Evaluation of R&D Projects Using Fuzzy MCDM Method

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***Abstract*— In recent years, global market competition leads companies to invest in R&D projects. Therefore, the selection of R&D projects constitutes an important part of project management in order to achieve the desired results and outputs. In this study, a hierarchical fuzzy multi-criteria decision making method was applied to determine the most suitable R&D project of a firm working in the machinery manufacturing sector in Turkey. The project selection criteria were divided into six main classes as technological, environmental, marketing, organizational, national benefits and financial issues. Related project selection methodology was applied to eight projects.**

Keywords—decision support systems, fuzzy sets, multi-criteria decision making, R&D project selection.

I. Introduction

Since the 1980's, with increasing of competitiveness and the rapid technological change, research and development is progressively seen as a significant contribution to advancement so it has been given a significant focus on government strategies due to its unique characteristics [1]. Research and development is critically important to the prolonged success of any association. Successful R&D is the difference between leading a new wave of next-generation products and a slow decline into obscurity and bankruptcy. The management of R&D endeavor is one of the most challenging tasks in any establishment. Project management is an attempt to attain more efficient utilization of resources within an establishment by getting work to flow horizontally as well as vertically. Moreover, all projects must be completed within the constraints of time, cost and performance [2].

The assessment, prioritization and selection of projects is a challenging action especially in project-oriented firms where it is needed to evaluate a set of proposals struggling for limited resources like equipment, human and budget [3]. Therefore, R&D supervisors are mostly met the problem of apportion resources of equipment, personnel, and funds to a wide range of projects. With a rapid increase in competition and restrictions of financial capabilities, the R&D project selection method that maximize the benefit of the organization has emerged as crucial factor.

Different techniques and methods have emerged for project selection process in the past decades ranging from qualitative review to quantitative mathematical programming and a plenty of studies have been published. Carlsson et al. [4] proposed fuzzy mixed integer programming model for the R&D optimal portfolio selection problem. Eilat et al. [5] presented a multi-criteria approach for evaluating R&D projects. The approach integrated the balanced scorecard (BSC) and data envelopment analysis (DEA) and developed an extended DEA model. Fang et al. [6] developed a bi-objective mixed-integer stochastic programming model to solve a mixed single-stage R&D projects and multi-stage securities portfolio selection problem. Yang and Hsieh [7] applied fuzzy Delphi multiple criteria decision-making method for six-sigma project selection. Bhattacharyya et al. [8] used a fuzzy multi-objective programming approach for decision making in the selection of R&D projects. to maximize the outcome and minimize the cost and risk involved in the problem under the constraints on resources, budget, interdependences, outcome, projects. Feng et al. [9] developed an integrated method which consists of analytic hierarchy process (AHP), scoring method and weighted geometric averaging method for collaborative R&D projects in China regarding ten criteria. Karasakal and Aker [10] proposed multiple criteria sorting methods based on data envelopment analysis (DEA) to evaluate research and development (R&D) projects. Lately, Song et al. [11] proposed an approach based on stochastic multi-criteria acceptability analysis (SMAA) to effectively manage the multi-criteria project portfolio selection and scheduling problem.

In this study, project selection with multi-criteria decision making (MCDM) is applied for a small-sized company in Turkey, which develops and produces special purpose machines with turnkey automation systems for its customers. It is a project-oriented company and has a R&D center authorized by the Ministry of Industry and Technology. The firm needs to determine a model for R&D project selection to meet the R&D center requirements and to maximize the outcomes.

The rest of the study is organized as follows. The employed fuzzy MCDM method is explained in Section 2. Section 3 illustrated the case study. Finally, conclusions are given in Section 4.

II. Hierarchical Fuzzy MCDM Approach

When a large number of performance attributes are to be considered in the evaluation process, it may be preferred to structure them in a multi-level hierarchy in order to conduct a more effective analysis. In this study, the hierarchical distance-based fuzzy MCDM algorithm introduced by Karsak and Ahiska [12] is employed for determining the most appropriate R&D project. This MCDM algorithm is based on the proximity to the ideal solution concept and which can address the problems containing both crisp and fuzzy data.

The proposed fuzzy MCDM approach can be described as follows:

***Step* 1.** Construct a committee of decision makers and define the alternatives, required selection criteria, and related sub-criteria in a hierarchical structure.

***Step* 2.** Construct the decision matrices for each decision makers that represent the importance weights of criteria and related sub-criteria, and the assessments corresponding to qualitative and quantitative sub-criteria.

