EVALUATION OF R&D PROJECTS EMPLOYING FUZZY MCDM PROCEDURES

(AR-GE PROJELERİNİN BULANIK ÇOK ÖLÇÜTLÜ KARAR VERME TEKNİKLERİ KULLANILARAK DEĞERLENDİRİLMESİ)

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LIST OF SYMBOLS

AHP	: Analytical Hierarchy Process
MP	: Mathematical Programming
GP	: Goal Programming
ANP	: Analytical Network Process
NPV	: Net Present Value
IP	: Integer Programming
ROV	: Real Option Valuation
MIP	: Mixed Integer Programming
MISP	: Mixed Integer Stochastic Programming
MOP	: Multi-Objective Programming
DEA	: Data Envelopment Analysis
TOPSIS	: Technique For Order Preference By Similarity To An Ideal Solution
GA	: Genetic Algorithm
MILP	: Mixed Integer Linear Programming
QFD	: Quality Function Deployment
MO-PSO	: Multi-Objective Particle Swarm Optimization
SMAA	: Stochastic Multi-Criteria Acceptability Analysis
ER	: Evidential Reasoning
MCDM	: Multiple Criteria Decision Making
MCDA	: Multiple Criteria Decision Analysis
MODM	: Multi Objective Decision Making
MADM	: Multi Attribute Decision Making
R&D	: Research and Development
OWA	: Ordered-Weighted Average
FI	: Fuzzy Integral

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ABSTRACT

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, meeting 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 project selection constitutes a significant part of project management in order to achieve the desired results and outputs. Project selection procedure is a policy-making task usually takes part in organizations such as technology-intensive companies, research institutes, and government-sponsored corporations. The selection of R&D projects is a complicated decision-making problem, as the evaluation process involves many qualitative and quantitative criteria. Therefore, decision makers generally face with vagueness in selection process.

Several methods have been used to determine the most adequate alternative for the R&D project selection problem and make the selection procedure more apparent. In this study, hierarchical fuzzy multi criteria decision making (MCDM) method and fuzzy integral (FI) mechanisms are employed to determine the most suitable R&D project for R&D center of a company working on a project-oriented in the machinery manufacturing sector.

The aim of the study is to provide a scientific way for R&D project selection process in the company. For this purpose, 6 main criteria (technological, environmental, marketing, organizational, national benefits and financial issues) and 27 sub-criteria are decided as the project selection criteria to execute the selection procedure. Related project selection methodologies are applied to 8 projects. Four decision makers are chosen for the assessment of alternatives.

After determining fundamental elements, decision matrices are constructed. Ordered weighted average (OWA) aggregation method is used for determining the weights of decision makers and aggregating their opinions. The rankings obtained from both hierarchical fuzzy MCDM and FI are indicated in Table 6.24 and Table 6.29, respectively. The results are discussed in Section 7.

ÖZET

Günümüzde küresel pazar rekabeti, başarılı Ar-Ge faaliyetlerinin kuruluşların devamlılığında, müşteri ihtiyaçlarına cevap vermede ve rekabette önde olmasında önem arz etmesi nedeniyle, şirketleri Ar-Ge projelerine yatırım yapmaya yönlendirmektedir. Bu nedenle Ar-Ge projesi seçimi, şirket başarısı için en önemli yatırım kararlarından biri olmuştur.

Ar-Ge projesi seçimi, istenilen sonuç ve çıktılara ulaşmak adına proje yönetimi alanında önemli bir yer tutar. Proje seçim prosedürü, teknoloji ağırlıklı firmalar, araştırma enstitüleri ve devlet destekli ortaklıklar vb. kuruluşlarda organizasyonel bir görevdir. Proje seçimi, değerlendirme sürecinin hem niteliksel hem de nicel kriterler içermesi nedeniyle de karmaşık bir süreçtir. Bu yüzden, karar vericiler genellikle seçim prosesinde belirsizliklerle karşı karşıya kalmaktadır.

Ar-Ge projesi seçim probleminde en uygun projeyi seçmek ve seçim sürecini daha anlaşılır duruma getirmek için birçok yöntem kullanılmıştır. Bu çalışmada makine imalatı sektöründe proje bazlı olarak çalışan bir firmanın, Ar-Ge merkezinde Ar-Ge projesi seçimi için hiyerarşik bulanık çok ölçütlü karar verme yöntemi ile bulanık integral yöntemi uygulanmıştır.

