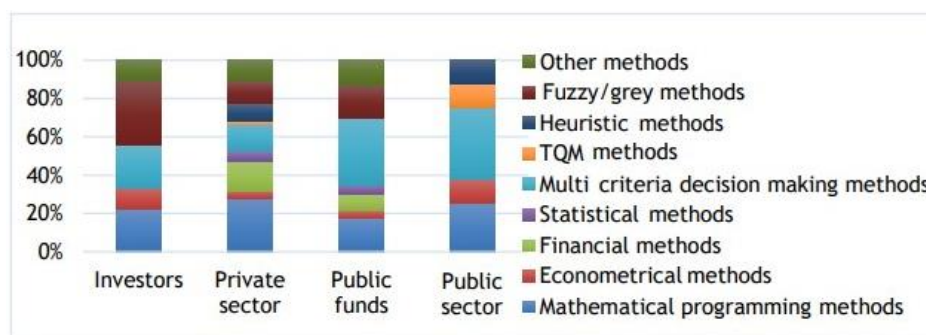


Figure 1. Distribution of methods used in R&D project selection (1977-2019)

Based on Figure 1, the methods most frequently employed across organizations are primarily Multi-Criteria Decision-Making (MCDM) techniques, followed by Mathematical Programming approaches. The most common trend involves the integration of mathematical programming models with MCDM methods (Türkmen & Topçu, 2021, p. 34). To apply MCDM techniques effectively, it is essential to define evaluation criteria that are directly related to the decision context. In the assessment of R&D project selection, a variety of criteria have been proposed in the literature. While some overlap across studies, the specific criteria often vary depending on the sector and the nature of the projects under consideration. A summary of the criteria identified in previous research is presented below in Table 1.

2.2. Multi Criteria Decision Making

There is a general structure when setting up Multi Criteria Decision Making (MCDM) problems, which involve selecting the best alternative among many criteria. Assuming

there are n alternatives and m criteria, the mathematical structure of an MCDM problem is as follows: $A = \{A_1, A_2, A_3, \dots, A_n\}$ represents the set of alternatives to be chosen to solve the problem. $C = \{C_1, C_2, C_3, \dots, C_m\}$ represents the set of specific criteria used for the assessment of A . The problem structure is visualized in the matrix in Figure 2 (Taherdoost and Madanchian, 2023, p. 79).

Table 1. Criteria Based on Sectors.

Sector	Project Name	Criteria	Reference
Petroleum industry	Project selection in oil fields development using AHP and fuzzy TOPSIS method	- Size/Complexity - Reasonableness of cost estimates - Scope adequacy - Level of detail - Duration - Technology - Location	Amiri (2010)
R&D Center	AHP-based formal system for R&D project evaluation	- Technical - Strategic - Organizational - Financial	Kumar (2004)
Development Agencies	Investment project evaluation by decision-making methodology based on type-2 fuzzy sets	- Sectoral - Economic - Institutional - Social - Political	Kılıç and Kaya (2014)
Air Defence Industry	Selection of air defence industry investment projects	- Project budget - Project duration - Dependency status - Number of employees - Contribution to domestic economy	Uçakcıoğlu and Eren (2017)
R&D Center	R&D project selection using the Analytic Network Process	- Technical - Organizational - Market based	Meade (2002)
Customer Centric Innovation	A fuzzy MCDM approach to support customer-centric innovation in virtual reality (VR) metaverse headset design	- Functionality - Materials - Comfort - Usability	Kwok and Tang (2023)
Defence Industry	R&D project selection in defence industry investment decisions	- Technological - Competitiveness - Domestic sourcing - Joint operations compliance - Effectiveness - Lead time - Threatening power - Personnel Need - Need for organizational change	Dağıstanlı (2024)
Cosmetics Industry	R&D project selection with Gray-WASPAS method	- Applicability of the project - Measures against risks - Market analysis - Strategic alignment cost - Investment payback period - Expected return	Şen (2023)

MCDM Matrix	C_1	C_2	...	C_n
A_1	x_{11}	x_{12}	...	x_{1n}
A_2	x_{21}	x_{22}	...	x_{2n}
...	...	...	x_{ij}	...
A_m	x_{m1}	x_{m2}	...	x_{mn}

Figure 2. MCDM Matrix.

