**Research Paper**
Academic Platform Journal of Engineering and Smart Systems (APJESS) 11(1), 1-10, 2023
ISSN: 2822-2385
Received: 16-Apr-2022 Accepted: 04-Oct-2022
https://doi.org/10.21541/apjess.1104601

# An Integrated Fuzzy MCDM Method for the Evaluation of R&D Projects

*[1]Mehtap DURSUN, [2]Melike KILIÇ

[1] Decision Analysis Research and Application Center, Galatasaray University, İstanbul, Türkiye, mdursun@gsu.edu.tr
[2] Decision Analysis Research and Application Center, Galatasaray University, İstanbul, Türkiye, melikegsu88@yahoo.com

**Abstract**

Research and development (R&D) activities are essential to guarantee continuity of firms, meet customer requirements and keep ahead in competition. R&D project selection constitutes a significant part of project management in order to achieve the desired results and outputs. In this study, an integrated fuzzy multi-criteria group decision making approach is developed for R&D project selection. The problem includes a hierarchical structure of the criteria, uncertainty in evaluating the relative importance of criteria/sub-criteria and rating of candidate projects. The method employs the ordered weighted average (OWA) operator as the aggregation operator, which helps to fully reflect the real behavior of the decision makers in group decision making problems. Fuzzy integral method, which does not require the assumption of the mutual independence of criteria, is used to rank the alternatives. The case study is conducted in a small-sized company in Turkey, which designs and produces special purpose machines. A R&D project selection model is developed to maximize the desired outputs. The results of the analysis show that technological, environmental, marketing, organizational, national and financial issues should be considered simultaneously in the evaluation process. The proposed method is shown to be efficient, generalizable and practical and it has several significant merits compared to the other methods.

***Keywords:*** Decision support systems; Fuzzy integral; Hierarchical decision making; OWA; R&D project selection.

## 1. INTRODUCTION

In recent years, global competitive environment leads many organizations to venture in research and development (R&D) activities since outstanding R&D activities are essential in order to guarantee continuity of firms, meet customer requirements and keeping ahead in competition. Consequently, the selection of R&D projects has become one of the most important investment decisions in the success of companies. R&D is always purposed to new discoveries, proceeding from hypotheses, original notions and their judgement. R&D is predominantly ambiguous regarding its ultimate results, the required period and required resources to accomplish it. Considering these issues, the management of R&D projects is one of compelling tasks in any establishment. Therefore, each decision maker who designated limited resources to a group of potential projects face to evaluate the potential rate of an R&D project in an organization.

The assessment, prioritizing, and selection of projects is a prospering action in project-oriented firms where limited resources (such as human, budget and equipment etc.) are struggled to be evaluated for a group of alternatives. 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. Project selection decisions are elaborate, due to uncertainness of data, technology dynamics, market, and long delivery time for R&D. Moreover, interdependency between organization resources and complicated projects make project decisions much more problematic. Inadequate R&D project selection may result as a negative affect significantly on corporations for many years [1].

The evaluation of R&D project alternatives, which needs to consider multiple conflicting criteria with the involvement of a group of experts, is an important multi-criteria group decision making problem. In classical multi-criteria decision making (MCDM) methods, the ratings and the weights of the criteria are assumed to be known precisely. In general, crisp data are not sufficient to model real-life situations, which involve imprecision and vagueness. Moreover, if the number of performance attributes increases in the evaluation process, constructing a multi-level hierarchical structure of the criteria is preferred to conduct more effective analysis. Hierarchical decision of the R&D project selection provides an efficient analysis enabling the mind to cope with diversity.

In group decision making problems, the comprehension, analysis and support of the process become increasingly difficult since each decision maker have his or her own idea on the problem. In retrospect, the decision process is most valuable in that it enables the group to identify and better appreciate the differences and similarities of their judgments [2]. For this type of problem, in order to fully reflect the real behavior of the group, a final decision should be made on significant level of consensus. Therefore, aggregation of expert opinions is key to properly conduct the evaluation process.

In this study, ordered weighted average (OWA) integrated fuzzy integral method is used for R&D project selection in a small-sized company in Turkey, which designs and produces special purpose machines for its customers from different industries including white goods, automotive, aerospace sectors. It is project-oriented company and has a R&D center authorized by the Ministry of Industry and Technology of Turkey. The ministry provides tax and R&D expense incentives for the firm for R&D centers, so they expect from the firm to make R&D activities and contribute to national R&D aims. Within this framework, the related company is forced to increase its R&D level to meet expectation and maintain sustainability of R&D center. Therefore, the firm needs to determine a model for R&D project selection with multi-criteria to meet both the R&D center requirements and to maximize the outcomes.

The advantages of this study can be summarized as follows. First, the method is a group decision making processes, which enable the group to identify and better appreciate the differences and similarities of their judgments. Second, the employed approach can handle evaluation criteria that are structured in multi-level hierarchies. Third, the methodology is apt to incorporate imprecise data into the analysis using fuzzy set theory. Fourth, it employs the OWA operator as the aggregation operator. OWA operator differs from the classical weighted average in that coefficients are not associated directly with a particular attribute but rather with an ordered position. It encompasses several operators since it can implement different aggregation rules by changing the order weights. Finally, the proposed approach does not employ fuzzy number ranking methods that can produce inconsistent results or even rankings contrary to intuition while comparing alternatives. Moreover, the proposed methodology does not require the assumption of the mutual independence of criteria. Considering the above-mentioned merits, proposed decision making framework is apt to conduct robust evaluation of the R&D project alternatives.
The rest of the study is organized as follows. Literature review part is provided in Section 2. Section 3 explains materials and methods. The application of the methodology to R&D project evaluation problem is illustrated in Section 4. Section 5 gives managerial implications and discussions. Finally, conclusions are provided in the last section.

## 2. LITERATURE REVIEW

In the literature, different techniques and methods have emerged for project assessment process varying from qualitative review to quantitative techniques and a plenty of studies have been published. Henriksen and Traynor [3] classify R&D project selection methods as rating, programming, decision analysis, economic models, artificial intelligence, interactive methods, portfolio optimization, and unconstructed studies.

Bhattacharyya et al. [4] used a fuzzy multi-objective programming method to decide the best alternative among candidate R&D projects to maximize outcomes and minimize cost and risk considering the limitations on resources, budget and interdependencies. Feng et al. [5] developed an integrated method which consists of weighted geometric averaging, analytic hierarchy process (AHP), and scoring methods for collaborative R&D projects in China regarding ten criteria. Khalili-Damghania and Sadi-Nezhad [6] improved decision support system for multi-objective project selection problem. Khalili-Damghania and Sadi-Nezhad [7] also offered a hybrid fuzzy multiple criteria group decision making method under six main criteria for the project selection problem. Hassanzadeh et al. [8] applied a multi-objective binary integer programming for R&D project portfolio selection and robust optimization is executed to handle imprecision. Bhattacharyya [1] introduced R&D project portfolio selection as a grey theory based multiple attribute decision making issue.