***Step* 3.** Aggregate the data employing weighted average method.

***Step* 4.** Normalize the aggregated data to obtain unit-free and comparable sub-criteria values. The normalized values for the data regarding benefit-related as well as cost-related quantitative sub-criteria are calculated via a linear scale transformation as

$$y'_{ijk} = \begin{cases} \dfrac{y_{ijk} - y^-_{jk}}{y^*_{jk} - y^-_{jk}}, & k \in CB_j;\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \\ \dfrac{y^*_{jk} - y_{ijk}}{y^*_{jk} - y^-_{jk}}, & k \in CC_j;\ i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \end{cases} \quad (1)$$

where y'_{ijk} denotes the normalized value of y_{ijk}, which is the value assigned to alternative *i* with respect to the sub-criterion *k* of criterion *j*, *m* is the number of alternatives, *n* is the number of criteria, CB_j is the set of benefit-related crisp sub-criteria of criterion *j* and CC_j is the set of cost-related crisp sub-criteria of criterion *j*, $y^*_{jk} = \max_i y_{ijk}$ and $y^-_{jk} = \min_i y_{ijk}$.

***Step* 5.** Aggregate the performance ratings of alternatives at the sub-criteria level to criteria level as follows:

$$\tilde{x}_{ij} = (x_{aij}, x_{bij}, x_{cij}) = \frac{\sum_k \tilde{w}^1_{jk} \otimes \tilde{y}_{ijk}}{\sum_k \tilde{w}^1_{jk}}, \forall i, j \quad (2)$$

where $\tilde{x}_{ij}$ represents the aggregate performance rating of alternative *i* with respect to criterion *j*, $\tilde{w}^1_{jk}$ indicates the average importance weight assigned to sub-criterion *k* of criterion *j*, and $\otimes$ is the fuzzy multiplication operator.

***Step* 6.** Normalize the aggregate performance ratings at criteria level using a linear normalization procedure, which results in the best value to be equal to 1 and the worst one to be equal to 0, as follows:

$$\tilde{r}_{ij} = (r_{aij}, r_{bij}, r_{cij}) = \left(\frac{x_{aij} - x^-_{aj}}{x^*_{cj} - x^-_{aj}}, \frac{x_{bij} - x^-_{aj}}{x^*_{cj} - x^-_{aj}}, \frac{x_{cij} - x^-_{aj}}{x^*_{cj} - x^-_{aj}} \right), \forall i, j \quad (3)$$

where $x^*_{cj} = \max_i x_{cij}$, $x^-_{aj} = \min_i x_{aij}$, and $\tilde{r}_{ij}$ denotes the normalized aggregate performance rating of alternative *i* with respect to criterion *j*.

***Step* 7.** Define the ideal solution $A^* = (r^*_1, r^*_2, \ldots, r^*_n)$ and the anti-ideal solution $A^- = (r^-_1, r^-_2, \ldots, r^-_n)$, where $r^*_j = (1,1,1)$ and $r^-_j = (0,0,0)$ for $j = 1, 2, \ldots, n$.

***Step* 8.** Calculate the weighted distances from ideal solution and anti-ideal solution (D^*_i and D^-_i, respectively) for each alternative as

$$D^*_i = \sum_j 1/2 \left\{ \max(w^1_{aj}|r_{aij} - 1|, w^1_{cj}|r_{cij} - 1|) + w^1_{bj}|r_{bij} - 1| \right\}, i = 1,2,...,m \quad (4)$$

$$D^-_i = \sum_j 1/2 \left\{ \max(w^1_{aj}|r_{aij} - 0|, w^1_{cj}|r_{cij} - 0|) + w^1_{bj}|r_{bij} - 0| \right\}, i = 1,2,...,m \quad (5)$$

***Step* 9.** Calculate the proximity of the alternatives to the ideal solution, P^*_i, by considering the distances from ideal and anti-ideal solutions as

$$P^*_i = D^-_i \Big/ \left(D^*_i + D^-_i \right), i = 1,2,..., m. \quad (6)$$

***Step* 10.** Rank the alternatives according to P^*_i values in descending order. Identify the alternative with the highest P^*_i as the best alternative.

III. CASE STUDY

Hierarchical fuzzy MCDM method is adopted for R&D project selection problem for the related case. This method has been proposed since the problem includes a hierarchical structure of the criteria, uncertainty in evaluating the relative importance of criteria/sub-criteria and grading of alternative projects.