In this context, x_{ij} signifies the value of alternative A_i based on C_j . The primary steps of MCDM problems begin with the definition of criteria. Main criteria, and if any, sub-criteria are identified and defined. In the next stage, the weighting of alternative resources used to address the problem, is determined. A variety of weighting methods

have been proposed and applied in the literature. In the final stage, the alternatives weighted through criteria, are ranked (Dua et al., 2024).

3. METHODOLOGY

3.1. The Full Consistency Method (FUCOM)

In facing challenges, companies make decisions by selecting among specific criteria. It is crucial for the company to analyse these criteria in detail and determine their priorities. There are many models in the literature for prioritizing criteria and calculating their weights. These models are classified depending on their application style. In this study, the FUCOM method, a novel approach, has been applied (Demir and Bircan, 2020). The FUCOM method is classified as a subjective method. However, its most notable characteristic is its attempt to minimize subjectivity by reducing deviations within the model towards zero. The major benefits of the FUCOM method are minimizing the effect of experts on the criteria, being a fast method because it requires only $(n - 1)$ criterion comparisons and being adaptable to different measurement scales, thus providing a flexible structure (Pamučar et al., 2018).

Consistency means that the deviation from full consistency (DFC) or the error value for the obtained weight vectors is minimized and it is achieved only when the mathematical consistency condition is applied. Based on the literature DFC in the range of $[0; 0,25]$ can be acceptable. The model of FUCOM method is given below by Equation 1:

$$\begin{aligned} & \text{Min } \chi \\ & \text{s.t. } \left| \frac{\omega_{j(k)}}{\omega_{j(k+1)}} - \varphi_{k/(k+1)} \right| \leq \chi, \forall j \\ & \left| \frac{\omega_{j(k)}}{\omega_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \leq \chi, \forall j \\ & \sum_{j=1}^n \omega_j = 1, \forall j \\ & \omega_j \geq 0, \forall j \end{aligned} \tag{1}$$

After the model is solved, $\omega_1, \omega_2, \dots, \omega_n$ are determined.

3.2. Fuzzy Full Consistency Method (F-FUCOM)

In classical logic, there is a clear distinction between what is true and what is false. However, as we delve into the complexities of the real world, propositions are rarely as clear-cut as they are in classical logic. Environments characterized by uncertainty and ambiguity, where such clarity is lacking, are referred to as *fuzzy*. In situations where classical logic proves inadequate, **fuzzy logic** plays a crucial role in enabling more nuanced analyses and achieving more realistic results.

The Azerbaijani scientist Lotfi Zadeh observed in 1965 that classical logic was insufficient for handling subjective or imprecise data and therefore introduced the concept of **fuzzy sets**. Although literature on fuzzy sets emerged in 1965, it initially received little attention in the Western world and even faced skepticism. However, interest in fuzzy logic began to grow in Japan and other Eastern countries during the 1970s, eventually gaining widespread acceptance (Garrido, 2018).

Humans perceive and interpret their surroundings by comparing new information with their existing understanding of the external world. Many aspects of daily life inherently reflect a fuzzy structure. For instance, when classifying people, we often use qualitative descriptors such as *young*, *middle-aged*, and *elderly*. Such classifications are inherently uncertain and cannot be represented precisely through numerical values, yet they are intuitively accepted by the human mind. As in classical logic, it is not possible to assign an exact numerical boundary to a category like *elderly* (Özan, 2010).

The **FUCOM** method evaluates alternatives using precise numerical values derived from classical logic. However, in real-life decision-making, processes are rarely so exact, they are uncertain, complex, and often involve subjective judgment. Consequently, constraining such evaluations to a single precise value can be problematic. The **Fuzzy FUCOM** method offers a more flexible and realistic representation of real-world uncertainty. Moreover, individuals often express preferences through linguistic terms such as *more important* rather than through exact numerical scales. While these linguistic expressions cannot be directly modeled using FUCOM, they can be effectively represented within the Fuzzy FUCOM framework.

Since the criteria used in this study involve subjective judgments and are open to interpretation, the **Fuzzy FUCOM** method is adopted to provide greater flexibility. This approach is particularly suitable in contexts characterized by high uncertainty, limited information, and significant human perception in decision-making (Hacısüleyman, 2019). The purpose of the Fuzzy FUCOM method is to identify the most suitable alternative among a set of options. Weighting in this process can be either objective or subjective, and it serves two main purposes: to indicate the importance of each criterion and to demonstrate its impact on the final outcome. In this method, linguistic expressions are represented by **triangular fuzzy numbers**, and the overall model structure remains consistent with that of the classical FUCOM approach.