Bu çalışmanın amacı, ilgili firmaya Ar-Ge projesi seçimi için bilimsel bir zemin oluşturmaktır. Belirlenen yöntemleri uygulamak adına 6 ana kriter (teknolojik, çevresel, pazarlama, organizasyonel, ulusal faydalar ve ekonomik hususlar) ve 27 alt kriter proje seçim kriterleri olarak belirlenmiştir. İlgili proje seçim yönetimleri 8 projeye uygulanmıştır. Alternatiflerin değerlendirilmesi için dört karar verici seçilmiştir.

Yöntemlerin uygulanması için gerekli ana bileşenlerin belirlenmesinden sonra karar matrisleri oluşturuldu. Karar vericilerin ağırlıklandırılması ve yapılan tüm değerlendirmeleri kapsayan ortak bir değer elde edilmesi için sıralı ağırlıklı ortalama yöntemi kullanıldı. Her iki yöntemden elde edilen sıralamalar sırasıyla Tablo 6.24 ve 6.29'da gösterildi. Sonuçlar 7. bölümde tartışıldı.

1 INTRODUCTION

Since the 1980’s, with increasing of competitiveness and the rapid technological change, research and development (R&D) is progressively seen as a significant contribution to advancement, so a substantial concentration on governance policies has been given due to its unrivalled features (Fernandes et al., 2018). Definition of R&D stated by Frascati Manual (OECD, 2015) is incorporating imaginative and organized work tackled so as to improve the level of knowledge – comprising knowledge of humanity, community and culture – and to design unfamiliar applications of present knowledge. Even if they are achieved by different performers, a group of common properties define R&D activities. R&D activities could be focused on accomplishing either general or specific targets. 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. Any R&D activity is organized and allocated, and targeted to emerge conclusion that can be easily transferred or commercialize in any market (OECD, 2015). R&D improvement are considerably vital to the elongated achievement of any organization. (Pitts, 2010) defines prospering R&D as the distinction between pioneering state-of-the-art technologies/products and gradual drop into failure and vagueness.

Project management is a pursuit to use resources more efficiently within an organization by providing tasks to progress both vertically and horizontally. Moreover, whole projects are required to be finalized within the certain time, expense and achievement (Kerzner, 1981). Considering these issues, the management of R&D endeavor 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 a research and development project in an organization. The complex point in making a decision is at the beginning, the probability of success of a project, if it can be prospering in its technical targets is generally puzzling to forecast. What is more, even if it could be foreseen definitely that an offered R&D project will reach its technical targets and emerge consequences, final effects of these outcomes are tough to know certainly within the technological and scientific association. These considerations make the successful selection of R&D projects much more challenging in two ways: the first one is selecting projects that will be successful as technically, gain powerful effect, and bring the association crucial awards, and the second one is to not ignore such kind of projects when one or more are among the choices (Henriksen & Traynor, 1999).

A feasible combination of project includes sub criteria of alternatives which could be constituted concerning various obvious limitations on resources. 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 (Toloo & Mirbolouki, 2019). Hence, R&D supervisors are mostly met the problem of apportion resources of equipment, personnel, and funds to a wide range of projects. R&D managing directors should choose projects judiciously because decision-making to begin a R&D project is both a business and technical decision. 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 is generally described as from the point of constraint optimization issue. Given a number of project alternatives, the objective of project selection decision is to apportion a limited group of resources to projects in a route that is alignment with the strategic plan of organization and stabilizes risk without ignoring the constraints. In addition, 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 (Bhattacharyya et al., 2011).

In this study, R&D project selection with multi-criteria by fuzzy decision making is applied for 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. 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 to meet both the R&D center requirements and maximize the outcomes.

Expectations from the R&D center and corporate strategies makes project decision-making much more complicated. The scope of the study is to construct a structured approach by multi criteria decision making (MCDM) method. The set of criteria are searched from the literature that are compatible with the company's goals and they are classified under six major titles. It is believed that following a scientific way will contribute the R&D project management of strategies of the company and it will also improve business processes.

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 & Traynor (1999) classify R&D project selection methods as rating, programming, decision analysis, economic models, artificial intelligence, interactive methods, portfolio optimization, and unconstructed studies.