Eight projects are determined for the evaluation. The evaluation is conducted by a committee of four decision makers. Also, weights are assigned to each decision-maker regarding their position in the company. The candidate projects and decision-making team are listed in Table 1 and Table 2.

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TABLE I. THE CANDIDATE PROJECTS

No	Project Name
1	Fuse Assembly Machine
2	Hot-forging Press Machine Automation
3	Glass Shelf Assembly Machine
4	Gear Console Assembly Machine
5	Sponge Conditioning and Separation Line
6	Lever Assembly Machine
7	Clips Feeder Line
8	Sleeve Production Line

TABLE II. THE DECISION MAKER'S WEIGHTS

Position	Weight
General Manager (DM_1)	0.35
R&D Center Director (DM_2)	0.30
Design Team Leader (DM_3)	0.15
Project Manager (DM_4)	0.20

The evaluation criteria are determined by reviewing the literature as in Table 3.

TABLE III. EVALUATION CRITERIA

Selection Criteria
Technological Issues (C_1)
Innovation of technology (C_{11})
Advancement of technology (C_{12})
Key of technology (C_{13})
Patentability (C_{14})
Uniqueness of technology/product (C_{15})
Technological extendibility (C_{16})
Environmental Issues (C_2)
Safety considerations (C_{21})
Benefits for human life (C_{22})
Political factors (C_{23})
Job creation opportunity (C_{24})
The satisfaction of the employee (C_{25})
Marketing Issues (C_3)
Opportunity/probability of market success (C_{31})
Potential size of market (C_{32})
Degree of competition (C_{33})
Opportunity for new technology/market (C_{34})
Organizational Issues (C_4)
Competence and experience on similar projects (C_{41})
Knowledge/skills availability (C_{42})
Facilities availability (C_{43})
Research staff availability (C_{44})
National Advantages Issues (C_5)
Collaboration of University and Industry (C_{51})
Contribution to national economy (C_{52})
Conducting Market Research (C_{53})
Contributions to the state of knowledge (C_{54})
Financial Issues (C_6)
Investment cost (C_{61})
Outsourced benefits and services cost (C_{62})
Contribution of profitability (C_{63})
Risk for development cost (C_{64})

The decision makers utilized the linguistic scale given in Figure 1 in order to rate the alternatives and the importance of criteria and related sub-criteria.

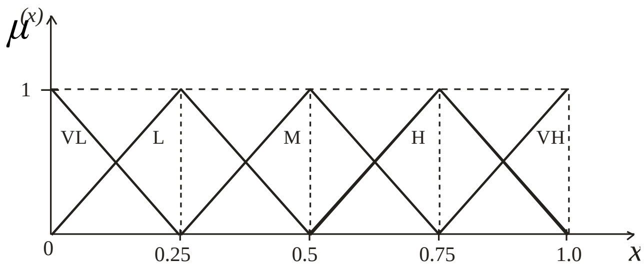

Fig. 1. A linguistic term set where VL = (0, 0, 0.25), L = (0, 0.25, 0.5), M = (0.25, 0.5, 0.75), H = (0.5, 0.75, 1), VH = (0.75, 1, 1)

The evaluation of decision makers are aggregated using the weights given in Table 2, and the aggregated data are provided in Tables 4-6. Then, the aggregated evaluations are normalized employing Eq. (1).

TABLE IV. AGGREGATED WEIGHTS OF MAIN CRITERIA

Main Criteria	Weights
1. Technological Issues	(0.61, 0.86, 1.00)
2. Environmental Issues	(0.43, 0.68, 0.93)
3. Marketing Issues	(0.31, 0.56, 0.73)
4. Organizational Issues	(0.45, 0.70, 0.95)
5. National Advantages Issues	(0.38, 0.63, 0.88)
6. Financial Issues	(0.71, 0.96, 1.00)

TABLE V. AGGREGATED WEIGHTS OF SUB CRITERIA

Sub Criteria	Fuzzy values
1.1.Innovation of technology	(0.65, 0.90, 0.95)
1.2.Advancement of technology	(0.49, 0.74, 0.95)
1.3.Key of technology	(0.40, 0.65, 0.86)
1.4.Patentability	(0.51, 0.76, 0.90)
1.5.Uniqueness of technology/product	(0.40, 0.65, 0.90)
1.6.Technological extendibility	0.50, 0.75, 1.00)
2.1.Safety considerations	(0.75, 1.00, 1.00)
2.2.Benefits for human life	(0.55, 0.80, 1.00)
2.3.Political factors	(0.00, 0.25, 0.50)
2.4.Job creation opportunity	(0.33, 0.53, 0.78)
2.5.The satisfaction of the employee	(0.45, 0.70, 0.88)
3.1.Opportunity/probability for market success	(0.48, 0.73, 0.89)
3.2.Potential size of market	(0.35, 0.60, 0.85)