3.3. Multi Attributive Ideal-Real Comparative Analysis (MAIRCA)

The **MAIRCA (Multi-Attributive Ideal-Real Comparative Analysis)** method is a multi-criteria decision-making (MCDM) approach introduced to the literature by Gigović et al. (2016). It facilitates the selection among alternatives by identifying the gaps between ideal and actual (empirical) rankings. The MAIRCA method is mathematically straightforward, conceptually clear, and relatively easy to apply. It can be used with both qualitative and quantitative criteria and yields reliable results even when dealing with a large number of alternatives and evaluation parameters. Moreover, comparative studies have shown that MAIRCA produces consistent and dependable outcomes relative to other MCDM methods (Yazgan and Agamyradova, 2021). The MAIRCA method consists of six main steps.

Step 1 Evaluation of alternatives: In the first step, alternatives defined by experts are evaluated based on the established criteria. The criteria may be either quantitative or qualitative. When the criteria are measurable, their real (numerical) values are used. For qualitative criteria, a standardized scoring system is applied to assess each alternative. It is essential that the decision-makers express their priorities accurately at this stage. The initial decision matrix is then constructed as shown in Figure 3 (Lukić, 2023, p. 56).

$$X = \begin{matrix} & \begin{matrix} C_1 & C_2 & \dots & C_n \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ \dots \\ A_m \end{matrix} & \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{matrix}$$

Figure 3. Initial Decision Matrix.

Step 2 Determination of P_{A_i} :

$$P_{A_i} = \frac{1}{m}; \sum_{i=1}^m P_{A_i} = 1, i = 1, 2, \dots, m \quad (2)$$

where m is the total number of alternatives and P_{A_i} represents the preference relation over the values of alternatives. Decision maker is neutral for all alternatives in this step. In this situation, P_{A_i} values are equal.

Step 3 Creation of the theoretical rating matrix (T_p): The rating matrix is created by multiplying preferences values (P_{A_i}) with criteria weight values. It is shown in Figure 4 (Lukić, 2023, p. 57).

$$T_p = \begin{matrix} & w_1 & w_2 & \cdots & w_n \\ \begin{matrix} P_{A_1} \\ P_{A_2} \\ \vdots \\ P_{A_m} \end{matrix} & \begin{bmatrix} t_{p11} & t_{p12} & \cdots & t_{p1n} \\ t_{p21} & t_{p22} & \cdots & t_{p2n} \\ \vdots & \vdots & \ddots & \vdots \\ t_{pm1} & t_{pm2} & \cdots & t_{pmn} \end{bmatrix} \end{matrix} = \begin{matrix} & w_1 & w_2 & \cdots & w_n \\ \begin{matrix} P_{A_1} \\ P_{A_2} \\ \vdots \\ P_{A_m} \end{matrix} & \begin{bmatrix} P_{A_1} \cdot w_1 & P_{A_1} \cdot w_2 & \cdots & P_{A_1} \cdot w_n \\ P_{A_2} \cdot w_1 & P_{A_2} \cdot w_2 & \cdots & P_{A_2} \cdot w_n \\ \vdots & \vdots & \ddots & \vdots \\ P_{A_m} \cdot w_1 & P_{A_m} \cdot w_2 & \cdots & P_{A_m} \cdot w_n \end{bmatrix} \end{matrix}$$

Figure 4. Theoretical Rating Matrix.

Step 4 Creation of the real rating matrix (T_r): The form of the real rating matrix is shown below in Figure 5 where n represents the total number of criteria and m shows the total number of alternatives (Lukić, 2023, p. 57).

$$T_r = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} t_{r11} & t_{r12} & \cdots & t_{r1n} \\ t_{r21} & t_{r22} & \cdots & t_{r2n} \\ \vdots & \vdots & \ddots & \vdots \\ t_{rm1} & t_{rm2} & \cdots & t_{rmn} \end{bmatrix} \end{matrix}$$

Figure 5. Real Rating Matrix.