Arratia et al. [9] presented mixed-integer linear programming for project portfolio selection. Cluzel et al. [10] adapted eco-innovation technique for R&D project portfolio selection in industries which eco-design prerequisites are favorably particular. Hosseini et al. [11] applied different project delivery method (PDM) to decide the most appropriate alternative regarding different selection criteria. Karasakal and Aker [12] executed multiple criteria sorting methods based on DEA to evaluate R&D projects. Jafarzadeh et al. [13] applied combination of fuzzy quality function deployment (QFD) and data envelopment analysis (DEA) for project portfolio selection regarding three significant constituents. Rad and Rowzan [14] purposed two-stage MO-PSO with TOPSIS for select project portfolio selection. Song et al. [15] proposed stochastic multi-criteria acceptability analysis (SMAA) to evaluate the multi-criteria project portfolio selection and scheduling problem. Liu et al. [16] developed the data-driven evidential reasoning rule-based model for project selection to gain verification from decision makers' evaluations as registered in previous datasets.

More recently, Binici and Aksakal [17] employed utility additive method for the evaluation of R&D projects. Mohagheghi et al. [18] develop and apply a novel Pythagorean fuzzy sets approach for construction project selection. Liu et al. [19] investigated a novel risk-based decision model to address the uncertainty and risk in the R&D project selection for a medical device company.

Although previously reported studies developed approaches for project selection process, further studies are necessary that considers a hierarchy of evaluation criteria and their related sub-criteria and also that does not require the assumption of the mutual independence of criteria. Moreover, aggregation of decision makers' opinions is crucial to properly conduct the evaluation process in the presence of multiple decision-makers, each one of them having his or her own viewpoint regarding the way the problem should be handled and the decision to be made. In this study, OWA integrated fuzzy integral method is proposed for R&D project selection problem. The proposed approach manages evaluation criteria that are structured in multi-level hierarchies and it employs the OWA operator as the aggregation operator, which helps to fully reflect the real behavior of the decision makers in group decision making problems.

## 3. MATERIALS AND METHODS

### 3.1. Ordered weighted average

One of key points in multi-criteria issues is aggregation of scorings, which obtained from decision makers, to gain an overall assessment for alternatives. Aggregation is simply described as the procedure of unifying a number of scorings into one representative score by means of an aggregation operator to acquire a universal value. In MCDM problems, each decision maker possesses her/his idea and might have diverse knowledge about alternatives. Considering these situations, aggregation methodologies are essential to cope with the process to actualize the overall characteristic of group decision making [20].

Various aggregation techniques have been examined to handle multiplicity characteristics in group decision making. In this paper, the OWA operator is utilized to aggregate decision-makers' assessments. The OWA operator was initially suggested by Yager [21]. It enables an aggregation between the "and", which needs all the criteria to be fulfilled; and the "or", which needs at least one of the criteria is fulfilled. Coefficients in this operator are directly related to an ordered arrangement rather than specific attribute. It can apply several aggregation rules by altering the order weights. The concept of OWA can be described as below [22].

Let $F = \{a_1, a_2, \dots, a_n\}$ be a group of values aggregated. OWA operator $F$ is stated as:

$$F\{a_1, a_2, \dots, a_n\} = \boldsymbol{w}\boldsymbol{b}^{\boldsymbol{T}} = \sum_{j=1}^{n} w_j b_j \quad (1)$$

$\boldsymbol{w} = (w_1, w_2, \dots, w_n)$ is a weighting vector where $w_i \in [0,1]$ and $\sum_{i=1}^{n} w_i = 1$, $\mathbf{b}$ is the related value vector which is ordered from the biggest one to the smallest one.

The characteristic of the OWA operator is that $a_i$ is not related with a specific weight $w_i$, but a weight $w_i$ is related with an ordered arrangement of $a_n$ [22]. Determining weights of OWA operator is a vital issue to implement it for decision making process. Weights of OWA operator are computed by means of fuzzy linguistic quantifiers as [23]

$$w_i = Q\left({i}/{n}\right) - Q\left({(i-1)}/{n}\right), \ i = 1, \dots, n \quad (2)$$

A non-decreasing relative quantifier $Q$ is stated by [23]

$$Q(y) = \begin{cases} 0, & y < a \\ \frac{y-a}{b-a}, & a \le y \le b \\ 1, & y > b \end{cases} \quad (3)$$

Some non-decreasing relative quantifiers are classified by terms "as many as possible", "most" and "at least half" with parameters ($a$,$b$) provided as (0.5, 1), 0.3, 0.8) and (0, 0.5), respectively. Since quantifiers have the ability of summarizing the properties of a class of objects without enumerating them, linguistic quantification is a very important topic in the field of knowledge representation and reasoning. Quantifiers in natural languages are usually vague in some sense. It is clear that two-valued logic is not suited to cope with vague quantifiers. There has been, therefore, increasing interest about logical treatment of quantifiers in human languages in fuzzy logic community [24].

### 3.2. Fuzzy measures and fuzzy integral

In many real-world problems, most criteria can have interdependent or interacting structure. This state makes their assessment complicated by additive measures precisely. Therefore, fuzzy integral models with $\lambda$-measure have been proposed for a better assessment of human subjectivity [25].

Fuzzy measures and integrals were firstly introduced by Choquet [26], in his paper "Theory of Capacities". In the related study, he proposed the usage of non-additive measures. The theory of fuzzy measures and theory of fuzzy set are well unified in a way that the fuzzy integral is an adequate instrument to aggregate the values of membership functions of fuzzy sets. Later, Sugeno [27] developed further Choquet's ideas. Sugeno offered two kinds of aggregation operators: one is named as fuzzy discrete Choquet integral and the other one is named as fuzzy discrete Sugeno integral. Outcome of aggregation executing Choquet integral depends on the value of each criterion while Sugeno integral is utilized to aggregate for the outcome depends on criteria rating on ordered scale aggregation. Therefore, the Sugeno integral is more suitable for qualitative criteria aggregation whereas the Choquet integral is more adequate for quantitative criteria aggregation [27].

The fuzzy integral regards the objective assessment provided by each information source ($h$-function) and each subset of these sources (by favor of fuzzy measure) in decision making procedure. This integrates information source and the value of these sources according to the decision. This fusion enables to tackle the uncertainty related with the procedure of emerging and processing information [28].

Basic definitions for fuzzy integral are presented as below.