3.3.Degree of competition	(0.63, 0.88, 1.00)
3.4.Opportunity for new technology/market	(0.48, 0.73, 0.89)
4.1.Competence and experience on similar projects	(0.70, 0.95, 1.00)
4.2.Knowledge/skills availability	(0.66, 0.91, 1.00)
4.3.Facilities availability	(0.66, 0.91, 1.00)
4.4.Research staff availability	(0.66, 0.91, 1.00)
5.1.Collaboration of University and Industry	(0.28, 0.53, 0.78)
5.2.Contribution to national economy	(0.50, 0.75, 1.00)
5.3.Conducting Market Research	(0.51, 0.76, 0.93)
5.4.Contributions to the state of knowledge	(0.75, 1.00, 1.00)
6.1.Inevstment Cost	(0.55, 0.80, 0.96)
6.2. Outsourced benefits and services cost	(0.14, 0.35, 0.60)
6.3. Contribution of profitability	(0.41, 0.66, 0.78)
6.4. Risk for development cost	(0.50, 0.75, 0.91)

The performance ratings of alternatives are aggregated to criteria level employing Eq. (3). Then the aggregated ratings are normalized to criteria level and the weighted distances from ideal solution and anti-ideal solution are calculated via Eqs. (4) and (5). Finally, the proximity of the alternatives to the ideal solution are computed and the alternatives are ranked according to these values as in Table 7.

TABLE VII. RANKING OF PROJECTS

Project	P_i*	Ranking
P_1	0.84	1
P_2	0.51	7
P_3	0.81	2
P_4	0.46	8
P_5	0.70	5
P_6	0.78	3
P_7	0.70	4
P_8	0.67	6