Values in the initial decision matrix are evaluated at the following formulas in Equations 3 to 6 depending on whether the criteria are to be maximized or minimized, and the real rating matrix values are obtained. For preferred criteria that are beneficial and therefore to be maximized, the formula is

$$t_{rij} = t_{pij} \left(\frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \right) \quad (3)$$

and for cost type criteria that are to be minimized, we have the following formula

$$t_{rij} = t_{pij} \left(\frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \right) \quad (4)$$

where x_{ij} , x_i^+ and x_i^- are the elements of the initial decision matrix (X), and x_i^+ and x_i^- are defined as follows:

$$x_i^+ = \max(x_1, x_2, \dots, x_m) \quad (5)$$

$$x_i^- = \min(x_1, x_2, \dots, x_m) \quad (6)$$

Step 5 Calculation of the gap matrix (G): The total gap matrix is obtained by taking difference between theoretical rating matrix and real rating matrix as given by Equation 7.

$$g_{ij} = t_{pij} - t_{rij} \quad (7)$$

Step 6 Final gap values of alternatives (Q_i): Final gap values are obtained by summing g_{ij} values for each alternative as it is defined in the following Equation (8).

$$Q_i = \sum_{j=1}^n g_{ij}, i = 1, 2, \dots, m \quad (8)$$

where n is the total number of criteria and m is the total number of alternatives.

3.4. Knapsack Problem

Knapsack problems aim to fill a container (the *knapsack*) of limited capacity in the most optimal manner. In the basic form of the knapsack problem, n items are defined, each with a weight or volume b_j and an associated benefit or value c_j . The objective is to select a combination of items that maximizes the total benefit without exceeding the knapsack's total capacity B .

The mathematical formulation of the **0–1 knapsack problem** is expressed by Equations (9) and (10), where each item can either be included ($x_j = 1$) or excluded

($x_j = 0$). The objective function seeks to maximize the total value of the selected items while respecting the capacity constraint.

$$\text{Min } z = \sum_{j=1}^n c_j x_j \quad (9)$$

$$\text{s.t. } \sum_{j=1}^n b_j x_j \leq B \quad (10)$$

Other variants of knapsack problems are also defined in the literature under different names. However, within the scope of this study, the 0-1 knapsack problem has been used. Therefore, other models have not been extensively reviewed, for example see Berberler (2009).

4. RESULTS

This study has been conducted at the R&D center of a company operating in the durable consumer good sector. Since a specific investment budget is allocated to the center; the available resources may be insufficient to finance all proposed projects. Accordingly, this study aims to develop a systematic and quantitative framework for selecting investment projects that maximize overall organizational benefits.

The first step was to define the evaluation criteria based on expert opinions and a comprehensive review of the relevant literature, ensuring consistency with contemporary research trends. At the second step, these criteria were weighted using the Full Consistency Method (FUCOM) and its fuzzy extension, the Fuzzy FUCOM (F-FUCOM) method. Following the weighting process, project alternatives were evaluated and ranked according to the defined criteria. Finally, at the third step, the optimal set of projects was determined under three distinct scenarios to guide investment decisions within the company's budget constraints.

Four main criteria and their corresponding sub-criteria were identified, resulting in a total of nine evaluation criteria. The main criteria are Economic, Institutional, Technological, and Strategic. The selection of these criteria was based on both a comprehensive review of the literature and expert consultations. The hierarchical structure of the criteria is illustrated in Figure 6 below.

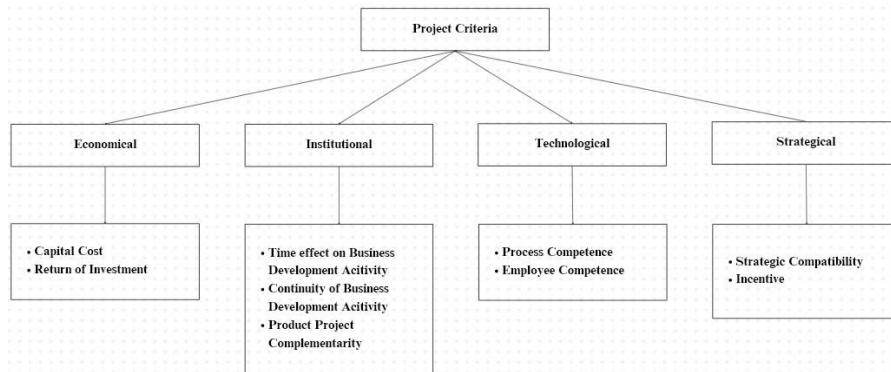


Figure 6. Project Criteria.