***Definition 1.*** Let $X$ be a group of information sources. $g$ fuzzy measure is described on the power set of $X$ with range [0,1], that satisfies below properties [28]:

(1) $g(\emptyset) = 0$ and $g(X) = 1$
(2) $g(A) \le g(B)\ if\ A \subseteq B$
(3) If $\{A_i\}$ is an increasing sequence of subsets of $X$, then $\lim_{i\to\infty} g(A_i) = g(\bigcup_{i=1}^{\infty} A_i)$

A fuzzy measure $g$ is called as Sugeno measure ($g_\lambda$-fuzzy measure), if it also satisfies below property:

(4) For all $A, B \subseteq X$ with $A \cap B = \emptyset$, $g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B)$ where $\lambda > -1$

***Definition 2.*** Think about the group of information sources and let $g^i = g(\{x_i\})$. The $x_i \rightarrow g^i$ mapping is called as a fuzzy density function. $g^i$, the fuzzy density value is represented as the importance of each information source $x_i$ [10].

The value of $\lambda$ for any Sugeno fuzzy measure can be determined by solving following equation [28]:

$$1 + \lambda = \prod_{i=1}^{n} (1 + \lambda g^i) \tag{4}$$

The fuzzy integral is described as:

$$\int_A h(x) o g(.) = \sup_{E \subseteq X} \left[ min \left( \min_{x \in E} h(x), g(A \cap E) \right) \right] = \sup_{\alpha \in [0,1]} [min(\alpha, g(A \cap F_\alpha)] \tag{5}$$

where $F_\alpha = \{x \mathrm{I} h(x) \geq \alpha\}$.

Assume that $h(x_1) \geq h(x_2) \geq \cdots \geq h(x_n)$ for a finite state. Then the fuzzy integral can be indicated as below

$$e = max_{i=1}^{n} [\min ((h(x_i), g(A_i))], \tag{6}$$

where $A_i = \{x_1, \ldots . x_i\}$

The value of $g(A_i)$ can be iteratively defined as

$$g(A_1) = g(\{x_1\}) \tag{7}$$

$$g(A_i) = g^i + g(A_{i-1}) + \lambda g^i g(A_{i-1}), \qquad \text{for } 1 < i \leq n$$

### 3.3. Employed decision methodology

The process of the employed method, which is illustrated in Figure 1, can be summarized as below.

***Step 1.*** Build a team of decision-makers. Establish the alternates, decision criteria, and associated sub-criteria in a hierarchy.

***Step 2.*** Structure decision matrices that specifies the scorings of alternate $i$ according to sub-criterion $k$ of criterion $j$, importance value of sub-criterion $k$ of criterion $j$, and importance value of criterion $j$ for the $l^{th}$ decision-maker, respectively**.**

***Step 3.*** Calculate the OWA weights of each decision maker. In this study quantifier “most” is employed as decision strategy.

***Step 4.*** Find the aggregated fuzzy evaluations of alternatives according to sub-criteria ($\tilde{x}_{ijk}$), the aggregated fuzzy importance weights of sub-criteria ($\tilde{w}_{jk}$), and the aggregated fuzzy importance weights of sub-criteria ($\tilde{w}_j$).

***Step 5.*** Unit-free and comparable sub-criteria values are attained by normalization of the aggregated decision matrix. The normalized values for the data are computed by means of equation (8) taking into account benefit-related sub-criteria ($CB_j$) as well as cost-related sub-criteria ($CC_j$).

$$\tilde{r}_{ijk} = \begin{cases} \left( \dfrac{x_{ijk}^1 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{ijk}^2 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{ijk}^3 - x_{jk}^-}{x_{jk}^* - x_{jk}^-} \right), k \in CB_j \\ \left( \dfrac{x_{jk}^* - x_{ijk}^3}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{jk}^* - x_{ijk}^2}{x_{jk}^* - x_{jk}^-}, \dfrac{x_{jk}^* - x_{ijk}^1}{x_{jk}^* - x_{jk}^-} \right), k \in CC_j \end{cases} \tag{8}$$

In equation (8), $\tilde{r}_{ijk}$ represents the normalized value of $\tilde{x}_{ijk}$, $m$ is the number of alternates, $n$ is the number of criteria, $x_{jk}^* = max_i x_{ijk}^3$ and $x_{jk}^- = min_i x_{ijk}^1$. The greater value is much preferred state for benefit-related sub-criteria, whereas the greater value is less preferred state for cost-related sub-criteria.

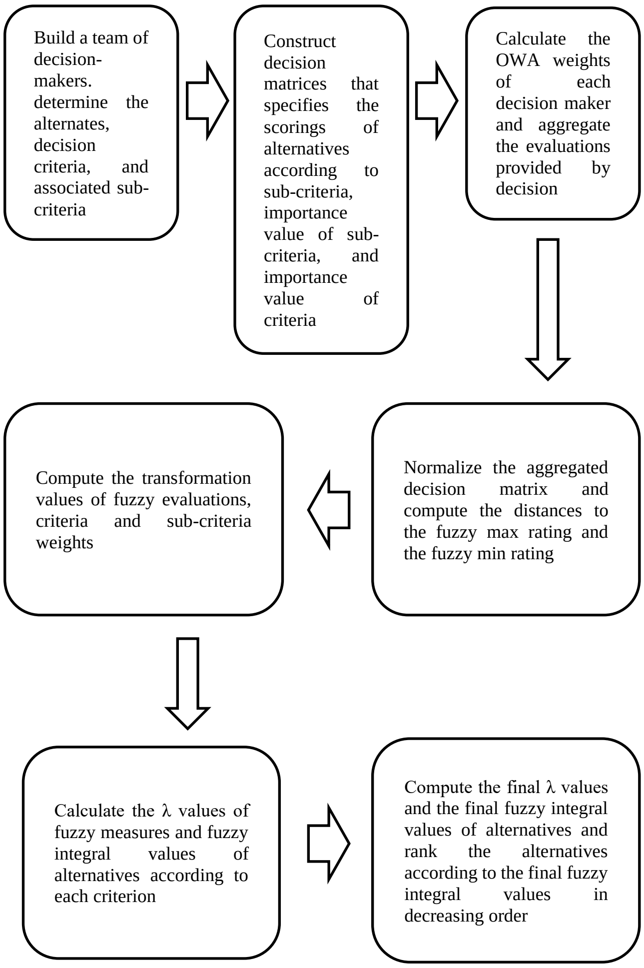


**Figure 1.** Illustration of the proposed method

***Step 6.*** The fuzzy max rating, $\tilde{P}^*$ (1,1,1), and the fuzzy min rating, $\tilde{P}^-$ (0,0,0), are defined. Then, the distances of the criteria weight and related sub-criteria weight, and the fuzzy ratings to the fuzzy max rating and the fuzzy min rating are calculated using Eq. (9).

$$d_v(\tilde{A}, \tilde{B}) = 0.5\{max(|a_1 - b_1|, |a_3 - b_3|) + |a_2 - b_2|\} \tag{9}$$

***Step 7.*** The transformation values of fuzzy weights of entire sub-criteria and criteria are computed as

$$RW_{jk} = \frac{wd_{jk}^-}{\left(wd_{jk}^- + wd_{jk}^*\right)} \quad (10)$$

$$RW_j = \frac{wd_j^-}{\left(wd_j^- + wd_j^*\right)} \quad (11)$$

where $wd_j^*$, $wd_{jk}^*$, $wd_j^-$ and $wd_{jk}^-$ represent the distances of the criteria weight and related sub-criteria weight to the fuzzy max rating and the fuzzy min rating, respectively.