TABLE VI. AGGREGATED RATINGS OF ALTERNATIVES

Sub-Criteria	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
1.1.Innovation of Technology	(0.70, 0.95, 1.00)	(0.20, 0.45, 0.70)	(0.70, 0.95, 1.00)	(0.09, 0.29, 0.54)	(0.50, 0.75, 1.00)	(0.61, 0.86,1.00)	(0.61, 0.86,1.00)	(0.54, 0.79, 1.00)
1.2.Advancement of technology	(0.65, 0.90, 0.95)	(0.23, 0.48, 0.73)	(0.65, 0.90, 0.95)	(0.23, 0.48, 0.73)	(0.58, 0.83, 0.95)	(0.49, 0.74, 0.95)	(0.29, 0.54, 0.79)	(0.45, 0.70, 0.95)
1.3.Key of technology	(0.65, 0.90, 0.95)	(0.28, 0.53, 0.78)	(0.56, 0.81, 0.95)	(0.25, 0.50, 0.75)	(0.56, 0.81, 0.95)	(0.65, 0.90, 0.95)	(0.56, 0.81, 0.95)	(0.49, 0.74, 0.95)
1.4.Patentability	(0.60, 0.85, 0.90)	(0.00, 0.05, 0.30)	(0.44, 0.69, 0.90)	(0.00, 0.25, 0.50)	(0.56, 0.81, 0.90)	(0.48, 0.73, 0.90)	(0.60, 0.85, 0.90)	(0.40, 0.65, 0.90)
1.5.Uniqueness of technology/product	(0.60, 0.85, 0.90)	(0.09, 0.30, 0.55)	(0.44, 0.69, 0.90)	(0.00, 0.18, 0.43)	(0.60, 0.85, 0.90)	(0.53, 0.78, 0.90)	(0.19, 0.44, 0.69)	(0.40, 0.65, 0.90)
1.6.Technological extendibility	(0.70, 0.95, 1.00)	(0.40, 0.65, 0.90)	(0.50, 0.75, 1.00)	(0.18, 0.43, 0.68)	(0.58, 0.83, 1.00)	(0.50, 0.75, 1.00)	(0.61, 0.86,1.00)	(0.50, 0.75, 1.00)
2.1.Safety considerations	(0.75, 1.00, 1.00)	(0.75,1.00,1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)
2.2.Benefits for human life	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)	(0.34, 0.59, 0.84)	(0.00, 0.25, 0.50)	(0.66, 0.91, 1.00)	(0.23, 0.48, 0.73)	(0.25, 0.50, 0.75)
2.3.Political factors	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)
2.4.Job creation opportunity	(0.23, 0.48, 0.73)	(0.08, 0.33, 0.58)	(0.23, 0.48, 0.73)	(0.08, 0.33, 0.58)	(0.23, 0.48, 0.73)	(0.23, 0.48, 0.73)	(0.30, 0.55, 0.73)	(0.23, 0.48, 0.73)
2.5.The satisfaction of the employee	(0.70, 0.95, 1.00)	(0.11, 0.36, 0.61)	(0.54, 0.79, 1.00)	(0.05, 0.30, 0.55)	(0.66, 0.91, 1.00)	(0.75, 1.00, 1.00)	(0.38, 0.63, 0.88)	(0.63, 0.88, 1.00)
3.1.Opportunity/probability for market success	(0.71, 0.96, 1.00)	(0.13, 0.38, 0.63)	(0.58, 0.83, 1.00)	(0.38, 0.63, 0.88)	(0.58, 0.83, 1.00)	(0.46, 0.71, 0.96)	(0.58, 0.83, 1.00)	(0.50, 0.75, 1.00)
3.2.Potential size of market	(0.75, 1.00, 1.00)	(0.21, 0.43, 0.68)	(0.75, 1.00, 1.00)	(0.00, 0.25, 0.50)	(0.66, 0.91, 1.00)	(0.43, 0.68, 0.88)	(0.54, 0.79, 0.91)	(0.50, 0.75, 1.00)
3.3.Degree of competition	(0.75, 1.00, 1.00)	(0.38, 0.59, 0.84)	(0.71, 0.96, 1.00)	(0.36, 0.61, 0.86)	(0.75, 1.00, 1.00)	(0.71, 0.96, 1.00)	(0.66, 0.91, 1.00)	(0.71, 0.96, 1.00)
3.4.Opportunity for new technology/market	(0.75, 1.00, 1.00)	(0.35, 0.60, 0.76)	(0.75, 1.00, 1.00)	(0.13, 0.30, 0.55)	(0.71, 0.96, 1.00)	(0.66, 0.91, 1.00)	(0.75, 1.00, 1.00)	(0.54, 0.79, 1.00)
4.1.Competence and experience on similar projects	(0.75, 1.00, 1.00)	(0.21, 0.46, 0.71)	(0.71, 0.96, 1.00)	(0.00, 0.25, 0.50)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.38, 0.63, 0.88)	(0.55, 0.80, 1.00)
4.2.Knowledge/skills availability	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)
4.3.Facilities availability	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)
4.4.Research staff availability	(0.66, 0.91, 1.00)	(0.25, 0.50, 0.75)	(0.58, 0.83, 1.00)	(0.25, 0.50, 0.75)	(0.66, 0.91, 1.00)	(0.66, 0.91, 1.00)	(0.41, 0.66, 0.91)	(0.59, 0.84, 1.00)
5.1.Collaboration of University and Industry	(0.58, 0.83, 1.00)	(0.00, 0.00, 0.25)	(0.50, 0.75, 1.00)	(0.00, 0.00, 0.25)	(0.54, 0.79, 0.91)	(0.66, 0.91, 1.00)	(0.05, 0.30, 0.55)	(0.50, 0.75, 1.00)
5.2.Contribution to national economy	(0.75, 1.00, 1.00)	(0.30, 0.55, 0.80)	(0.75, 1.00, 1.00)	(0.33, 0.58, 0.83)	(0.75, 1.00, 1.00)	(0.63, 0.88,1.00)	(0.75, 1.00, 1.00)	(0.66, 0.91, 1.00)
5.3.Conducting Market Research	(0.75, 1.00, 1.00)	(0.41, 0.66, 0.91)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)	(0.58, 0.83, 1.00)
5.4.Contributions to the state of knowledge	(0.75, 1.00, 1.00)	(0.24, 0.49, 0.70)	(0.70, 0.95, 1.00)	(0.16, 0.41, 0.63)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	(0.45, 0.70, 0.91)	(0.70, 0.95, 1.00)
6.1.Inevstment Cost	(450, 530,550)	(420, 450, 500)	(460, 480, 510)	(150, 158, 160)	(1400, 1500, 1700)	(720, 758, 800)	(360, 390, 410)	(1200, 1300, 1500)
6.2. Outsourced benefits and services cost	(20, 25, 30)	(10, 13, 15)	(20, 25, 30)	(5, 8, 10)	(45, 56, 60)	(15, 18, 20)	(10, 12, 15)	(40, 44, 50)
6.3. Contribution of profitability	(0.66, 0.91, 1.00)	(0.28, 0.53, 0.78)	(0.66, 0.91, 1.00)	(0.19, 0.33, 0.58)	(0.66, 0.91, 1.00)	(0.66, 0.91, 1.00)	(0.66, 0.91, 1.00)	(0.50, 0.75, 1.00)
6.4. Risk for development cost	(0.59, 0.84, 1.00)	(0.09, 0.30, 0.55)	(0.54, 0.79, 1.00)	(0.00, 0.16, 0.41)	(0.66, 0.91, 1.00)	(0.55, 0.80, 1.00)	(0.21, 0.46, 0.71)	(0.54, 0.79, 1.00)