Song et al. (2019) proposed stochastic multi-criteria acceptability analysis (SMAA) to evaluate the multi-criteria project portfolio selection and scheduling problem. Liu et al. (2019) developed the data-driven evidential reasoning rule-based model for project selection to gain verification from decision makers' evaluations as registered in previous datasets. Jafarzadeh et al. (2018) applied combination of fuzzy quality function deployment (QFD) and data envelopment analysis (DEA) for project portfolio selection regarding three significant constituents. Rad & Rowzan (2018) purposed two-stage MO-PSO with TOPSIS for select project portfolio selection. Karasakal & Aker (2017) executed multiple criteria sorting methods based on DEA to evaluate R&D projects. Hosseini et al. (2016) applied different project delivery method (PDM) to decide the most appropriate alternative regarding different selection criteria. Arratia et al. (2016) presented mixed-integer linear programming for project portfolio selection. Cluzel et al. (2016) adapted eco-innovation technique for R&D project portfolio selection in industries which eco-design prerequisites are favorably particular. Bhattacharyya (2015) introduced R&D project portfolio selection as a grey theory based multiple attribute decision making issue. Hassanzadeh et al. (2014) applied a multi-objective binary integer programming for R&D project portfolio selection and robust optimization is executed to handle imprecision. Huang & Zhao (2014) argued R&D project selection considering net income investment cost as uncertain data. Khalili-Damghania & Sadi-Nezhad (2013a) improved decision support system for multi-objective project selection problem.

Khalili-Damghania & Sadi-Nezhad (2013b) also offered a hybrid fuzzy multiple criteria group decision making method under six main criteria for the project selection problem. Feng et al. (2011) 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. Bhattacharyya et al. (2011) 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. Yang & Hsieh (2009) applied Delphi fuzzy multiple criteria decision-making method for six-sigma project selection. Fang et al. (2008) presented a bi-objective mixed-integer stochastic programming model to solve R&D projects selection problem. Eilat et al. (2008) employed a multi-criteria approach to assess R&D projects by integrating the balanced scorecard (BSC) and DEA. Huang et al. (2008) suggested a fuzzy analytic hierarchy process method for the selection of government sponsored R&D projects with multiple-attribute. Carlsson et al. (2007) implemented fuzzy mixed integer programming model to decide the optimal R&D portfolio selection problem and argued if the technique can be applied to construct decision support tools for the same problem in a corporate organization. Wang & Hwang (2007) benefited from a fuzzy zero–one integer programming model to formulate the R&D portfolio selection problem to deal with both flexible and uncertain parameters to make a decision on the optimal project portfolio. Huang (2007) employed net present value and designed a hybrid intelligent algorithm combining genetic algorithm and random fuzzy simulation to solve random fuzzy uncertainty in project selection. Wang et al. (2005) elaborated AHP with fuzzy scoring to assess a group of R&D projects in Chinese Ministry of Science and Technology considering ten main criteria. Ringuest et al. (2004) applied mean-Gini analysis to five simulated and 30 real candidate R&D projects by estimating the Gini coefficient and expected return. Tian et al. (2002) presented a hybrid model which combines mathematical models with knowledge rules for R&D project decision-making. Meade & Presley (2002) proposed the analytic network process (ANP) to evaluate a set of R&D project proposals with different criteria. Pillai et al. (2002) suggested integrated performance index for multi-criteria projects covering the whole lifecycle of R&D projects. Badri et al. (2001) applied mixed goal programming to IS projects as project selection methodology in health service institutions.

Radulescu (2001) offered zero-one mathematical programming to determine the best alternative thinking of limited resources and risk. Oral et al. (2001) suggested disaggregation multi-criterion approach for project evaluation ad selection. Lee & Kim (2001) applied an integrated technique which includes Delphi, ANP and zero-one goal programming for interdependent IS project selection problems. Jiang & Klein (1999) searched the effect of strategic orientation on organizations for information systems while selecting projects under hierarchical criteria. Hwang & Yu (1998) proposed comparative analysis by majority-rule methods based on fuzzy set priority as project assessment technique. Balachandra & Friar (1997) proposed contingency methodology with contextual variables for R&D project models regarding 4 main criteria and 13 sub criteria. Lee & Om (1996) made a comparison between public and private institutes regarding the same criteria considering in the selection process of an R&D project from multiple proposals.

A literature review of project selection by multi criteria is stated in Table 2.1.