***Step 8.*** The transformation values of all normalize fuzzy evaluations are computed.

$$RI_{ijk} = \frac{d_{ijk}^-}{\left(d_{ijk}^- + d_{ijk}^*\right)} \quad (12)$$

where $d_{ijk}^*$ and $d_{ijk}^-$ represent the distances of the fuzzy ratings to the fuzzy max rating and the fuzzy min rating, respectively.

***Step 9.*** $\lambda$ values of fuzzy measures and fuzzy integral values of whole options according to each criterion are calculated with the help of using Equation (4)-(7). The $h$ function is the transformation values of normalized fuzzy evaluations $RI_{ijk}$ and $g(A_1) = g^1 = RW_1$.

***Step 10.*** The final $\lambda$ values and the final fuzzy integral values of options are computed. The options are ranked with respect to the final fuzzy integral values in decreasing order.

## 4. CASE STUDY

In this study, OWA integrated fuzzy integral method is used for R&D project selection in a small-sized company in Turkey, which designs and produces special purpose machines for its customers from different industries including white goods, automotive, aerospace sectors. The problem includes a hierarchical structure of the criteria, uncertainty in evaluating the relative importance of criteria/sub-criteria and rating of candidate projects.

**Table 1.** The candidate projects

| No | Project Name |
|---|---|
| $P_1$ | Fuse Assembly Machine |
| $P_2$ | Hot-forging Press Machine Automation |
| $P_3$ | Glass Shelf Assembly Machine |
| $P_4$ | Gear Console Assembly Machine |
| $P_5$ | Sponge Conditioning and Separation Line |
| $P_6$ | Lever Assembly Machine |
| $P_7$ | Clips Feeder Line |
| $P_8$ | Sleeve Production Line |

The company has eight candidate R&D projects as explained in Table 1.

The evaluation criteria and sub-criteria are derived from literature and experts' opinions as in Table 2. To provide a better understanding of project selection criteria, they are categorized as 27 sub-criteria which are aggregated into six major criteria.

**Table 2.** R&D project selection criteria

| Selection Criteria |
|---|
| Technological Issues ($C_1$) ([29], [30]) |
| 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 ($C_2$) ( [30], [31], [32]) |
| 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 ($C_3$) ( [30], [31]) |
| 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 ($C_4$) ([31]) |
| 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 ($C_5$) ([30]) |
| 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 ($C_6$) ( [29], [33]) |
| Investment cost ($C_{61}$) |
| Outsourced benefits and services cost ($C_{62}$) |
| Contribution of profitability ($C_{63}$) |
| Risk for development cost ($C_{64}$) |

The evaluation is conducted by a committee of four decision makers that includes general manager, R&D center director, design team leader and project manager. The decision makers scored alternatives with respect to criteria and sub-criteria by using the linguistic scale given in Figure 2.

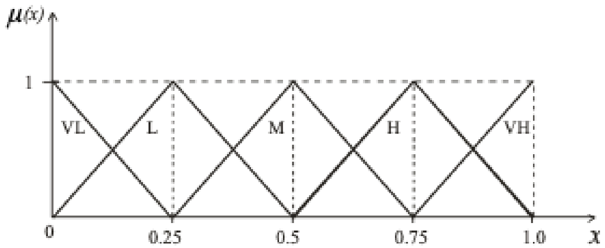


**Figure 2.** Fuzzy linguistic term set [23]

The obtained evaluations are aggregated by using OWA operator and the weights of OWA operator are calculated by employing the non-decreasing relative quantifier $Q$ stated in Equations 2 and 3 as **w** = (0.0, 0.4, 0.5, 0.1). The results are given in Tables 3 and 4.

The aggregated values are normalized by using Equation 8. The fuzzy max rating, $\tilde{P}^*$ (1,1,1), and the fuzzy min rating, $\tilde{P}^-$ (0,0,0), are defined. Then, the distances, are calculated regarding the Equation 9. The transformation values of fuzzy weights of criteria and sub-criteria are calculated by using Equation 10 and 11. The results are listed in Table 5.