After defining the criteria, the Full Consistency Method (FUCOM) was applied, and two experts were asked to rank the criteria according to their relative importance. During this process, it was observed that the experts experienced some difficulty in assigning precise numerical rankings. Therefore, they were invited to express their prioritization using linguistic variables. Following the FUCOM procedure, the Fuzzy FUCOM (F-FUCOM) method was also applied in a similar manner. The results obtained from both methods are presented in Table 2 below.

When comparing the final values obtained from the Fuzzy FUCOM (F-FUCOM) and FUCOM methods, a ranking discrepancy was identified between the

criteria *Continuity of Business Development* and *Process Competence*. No differences in the importance ranking were observed among the remaining criteria. Consequently, further analysis was conducted using the FUCOM results, as this approach is less complex while still ensuring reliable outcomes. In agreement with the company's experts, it was decided to proceed with the FUCOM-derived weights.

Table 2. Final Weights of Criteria (F-FUCOM).

Symbol	Criteria	Final Weights	Rank F-FUCOM	Final Weights	Rank FUCOM
C11	Capital cost	0.11	4	0.14	4
C12	Return of investment	0.16	2	0.22	2
C21	Time effect on business development activity	0.04	8	0.04	8
C22	Continuity of business development activity	0.13	3	0.25	1
C23	Product-project complementarity	0.07	6	0.06	6
C31	Process competence	0.17	1	0.15	3
C32	Employee competence	0.07	7	0.05	7
C41	Strategic compatibility	0.09	5	0.07	5
C42	Incentive	0.03	9	0.01	9

In the second stage of the study, the project alternatives were evaluated according to the defined criteria using the MAIRCA method. The results obtained from the MAIRCA model are presented in Table 3.

Table 3. Final Values (Q_i)

Alt.	C11	C12	C21	C22	C23	C31	C32	C41	C42	Q_i	Rank
1	0.006	0.013	0.000	0.015	0.003	0.009	0.003	0.003	0.001	0.053	17
2	0.000	0.013	0.002	0.000	0.000	0.009	0.003	0.004	0.001	0.033	4
3	0.002	0.013	0.000	0.015	0.003	0.009	0.003	0.003	0.001	0.049	16
4	0.002	0.013	0.002	0.015	0.003	0.004	0.002	0.004	0.001	0.046	15
5	0.000	0.013	0.002	0.007	0.003	0.006	0.003	0.004	0.001	0.038	7
6	0.002	0.013	0.000	0.015	0.001	0.004	0.001	0.000	0.001	0.037	6
7	0.005	0.013	0.001	0.011	0.002	0.004	0.003	0.004	0.001	0.045	14
8	0.002	0.013	0.002	0.007	0.002	0.008	0.003	0.001	0.001	0.039	8
9	0.001	0.013	0.001	0.000	0.002	0.007	0.003	0.004	0.001	0.031	3
10	0.001	0.013	0.001	0.011	0.001	0.007	0.003	0.004	0.001	0.041	11
11	0.001	0.000	0.001	0.015	0.003	0.003	0.002	0.003	0.000	0.028	2
12	0.002	0.007	0.001	0.007	0.001	0.000	0.000	0.001	0.000	0.018	1
13	0.000	0.000	0.002	0.015	0.004	0.007	0.002	0.004	0.001	0.034	5
14	0.000	0.007	0.002	0.015	0.004	0.007	0.002	0.003	0.001	0.039	9
15	0.008	0.013	0.001	0.011	0.003	0.006	0.002	0.000	0.001	0.044	13
16	0.005	0.013	0.001	0.011	0.003	0.006	0.002	0.000	0.001	0.040	10
17	0.005	0.013	0.000	0.015	0.002	0.003	0.003	0.002	0.001	0.043	12

It is expected that the total gap values (Q_i) approach zero, and the alternative with the lowest gap is selected as the most favorable option. Accordingly, the first project chosen for investment is *Project 12*, followed by *Project 11* and *Project 9*. The least preferred alternative is *Project 1*.

After determining the criteria weights using the FUCOM method, the project priority rankings were obtained through the MAIRCA method. However, directly

relying on the MAIRCA-based ranking may not adequately address the company's investment decision-making process, as the company operates under a specific budget constraint. Therefore, the priority order derived from the MAIRCA method was used as an input to the knapsack algorithm. By integrating MAIRCA with the knapsack approach, both the relative importance of projects and the company's financial limitations were considered.