According to the results of the analysis, Fuse Assembly Machine project is identified as the most suitable project, which is followed by Glass Shelf Assembly Machine project. Hot-forging Press Machine Automation project and Gear Console Assembly Machine project are not suitable projects for the case company.

IV. Conclusion

Identifying the most appropriate project that match up with the organization's goals is getting much more importance under restricted resources. Therefore, R&D project selection is a challenging process for many decision-makers since it includes evaluation of a wide range of factors, including economic, technical strategic etc. It is also a complex procedure with a characteristic of multi steps, a group of decision-maker who have diverse ideas and experiences, multiple and contradictory objectives, imprecision in forecasting future achievement and high risk in projects.

In this study, a hierarchical fuzzy MCDM method is employed to select the most suitable R&D project in a company. Selection criteria are determined by means of literature. A hierarchical structure for criteria including 6 main criteria and 27 sub-criteria were decided. 4 decision-makers and 8 projects took part for selection process. The suggested methodology can be applied for further evaluation of other R&D projects in the company. This technique will lead a scientific way, which corresponds to needs in the R&D center to determine the most appropriate alternative. Future researches might focus on employing an analytical technique to determine the weights of the decision makers.

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References

[1] G. Fernandes, S. Moreira, M. Araújo, E. B. Pinto, and R. J. Machado, "Project management practices for collaborative university-industry R&D: A hybrid approach," *Procedia Computer Science*, vol. 138, pp. 805-814, 2018.

[2] H. Kerzner, "The R&D project manager," *Project Management Quarterly*, vol. 12, pp. 20-24, 1981.

[3] M. Toloo and M. Mirbolouki, "A new project selection method using data envelopment analysis," Computers and Industrial Engineering, vol. 138, 106119, 2019.

[4] C. Carlsson, R. Fullér, M. Heikkilä, and P. Majlender, "A fuzzy approach to R&D project portfolio selection," International Journal of Approximate Reasoning, vol. 44(2), pp. 93105, 2007.

[5] H. Eilat, B. Golany, and A. Shtub, "R&D project evaluation: An integrated DEA and balanced scorecard approach," Omega, vol. 36(5), pp. 895-912, 2008.

[6] Y. Fang, L. Chen, and M. Fukushima, "A mixed R&D projects and securities portfolio selection model," European Journal of Operational Research, vol. 185(2), pp. 700-715, 2008.

[7] T. Yang and C. H. Hsieh, "Six-Sigma project selection using national quality award criteria and Delphi fuzzy multiple criteria decision-making method," Expert Systems with Applications, vol. 36(4), pp. 7594-7603, 2009.

[8] R. Bhattacharyya, P. Kumar, and S. Kar, "Fuzzy R&D portfolio selection of interdependent projects," Computers and Mathematics with Applications, vol. 62(10), pp. 3857-3870, 2011.

[9] B. Feng, J. Ma, and Z. P. Fan, "An integrated method for collaborative R&D project selection: Supporting innovative research teams," Expert Systems with Applications, vol. 38(5), pp. 5532-5543, 2011.

[10] E. Karasakal and P. Aker, "A multicriteria sorting approach based on data envelopment analysis for R&D project selection problem," Omega, vol. 73, pp. 79-92, 2017.

[11] S. Song, F. Yang, and Q. Xia, "Multi-criteria project portfolio selection and scheduling problem based on acceptability analysis," Computers and Industrial Engineering, vol. 135, pp. 793-799, 2019.

[12] E. E. Karsak and S. S. Ahiska, "Fuzzy Multi-Criteria Decision Making Approach for Transport Projects Evaluation in Istanbul," Lecture Notes in Computer Science, vol. 3483, pp. 301-311, 2005.

[13] *Science: International Multiconference of Engineers and Computer Scientist 2010*, pp. 1–6.