**Table 3.** The aggregated ratings of projects according to sub-criteria

| Sub-Criterion | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ | $P_7$ | $P_8$ |
|---|---|---|---|---|---|---|---|---|
| $C_{11}$ | (0.725,0.975,1.000) | (0.225,0.475,0.725) | (0.725,0.975,1.000) | (0.000,0.225,0.475) | (0.500,0.750,1.000) | (0.600,0.850,1.000) | (0.600,0.850,1.000) | (0.500,0.750,1.000) |
| $C_{12}$ | (0.700,0.950,0.975) | (0.100,0.350,0.600) | (0.700,0.950,0.975) | (0.100,0.350,0.600) | (0.575,0.825,0.975) | (0.475,0.725,0.975) | (0.250,0.500,0.750) | (0.475,0.725,0.975) |
| $C_{13}$ | (0.700,0.950,0.975) | (0.325,0.575,0.825) | (0.575,0.825,0.975) | (0.250,0.500,0.750) | (0.575,0.825,0.975) | (0.700,0.950,0.975) | (0.575,0.825,0.975) | (0.475,0.725,0.975) |
| $C_{14}$ | (0.675,0.925,0.950) | (0.000,0.025,0.275) | (0.450,0.700,0.950) | (0.000,0.250,0.500) | (0.550,0.800,0.950) | (0.450,0.700,0.950) | (0.675,0.925,0.950) | (0.450,0.700,0.950) |
| $C_{15}$ | (0.675,0.925,0.950) | (0.000,0.225,0.475) | (0.450,0.700,0.950) | (0.000,0.225,0.475) | (0.675,0.925,0.950) | (0.550,0.800,0.950) | (0.100,0.350,0.600) | (0.450,0.700,0.950) |
| $C_{16}$ | (0.725,0.975,1.000) | (0.450,0.700,0.950) | (0.500,0.750,1.000) | (0.225,0.475,0.725) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.600,0.850,1.000) | (0.500,0.750,1.000) |
| $C_{21}$ | (0.750,1.000,1.000) | (0.750,1.000,1.000) | (0.750,1.000,1.000) | (0.750,1.000,1.000) | (0.750,1.000,1.000) | (0.750,1.000,1.000) | (0.750,1.000,1.000) | (0.750,1.000,1.000) |
| $C_{22}$ | (0.750,1.000,1.000) | (0.500,0.750,1.000) | (0.750,1.000,1.000) | (0.350,0.600,0.850) | (0.000,0.250,0.500) | (0.725,0.975,1.000) | (0.100,0.350,0.600) | (0.325,0.575,0.825) |
| $C_{23}$ | (0.100,0.350,0.600) | (0.100,0.350,0.600) | (0.100,0.350,0.600) | (0.100,0.350,0.600) | (0.100,0.350,0.600) | (0.100,0.350,0.600) | (0.100,0.350,0.600) | (0.100,0.350,0.600) |
| $C_{24}$ | (0.200,0.450,0.700) | (0.000,0.250,0.500) | (0.200,0.450,0.700) | (0.000,0.250,0.500) | (0.200,0.450,0.700) | (0.200,0.450,0.700) | (0.200,0.450,0.700) | (0.200,0.450,0.700) |
| $C_{25}$ | (0.725,0.975,1.000) | (0.100,0.350,0.600) | (0.500,0.750,1.000) | (0.000,0.250,0.500) | (0.600,0.850,1.000) | (0.750,1.000,1.000) | (0.350,0.600,0.850) | (0.600,0.850,1.000) |
| $C_{31}$ | (0.725,0.975,1.000) | (0.100,0.350,0.600) | (0.500,0.750,1.000) | (0.350,0.600,0.850) | (0.500,0.750,1.000) | (0.475,0.725,0.975) | (0.500,0.750,1.000) | (0.500,0.750,1.000) |
| $C_{32}$ | (0.750,1.000,1.000) | (0.225,0.450,0.700) | (0.750,1.000,1.000) | (0.000,0.250,0.500) | (0.725,0.975,1.000) | (0.350,0.600,0.850) | (0.575,0.825,0.975) | (0.500,0.750,1.000) |
| $C_{33}$ | (0.750,1.000,1.000) | (0.325,0.550,0.800) | (0.725,0.975,1.000) | (0.325,0.575,0.825) | (0.750,1.000,1.000) | (0.725,0.975,1.000) | (0.725,0.975,1.000) | (0.725,0.975,1.000) |
| $C_{34}$ | (0.750,1.000,1.000) | (0.225,0.475,0.725) | (0.750,1.000,1.000) | (0.100,0.325,0.575) | (0.725,0.975,1.000) | (0.725,0.975,1.000) | (0.750,1.000,1.000) | (0.500,0.750,1.000) |
| $C_{41}$ | (0.750,1.000,1.000) | (0.225,0.475,0.725) | (0.725,0.975,1.000) | (0.000,0.250,0.500) | (0.750,1.000,1.000) | (0.750,1.000,1.000) | (0.350,0.600,0.850) | (0.500,0.750,1.000) |
| $C_{42}$ | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) |
| $C_{43}$ | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) | (0.500,0.750,1.000) |
| $C_{44}$ | (0.600,0.850,1.000) | (0.325,0.575,0.825) | (0.500,0.750,1.000) | (0.325,0.575,0.825) | (0.600,0.850,1.000) | (0.600,0.850,1.000) | (0.475,0.725,0.975) | (0.500,0.750,1.000) |
| $C_{51}$ | (0.500,0.750,1.000) | (0.000,0.000,0.250) | (0.500,0.750,1.000) | (0.000,0.000,0.250) | (0.575,0.825,0.975) | (0.725,0.975,1.000) | (0.000,0.250,0.500) | (0.500,0.750,1.000) |
| $C_{52}$ | (0.750,1.000,1.000) | (0.275,0.525,0.775) | (0.750,1.000,1.000) | (0.250,0.500,0.750) | (0.750,1.000,1.000) | (0.600,0.850,1.000) | (0.750,1.000,1.000) | (0.725,0.975,1.000) |
| $C_{53}$ | (0.750,1.000,1.000) | (0.475,0.725,0.975) | (0.750,1.000,1.000) | (0.250,0.500,0.750) | (0.750,1.000,1.000) | (0.500,0.750,1.000) | (0.750,1.000,1.000) | (0.500,0.750,1.000) |
| $C_{54}$ | (0.750,1.000,1.000) | (0.225,0.475,0.725) | (0.725,0.975,1.000) | (0.100,0.350,0.600) | (0.750,1.000,1.000) | (0.750,1.000,1.000) | (0.475,0.725,0.975) | (0.725,0.975,1.000) |
| $C_{61}$ | (450,530,550) | (420,450,500) | (460,480,510) | (150,200,250) | (1000,1200,1400) | (720,758,800) | (360,390,410) | (1200,1300,1500) |
| $C_{62}$ | (20,25,30) | (10,13,15) | (20,25,30) | (10,15,20) | (45,56,60) | (15,18,20) | (10,12,15) | (40,44,50) |
| $C_{63}$ | (0.600,0.850,1.000) | (0.200,0.450,0.700) | (0.600,0.850,1.000) | (0.100,0.350,0.600) | (0.600,0.850,1.000) | (0.600,0.850,1.000) | (0.600,0.850,1.000) | (0.500,0.750,1.000) |
| $C_{64}$ | (0.600,0.850,1.000) | (0.000,0.225,0.475) | (0.500,0.750,1.000) | (0.100,0.350,0.600) | (0.725,0.975,1.000) | (0.500,0.750,1.000) | (0.225,0.475,0.725) | (0.500,0.750,1.000) |

**Table 4.** The aggregated importance values of criteria and sub-criteria

| Criterion | | Aggregated Weights |
|---|---|---|
| $C_1$ | | (0.600,0.850,1.000) |
| | $C_{11}$ | (0.700,0.950,0.975) |
| | $C_{12}$ | (0.475,0.725,0.975) |
| | $C_{13}$ | (0.350,0.600,0.850) |
| | $C_{14}$ | (0.550,0.800,0.950) |
| | $C_{15}$ | (0.450,0.700,0.950) |
| | $C_{16}$ | (0.500,0.750,1.000) |
| $C_2$ | | (0.475,0.725,0.975) |
| | $C_{21}$ | (0.750,1.000,1.000) |
| | $C_{22}$ | (0.500,0.750,1.000) |
| | $C_{23}$ | (0.000,0.250,0.500) |
| | $C_{24}$ | (0.200,0.425,0.675) |
| | $C_{25}$ | (0.325,0.575,0.825) |
| $C_3$ | | (0.100,0.350,0.600) |
| | $C_{31}$ | (0.350,0.600,0.850) |
| | $C_{32}$ | (0.325,0.575,0.825) |
| | $C_{33}$ | (0.600,0.850,1.000) |
| | $C_{34}$ | (0.350,0.600,0.850) |
| $C_4$ | | (0.475,0.725,0.975) |
| | $C_{41}$ | (0.725,0.975,1.000) |
| | $C_{42}$ | (0.725,0.975,1.000) |
| | $C_{43}$ | (0.725,0.975,1.000) |
| | $C_{44}$ | (0.725,0.975,1.000) |
| $C_5$ | | (0.325,0.575,0.825) |
| | $C_{51}$ | (0.225,0.475,0.725) |
| | $C_{52}$ | (0.500,0.750,1.000) |
| | $C_{53}$ | (0.475,0.725,0.975) |
| | $C_{54}$ | (0.750,1.000,1.000) |
| $C_6$ | | (0.725,0.975,1.000) |
| | $C_{61}$ | (0.475,0.725,0.975) |
| | $C_{62}$ | (0.100,0.325,0.575) |
| | $C_{63}$ | (0.300,0.550,0.700) |
| | $C_{64}$ | (0.575,0.825,0.975) |