Within this framework, the objective was to maximize the overall benefit based on project prioritizations, using the knapsack model to achieve the best possible investment outcome. Three scenarios have been created:

- **Scenario 1:** The total available budget was considered as 500 T€. The optimal investment to be made was found as 476.5 T€, yielding a total benefit of 145. Under this scenario, all projects except *Project 1*, *Project 3*, and *Project 15* were selected for investment.
- **Scenario 2:** The available budget was reduced by 15%, to 425 T€. The total investment amounted to 423.5 T€, and the total benefit achieved was 143. In this case, all projects except *Project 1*, *Project 7*, and *Project 15* were selected.
- **Scenario 3:** A project dependency rule was introduced, based on output of MAIRCA method and stipulating that *Project 11* could not be selected without *Project 12*. With this dependency incorporated and an available budget of 500 T€, the total investment was 495.5 T€ and the total benefit 143. Under these conditions, all projects except *Project 1*, *Project 3*, *Project 4*, and *Project 7* were chosen for investment.

5. CONCLUSION

Understanding a company's characteristics and identifying its critical points are highly for effective decision-making. Therefore, this study aims to replace and improve an experience-based decision process with a quantitative, structured approach. The proposed methodology is implemented in three main stages.

In the first stage, the selection criteria were defined based on the characteristics of the R&D center, and their corresponding weights were calculated. During this process, the focus was placed specifically on project selection problems within R&D centers, distinguishing the study from general project selection approaches. Both the literature and expert opinions were used in defining the criteria. The selected criteria were found to be consistent with those frequently used in the literature, where *budget*, *technology*, and *technical* factors are among the most common. Similar studies using the criteria are shown in Table 1.

The second stage involved the application of the FUCOM method for the initial evaluation. Since fuzzy logic is effective in environments where judgments are imprecise or uncertain, the F-FUCOM method was also employed to better express uncertainty in subjective evaluations (Liu et al., 2020). The results obtained from FUCOM and F-FUCOM were compared to determine the weights of each criterion. Although some differences were observed in the weights and rankings, these variations were not significant.

In the third stage, projects were evaluated according to the defined criteria and ranked using the MAIRCA model. The use of the MAIRCA method in R&D project selection is still limited in the literature, which enhances the contribution of this study. Finally, projects were selected using the knapsack algorithm under three budget scenarios.

As a result, the company has gained the ability to adapt effectively to changing conditions. According to the FUCOM results, *Continuity of Business Development Activity* was identified as the most important criterion, while *Incentive* had the lowest weight. The MAIRCA model prioritized *Project 12* as the top investment, followed by *Project 11* and *Project 9*, while *Project 1* was the least preferred.

Using the knapsack algorithm, benefit values of 145, 143, and 143 were obtained for the three scenarios, with total investment costs of 476.5 T€, 423.5 T€, and 495.5 T€, respectively. In all scenarios, *Project 1* was not selected, which is consistent with the MAIRCA ranking. However, in Scenario 2, *Project 3* was selected instead of *Project 15*, despite *Project 15* having a higher priority in the MAIRCA results. This highlights the importance of evaluating projects under different scenarios, as varying constraints can significantly influence outcomes.

The proposed approach in this study, which integrates MCDM methods with mathematical optimization, is supported by the literature and has been demonstrated to have practical advantages. The methodology developed in this research can be applied to other R&D centers. To improve reliability, two experts were involved in the evaluation process instead of relying on a single decision-maker, and a flexible decision-support mechanism was established to enable rapid assessment under multiple scenarios. In future research, new criteria can be introduced to address emerging needs, and involving more experts can enhance the diversity of evaluations. However, careful selection of experts remains essential to maintain consistency with the study's objectives.

Beyond the specific R&D case, the comparison between FUCOM and F-FUCOM revealed no major differences, indicating that the approach can be effectively applied in complex environments. The methods require a limited number of comparisons, incorporate subjective judgments, and ensure consistency. Thus, the proposed methodology can be adapted to different sectors. The originality of this study lies in the integration of FUCOM/Fuzzy FUCOM with the MAIRCA and knapsack approaches, a combination rarely explored in the literature. This integration demonstrates their applicability in R&D project prioritization and establishes a foundation for extending the approach to other industries, provided that sector-specific criteria are appropriately defined.

Information on Plagiarism

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Ethics committee approval was not required.

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The authors' contributions to this study are equal.

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There is no conflict of interest to declare with any institution or person within the framework of the study.

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