Table 2:1: Literature review on R&D project selection methods

Reference	Project Selection Method
Lee & Om (1996)	Five-point Likert scale, Kolmogorov-Smirnov test
Balachandra & Friar (1997)	Contingency-based model
Hwang & Yu (1998)	Fuzzy set priority
Jiang & Klein (1999)	Strategic orientation
Lee & Kim (2001)	Delphi, ANP, GP
Oral et al. (2001)	Disaggregation multi-criterion approach
Radulescu (2001)	MP
Badri et al. (2001)	GP
Meade & Presley (2002)	ANP
Pillai et al. (2002)	Integrated performance index
Tian et al. (2002)	A hybrid knowledge and model system
Ringuest et al. (2004)	Mean–Gini analysis
Wang et al. (2005)	AHP
Huang (2007)	NPV, IP
Wang & Hwang (2007)	ROV model
Carlsson et al. (2007)	Fuzzy MIP
Huang et al. (2008)	Fuzzy AHP
Eilat et al. (2008)	DEA, balanced scorecard approach
Fang et al. (2008)	MISP
Yang & Hsieh (2009)	Delphi FMCDM method
Feng et al. (2011)	AHP, scoring method, weighted geometric averaging method
Bhattacharyya et al. (2011)	Fuzzy MOP

Table 2.1: Literature Review on R&D Project Selection Methods (continued)

Reference	Project Selection Method
Khalili-Damghania & Sadi-Nezhad (2013a)	TOPSIS based fuzzy GP
Khalili-Damghania & Sadi-Nezhad (2013b)	GP, fuzzy TOPSIS
Huang & Zhao (2014)	GA
Hassanzadeh et al. (2014)	IP
Bhattacharyya (2015)	Grey theory-based model
Arratia et al. (2016)	MILP
Cluzel et al. (2016)	Eco-innovation method
Hosseini et al. (2016)	AHP
Karasakal & Aker (2017)	DEA
Jafarzadeh et al. (2018)	QFD, DEA
Rad & Rowzan (2018)	MO-PSO with TOPSIS
Song et al. (2019)	SMAA
Liu et al. (2019)	ER rule

3 MULTIPLE CRITERIA DECISION MAKING

Decision making systems to solve multi criteria issues has developed remarkably in recent years and different methods are applied in a wide range of field (Gilliams et al., 2005). Multiple criteria decision-making (MCDM) figures in these techniques. Generally speaking, MCDM model states that systematic methods for assessing, prioritizing and choosing the most appropriate option among a group of convenient ones that are classified as multiple-generally contradictory, levels of acquisitions for a group of criteria (Campanella & Ribeiro, 2011). Dotoli et al. (2020) describes MCDM methods as mathematical instruments which assists decision makers organizing, determining, rating and solving issues in a successive path among many options considering multiple conflicting criteria in tremendously complicated circumstances. Regarding the nature of decision alternates, MCDM techniques can be categorized in two titles: Multi Objective Decision Making (MODM), in which the decision alternates set is directly characterized by constraints instead of giving decision alternates using multiple objective programming and Multi Attribute Decision Making (MADM), in which alternatives are generally pre-established and limited (Vommi & Kakollu, 2017).

MODM and MADM problems can be sorted out as individual decision maker problems and group decision makers problems. These can be also classified into fuzzy decisions, probabilistic decisions and determinative decisions. Determinative decision problems suppose that necessary information and the data are identified certainly, and determinative relation exists between each decision and every decision and the reciprocal decision outcome. Probabilistic studies carry out a decision state under imprecision related with the situation of problem's ecosystem and related with the relations between the decision and its outcomes. Thinking of inherent vagueness of information placed in decision making is also possible; fuzzy decision making carries out this kind of vagueness (Malczewski, 1999).

Malczewski (1999) states that MCDM problems include six elements in general:

1. An object or a set of objects the decision maker(s) strive to accomplish
2. An individual decision maker or a decision-making team took part in the decision-making mechanism together with their inclination according to decision criteria
3. A group of decision criteria (objectives or attributes) which the decision makers assess options
4. A group of decision alternates
5. The group of uncontrollable variables or decision system
6. The group of results linked with each alternate-attribute match

A decision matrix was introduced by Malczewski (1999) to show the relations among the components of MCDM in Figure 3.1. Below matrix describes the decision consequences for a set of alternates and a set of decision criteria.