**Table 5.** The transformation values of criteria and sub-criteria

| Criterion | | Transformation values |
|---|---|---|
| $C_1$ | | 0.771 |
| | $C_{11}$ | 0.846 |
| | $C_{12}$ | 0.680 |
| | $C_{13}$ | 0.580 |
| | $C_{14}$ | 0,729 |
| | $C_{15}$ | 0.660 |
| | $C_{16}$ | 0.700 |
| $C_2$ | | 0.680 |
| | $C_{21}$ | 0.889 |
| | $C_{22}$ | 0.700 |
| | $C_{23}$ | 0.300 |
| | $C_{24}$ | 0.444 |
| | $C_{25}$ | 0.560 |
| $C_3$ | | 0.380 |
| | $C_{31}$ | 0.580 |
| | $C_{32}$ | 0.560 |
| | $C_{33}$ | 0.771 |
| | $C_{34}$ | 0.580 |
| $C_4$ | | 0.680 |
| | $C_{41}$ | 0.868 |
| | $C_{42}$ | 0.868 |
| | $C_{43}$ | 0,868 |
| | $C_{44}$ | 0.868 |
| $C_5$ | | 0.560 |
| | $C_{51}$ | 0.480 |
| | $C_{52}$ | 0.700 |
| | $C_{53}$ | 0.680 |
| | $C_{54}$ | 0.889 |
| $C_6$ | | 0.868 |
| | $C_{61}$ | 0.680 |
| | $C_{62}$ | 0.364 |
| | $C_{63}$ | 0.521 |
| | $C_{64}$ | 0.750 |

The transformation values of normalized fuzzy evaluations are calculated by means of Equation 12. The results are listed in Table 6.

λ values of fuzzy ratings and fuzzy integral values of entire options according to each criterion are calculated by means of Equation (4-7) by setting $g(A_1) = g^1 = RW_1$. The results are listed in Table 7.

Final fuzzy integral values are calculated, and options are ranked according to final fuzzy integral values in decreasing order. The results are listed in Table 8.

**Table 8.** Final FI values and ranking

| Alternatives | FI | Ranking |
|---|---|---|
| $P_1$ | 0.8602 | 3 |
| $P_2$ | 0.7826 | 8 |
| $P_3$ | 0.8711 | 1 |
| $P_4$ | 0.8276 | 6 |
| $P_5$ | 0.8438 | 4 |
| $P_6$ | 0.8602 | 2 |
| $P_7$ | 0.8367 | 5 |
| $P_8$ | 0.7997 | 7 |

**Table 6.** The transformation values of normalized fuzzy evaluations

| Sub Criterion | $RI_{1jk}$ | $RI_{2jk}$ | $RI_{3jk}$ | $RI_{4jk}$ | $RI_{5jk}$ | $RI_{6jk}$ | $RI_{7jk}$ | $RI_{8jk}$ |
|---|---|---|---|---|---|---|---|---|
| $C_{11}$ | 0.868 | 0.480 | 0.868 | 0.283 | 0.700 | 0.771 | 0.771 | 0.700 |
| $C_{12}$ | 0.852 | 0.333 | 0.852 | 0.333 | 0.744 | 0667 | 0.467 | 0.667 |
| $C_{13}$ | 0.826 | 0.462 | 0.703 | 0.385 | 0.703 | 0826 | 0.703 | 0.615 |
| $C_{14}$ | 0.862 | 0.138 | 0.688 | 0.313 | 0.761 | 0.688 | 0.862 | 0.688 |
| $C_{15}$ | 0.862 | 0.295 | 0.688 | 0.295 | 0.862 | 0.761 | 0.396 | 0.688 |
| $C_{16}$ | 0.836 | 0.585 | 0.634 | 0.366 | 0.634 | 0.634 | 0.718 | 0.634 |
| $C_{21}$ | 0.667 | 0.667 | 0.667 | 0.667 | 0.667 | 0.667 | 0.667 | 0.667 |
| $C_{22}$ | 0.889 | 0.700 | 0.889 | 0.580 | 0.300 | 0.868 | 0.380 | 0.560 |
| $C_{23}$ | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 |
| $C_{24}$ | 0.605 | 0.395 | 0.605 | 0.395 | 0.605 | 0.605 | 0.605 | 0.605 |
| $C_{25}$ | 0.868 | 0.380 | 0.700 | 0.300 | 0.771 | 0.889 | 0.580 | 0.771 |
| $C_{31}$ | 0.855 | 0.326 | 0.674 | 0.543 | 0.674 | 0.652 | 0.674 | 0.674 |
| $C_{32}$ | 0.889 | 0.465 | 0.889 | 0.300 | 0.868 | 0.580 | 0.750 | 0.700 |
| $C_{33}$ | 0.844 | 0.384 | 0.815 | 0.405 | 0.844 | 0.815 | 0.815 | 0.815 |
| $C_{34}$ | 0.878 | 0.435 | 0.878 | 0.308 | 0.855 | 0.855 | 0.878 | 0.674 |
| $C_{41}$ | 0.889 | 0.480 | 0.868 | 0.300 | 0.889 | 0.889 | 0.580 | 0.700 |
| $C_{42}$ | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 |
| $C_{43}$ | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 |
| $C_{44}$ | 0.686 | 0.405 | 0.595 | 0.405 | 0.686 | 0.686 | 0.568 | 0.595 |
| $C_{51}$ | 0.700 | 0.111 | 0.700 | 0.111 | 0.750 | 0.868 | 0.300 | 0.700 |
| $C_{52}$ | 0.857 | 0.400 | 0.857 | 0.375 | 0.857 | 0.711 | 0.857 | 0.831 |
| $C_{53}$ | 0.857 | 0.600 | 0.857 | 0.375 | 0.857 | 0.625 | 0.857 | 0.625 |
| $C_{54}$ | 0.878 | 0.435 | 0.855 | 0.326 | 0.878 | 0.878 | 0.652 | 0.855 |
| $C_{61}$ | 0.721 | 0.766 | 0.749 | 0.946 | 0.258 | 0.547 | 0.818 | 0.167 |
| $C_{62}$ | 0.682 | 0,924 | 0.682 | 0.864 | 0.165 | 0.829 | 0.933 | 0.327 |
| $C_{63}$ | 0.750 | 0.413 | 0.750 | 0.326 | 0.750 | 0.750 | 0.750 | 0.674 |
| $C_{64}$ | 0.229 | 0.717 | 0.300 | 0.620 | 0.132 | 0.300 | 0.520 | 0.300 |