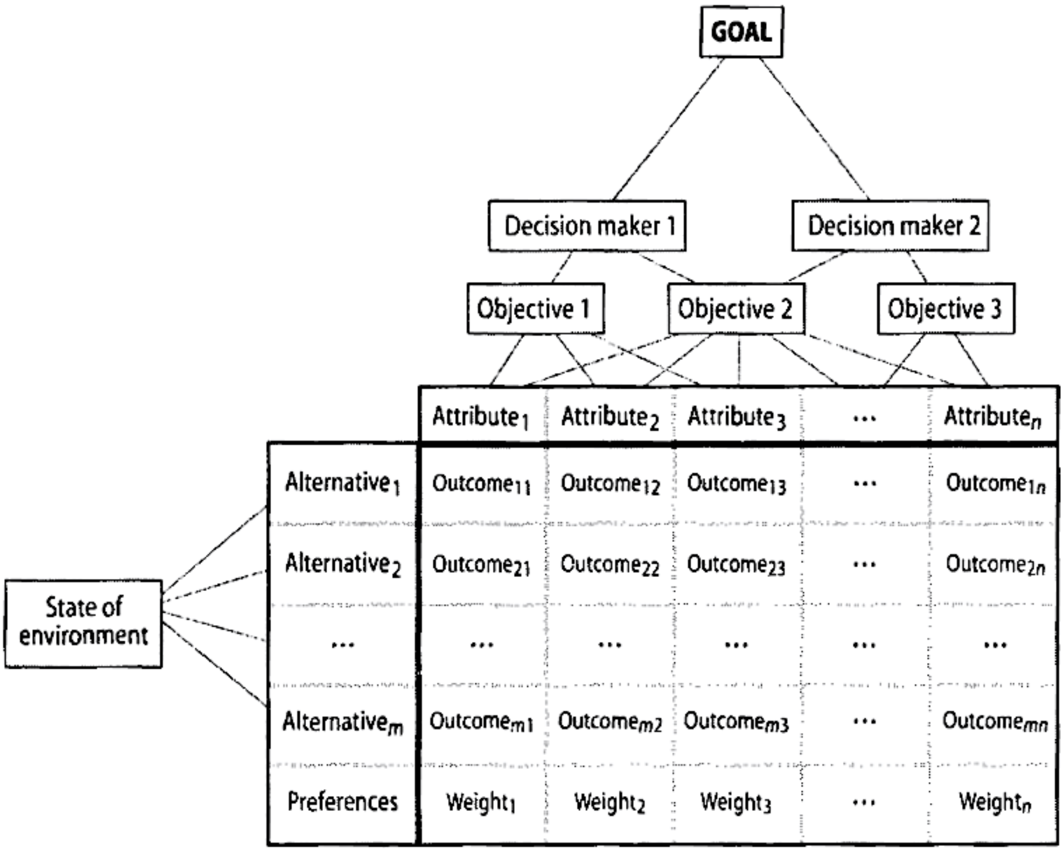

Figure 3.1: Scheme for MCDM (Malczewski, 1999)

A detailed application of MCDM includes eight main steps (Phillips, 2009):

1. Construct the decision framework,
   1.1. Structure goals of the MCDM and define decision maker and other critical participants.
   1.2. Structure the system for running the MCDM.
   1.3. Think about the framework of valuation.

2. Describe the options/alternatives to be evaluated.

3. Describe goals and criteria which exhibit the value according to the outcomes of each alternative.
   3.1. Specify criteria to evaluate the results of each alternate.
   3.2. Cluster the criteria in a hierarchical way under levels of objectives in a hierarchy to categorize them.

4. "Scoring step": Evaluate the scoring of each alternative with the criteria. Next, evaluate the rating related with the results of each alternative for each criterion.
   4.1. Identify the results of alternatives.
   4.2.Grade the alternatives on the criteria.
   4.3.Control the grades of on each criterion if they are in consistency.

5. "Weighting step": Make assignment of weights for each of the criterion to demonstrate importance of the decision.

6. Integrate the ratings and weights at each step in the hierarchy for each alternative to acquire an inclusive consequence.

7. Analyze the consequences

8. Perform a sensitivity analysis to variations in weights or ratings for the outcomes.
   8.1.Perform a sensitivity analysis to make sure if other preferences or weights impact whole ranking of the alternatives.
   8.2. Consider the negative and positive sides of preferred alternatives and make a comparison couples of alternatives.
   8.3. Generate potential new alternatives that could be better than original ones.
   8.4. Repeat steps until reasonable and successful model is received.