**Table 7.** λ values of fuzzy scales and FI values

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ |
|---|---|---|---|---|---|---|
| $\lambda$ | -0.9994 | -0.9938 | -0.97935 | -0.9997 | -0.994 | -0.97036 |
| $P_1$ | 0.730 | 0.618 | 0.879 | 0.859 | 0.875 | 0.694 |
| $P_2$ | 0.550 | 0.683 | 0.441 | 0.499 | 0.544 | 0.804 |
| $P_3$ | 0.877 | 0.827 | 0.869 | 0.830 | 0.856 | 0.709 |
| $P_4$ | 0.372 | 0.652 | 0.477 | 0.498 | 0.369 | 0.863 |
| $P_5$ | 0.825 | 0.717 | 0.856 | 0.859 | 0.369 | 0.498 |
| $P_6$ | 0.801 | 0.853 | 0.823 | 0.859 | 0.867 | 0.698 |
| $P_7$ | 0.834 | 0.655 | 0.844 | 0.577 | 0.836 | 0.828 |
| $P_8$ | 0.698 | 0.721 | 0.787 | 0.684 | 0.848 | 0.492 |

When the results are examined, $P_3$, $P_6$ and $P_1$ can be thought as the most appropriate projects considering technical, financial and national issues. If $P_5$ and $P_7$ are considered, they were expected to be in higher position in ranking since they have high scorings. Their rankings can be explained by investment cost. Both $P_5$ and $P_7$ have higher investment cost than the others. Therefore, it can be said that this sub-criterion has an important effect on ranking. Also, it can be emphasized that reasonable costs for projects and other requirements must meet on a common ground for the sustainability of R&D activities.

Previously, several researchers have used different fuzzy MCDM techniques for project selection. These methods possess several advantages such as the consideration of imprecision and vagueness inherent in the problem, but they also incorporate some shortcomings. Defuzzification has been commonly used in fuzzy MCDM methods. Freeling [34] stated that by reducing the whole analysis to a single number, much of the information which has been intentionally kept throughout calculations is lost. Thus, defuzzification might essentially contradict with the key objective of minimizing the loss of information throughout the analysis. Moreover, obtaining pairwise comparisons in widely used techniques such as AHP and ANP may become quite complex especially when the number of attributes and/or alternatives increases. Apart from this, Saaty and Tran [35] claimed that uncertainty in the AHP was successfully remedied by using intermediate values in the 1–9 scale combined with the verbal scale and that seemed to work better to obtain accurate results than using fuzzy AHP. Fuzzy TOPSIS and fuzzy VIKOR assume mutual independence of attributes, which can be highly restrictive for decisions processes that usually incorporate inner dependencies among attributes.

## 5. DISCUSSIONS AND CONCLUSIONS

Today, due to the rapid globalization, achieving competitive advantage is based on the information. Information is changed into science and technology with research and development studies. The sustainable development of a country is only possible conceivable by expanding the data content and by changing the increasing information into science and technology. Thus, research and development have great importance. Determining the most appropriate R&D project that match up with the organization's goals is getting much more importance under restricted resources, since the projects that contribute to technical and economic success have a constructive effect. Such projects also accommodate the organization composing a list of preferential projects that will develop the success and will provide a comprehensive extent and strategic way for the organization. R&D project selection constitutes a significant part of project management in order to achieve the desired results and outputs. Therefore, R&D project selection is a challenging process for the organizations, 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 conflicting objectives, imprecision in forecasting future achievement and high risk in projects. It can be predicted that a considerable effort needs to determine the best alternative. For this reasons, decision-maker require a scientific guide to select and evaluate R&D projects.

In this study, OWA integrated fuzzy integral method is implemented to select the best R&D project in a company which has a R&D center authorized by Turkish Ministry of Industry and Technology. Selection criteria are determined by means of literature review and experts' opinions. A hierarchical structure for criteria including 6 main criteria and 27 sub-criteria are constructed. Structuring the criteria in a multi-level hierarchy enables to conduct more effective analysis when a large number of performance attributes are to be considered in the evaluation process. 4 decision-makers and 8 projects take part for selection process. OWA aggregation method is applied to weight decision makers and aggregate their ratings. In project selection process that considers multiple conflicting criteria, determining the weights of criteria, and the ratings of alternatives is difficult. Decision makers attempt to weight criteria and alternatives according to her/his own preference and her/his own past experiences. Nevertheless, such individual knowledge is difficult to gain due to the following causes: (1) decision maker(s) does not have enough time and energy completely understand such problems; (2) decision maker(s) might have limited information and experience to evaluate criteria; and (3) decision maker(s) preferences may change with time. Thus, the use of an appropriate aggregation operator, which reflects the real behavior of the group is essential. OWA implements different aggregation rules by changing the order weights, and it encompasses other aggregation operators.
The results of the analysis provide ranking of alternative R&D projects in the case company. It also shows that technological, environmental, marketing, organizational, national and financial issues should be considered simultaneously in the evaluation process. The proposed method is shown to be efficient, generalizable and practical and it has several significant merits compared to the other methods.

In this study, four experts are provided the evaluations. From a statistical point of view, this number is insufficient. This issue can be stated as a limitation of the study. However, with a rapid increase in competition and restrictions of financial capabilities, R&D projects evaluation becomes crucial for the organizations. Furthermore, interdependency between organization resources and complicated projects make project decisions much more problematic. Thus, the evaluation is conducted by a committee of four decision makers that includes general manager, R&D center director, design team leader and project manager, who are specialists on project management. In order to make a robust decision the use of many more experts in divers disciplines requires the elimination of the outliers by employing an analytical method, which will be addressed in the future researches. Moreover, implementing the proposed methodology to real-world group decision making problems in diverse disciplines and extensions of the proposed methodology by combining both subjective and objective importance weight assessments of the criteria and related sub-criteria might be the subjects of the future researches.

**Author Contributions:** Conceptualization: M.D.; Material and Methodology: M.D., M.K.; Supervision: M.D.; Visualization: M.K.; Writing-Original Draft: M.D., M.K.; All authors have read and agreed to the published version of manuscript.
**Conflict of Interest:** No conflict of interest was declared by the authors.
**Financial Disclosure:** This research was financially supported by Galatasaray University Research Fund Grant Number FOA-2022-1092.

## REFERENCES

[1] R. Bhattacharyya, "A Grey Theory Based Multiple Attribute Approach for R&D Project Portfolio Selection," Fuzzy Information and Engineering, vol. 7, no. 2, pp. 211–225, 2015.

[2] C. Muralidharan, N. Anantharaman, and S. G. Deshmukh, "A multi-criteriagroup decision making model for supplier rating," The Journal of Supply Chain Management, vol. 38, no. 4, pp. 22–33, 2002.

[3] A. D. Henriksen and A. J. Traynor, " A practical R&D project-selection scoring tool," IEEE Transactions on Engineering Management, vol. 46, no. 2, pp. 158-170, 1999.

[4] R. Bhattacharyya, P. Kumar, P. and S. Kar, "Fuzzy R&D portfolio selection of interdependent projects," Computers and Mathematics with Applications, vol. 62, no. 10, pp. 3857-3870, 2011.

[5] 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, no. 5, pp. 5532-5543, 2011.

[6] K. Khalili-Damghania and S. Sadi-Nezhad, "A decision support system for fuzzy multi-objective multi-period sustainable project selection," Computers & Industrial Engineering, vol. 64, no. 4, pp. 1045-1060, 2013.

[7] K. Khalili-Damghania and S. Sadi-Nezhad, "A hybrid fuzzy multiple criteria group decision making approach for project selection," Applied Soft Computing, vol. 13, no. 1, pp. 339-352, 2013.

[8] F. Hassanzadeh, H. Nemati and M. Sun, "Robust optimization for interactive multiobjective programming with imprecise information applied to R&D project portfolio selection," European Journal of Operational Research, vol. 238, no. 1, pp. 41-53, 2014.

[9] M. N. M. Arratia, I. F. López, S. E. Schaeffer, and L. Cruz-Reyes, "Static R&D project portfolio selection in public organizations," Decision Support Systems, vol. 84, pp. 53-63, 2016.

[10] F. Cluzel, B. Yannou, D. Millet, and Y. Leroy, "Eco-ideation and eco-selection of R&D projects portfolio in complex systems industries," Journal of Cleaner Production, vol. 112, no. 5, pp. 4329-4343, 2016.

[11] A. Hosseini, O. Lædre, B. Andersen, O. Torp, N. Olsson, and J. Lohne, "Selection Criteria for Delivery Methods for Infrastructure Projects," Procedia-Social and Behavioral Sciences, vol. 226, pp. 260-268, 2016.

[12] 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.

[13] H. Jafarzadeh, P. Akbari, and B. Abedin, "A methodology for project portfolio selection under criteria prioritisation, uncertainty and projects interdependency – combination of fuzzy QFD and DEA," Expert Systems with Applications, vol. 110, pp. 237-249, 2018.

[14] H. F. Rad and S. M. Rowzan, "Designing a hybrid system dynamic model for analyzing the impact of strategic alignment on project portfolio selection," Simulation Modelling Practice and Theory, vol. 89, pp. 175-194, 2018.

[15] 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.

[16] F. Liu, Y. W. Chen, J. B. Yang, D. L. Xu, and W. Liu, "Solving multiple- criteria R&D project selection problems with a data-driven evidential reasoning rule," International Journal of Project Management, vol. 37, no. 1, pp. 87-97, 2019.

[17] E. Binici and E. Aksakal, "A new approach to R&D project selection problem and a solution proposal: UTA method," Pamukkale University Journal of Engineering Sciences, vol. 26, no. 1, pp. 211-226, 2020.

[18] V. Mohagheghi, S. M. Mousavi, M. Mojtahedi, S. Newton, "Evaluating large, high-technology project portfolios using a novel interval-valued Pythagorean fuzzy set framework: An automated crane project case study," Expert Systems with Applications, vol. 162, no. 1, 113007, 2020.

[19] P. Liu, B. Zhu, H. Seiti, and L. Yang, "Risk-based decision framework based on R-numbers and best-worst method and its application to research and development project selection," Information Sciences, vol. 571, no. 1, pp. 303-322, 2021.

[20] W. R. W. Mohd and L. Abdullah, "Aggregation methods in group decision making: A decade survey," Informatica (Slovenia), vol. 41, no. 1, pp. 71–86, 2017.

[21] R. R. Yager, "On ordered weighted averaging aggregation operators in multi-criteria decision making," IEEE Transactions on Systems Man and Cybernetics, vol. 18, no. 1, pp. 183–190, 1988.

[22] D. P. Filev and R. R. Yager, "On the issue of obtaining OWA operator weights," Fuzzy Sets and Systems, vol. 94, pp. 157–169, 1998.

[23] M. Dursun, E. E. Karsak, and M. A. Karadayi, "A fuzzy multi-criteria group decision making framework for evaluating health-care waste disposal alternatives," Expert Systems with Applications, vol. 38, no. 9, pp. 11453-11462, 2011.

[24] M. Ying, "Linguistic quantifiers modeled by Sugeno integrals," Artificial Intelligence, vol. 170, pp. 581-606, 2006.

[25] M. Ayub, Choquet and Sugeno Integrals, Master Thesis, Blekinge Institute of Technology, 2009.

[26] G. Choquet, "Theory of capacities," Annales de l'Institut Fourier, vol. 5, pp. 131-295, 1954.

[27] M. Sugeno, Theory of fuzzy integrals and its applications, Thesis, Tokyo Institute of Technology, 1974.

[28] J. M. Keller, J. Osborn, "Training the fuzzy integral," International Journal of Approximate Reasoning, vol. 15, no. 1, pp. 1-24, 1996.

[29] R. Balachandra, J. H. Friar, "Factors for success in r&d projects and new product innovation: a contextual framework," IEEE Transactions on Engineering Management, vol. 44, no. 3, pp. 276-287, 1997.

[30] C. C. Huang, P. Y. Chu, and Y. H. Chiang, "A fuzzy AHP application in government-sponsored R&D project selection," Omega, vol. 36, no. 6, pp. 1038-1052, 2008.

[31] A. S. Pillai, A. Joshi, and K. S. Rao, “Performance measurement of R&D projects in a multi-project, concurrent engineering environment,” International Journal of Project Management, vol. 20, no. 2, pp. 165-177, 2002.

[32] G. Jin, S. Sperandio, and P. Girard, “Selection of design project with the consideration of designers’ satisfaction factors and collaboration ability,” Computers and Industrial Engineering, vol. 131, pp. 66-81, 2019.

[33] J. J. Jiang and G. Klein, “Project selection criteria by strategic orientation,” Information and Management, vol. 36, no. 2, pp. 63-75, 1999.

[34] S. Freeling, “Fuzzy sets and decision analysis,” IEEE Transactions on Systems, Man, and Cybernetics, vol. 10, pp. 341-354, 1980.

[35] T. L. Saaty and L. T. Tran, “On the invalidity of fuzzifying numerical judgments in the analytic hierarchy process,” Mathematical and Computer Modelling, vol. 46, pp. 962-975, 2007.