R&D project assessment and selection procedure is a significant and frequent process for many organizations. R&D project evaluation and selection is generally a complex multi-criteria decision-making process. The decision makers face to judge which alternative is the best for application. Therefore, organizations require a structured, consistent and formalized method to make their decisions and outcomes transparent and reliable (Liu et al., 2019). When we think about vital role of project selection procedure in organizations, finding the best alternative for the related organization can be achieved by MCDM techniques regarding qualitative and quantitative considerations of project alternatives.

4 FUZZY SET THEORY

Most of conventional tools for modelling, analyzing and computing are crisp and deterministic- that is yes or no type rather than more or less type. In set theory, a constituent can be either a member of a set or not; in optimization, a solution can be feasible or not. It means that they are always include precision. Precision applies that a model is definitive, it includes no uncertainty. However, when we think about features of real-world systems, they are usually uncertain and cloudy. It can be called this uncertainty and vagueness as fuzziness (Zimmermann, 2001).

Fuzzy set theory was firstly introduced by Lotfi. A. Zadeh. Zadeh (1965) defines a fuzzy set as a group of items with a continuity of degrees of membership. This kind of a set is identified by a membership function which designates a grade of membership ranging between zero and one for each item. The concepts of union, inclusion, intersection, relation, complement, convexity, etc., can be broadened to such sets, and distinct properties of these concepts in the framework of fuzzy sets can be built. The concept of a fuzzy set implements a favorable aspect of beginning for the structure of a conceptual environment which complements in many aspects the environment utilized in the state of ordinary sets, but is more common than the latter and, probably, might confirm to have a much broader extent of applicability, especially in the areas of pattern classification and information processing. Originally, such an environment provides a reasonable manner of handling with problems in which the source of imprecision is the absence of clearly described measures of class membership instead of the presence of random variables.

Basic definitions for fuzzy sets can be classified as below (Zimmermann, 2001):

Definition 1: If X is a space of objects defined by x, a fuzzy set $\tilde{A}$ in X is a group of arranged couples:

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) \text{ I } x \in X\} \tag{1}$$

$\mu_{\tilde{A}}(x)$ represents membership function showing degree of compatibility of x in $\tilde{A}$ that directs X. The membership function ranges from 0 to 1.

Definition 2: The support of a fuzzy set $\tilde{A}$, denoted as $S(\tilde{A})$, is the crisp set of all x ∈ X such that $\mu_{\tilde{A}}(x)>0$.

***Definition 3*:** The group of components that belong to the fuzzy set $\tilde{A}$ to the degree α is referred to the α -level set:

$$A_\alpha = \{x \in X \text{ I } \mu_{\tilde{A}}(x) \geq \alpha\} \tag{2}$$

A'_α = $\{x \in X \text{ I } \mu_{\tilde{A}}(x) > \alpha\}$ is called as "strong α-level set" or "strong α-cut.

Definition 4: If below condition is fulfilled, any fuzzy set $\tilde{A}$ is a convex.

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min\{\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)\}, x_1, x_2 \in X, \lambda \in [0,1] \tag{3}$$

All α -level sets are convex as well if a fuzzy set is convex.

Definition 5: The quantity $|\tilde{A}|$ is stated as below for a finite fuzzy set $\tilde{A}$,

$$|\tilde{A}| = \sum_{x \in X} \mu_{\tilde{A}}(x) \tag{4}$$

$\|A\| = {|\tilde{A}|}/{|x|}$ is denoted as the relative quantity of $\tilde{A}$. It can be clearly observed that the relative quantity of as fuzzy set depends on the quantity of the space X.

Definition 6: The membership function $\mu_{\tilde{C}}(x)$ of the intersection $\tilde{C} = \tilde{A} \cap \tilde{B}$ is pointwise defined by:

$$\mu_{\tilde{C}}(x) = \min\{\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x)\},\ x \in X \tag{5}$$

Definition 7: The membership function $\mu_{\tilde{D}}(x)$ of the union $\tilde{D} = \tilde{A} \cup \tilde{B}$ is pointwise is defined by:

$$\mu_{\tilde{D}}(x) = \max\{\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x)\},\ x \in X \tag{6}$$

Definition 8: The membership function of the complement of a normalized fuzzy set $\tilde{A}$, $\mu_{\emptyset\tilde{A}}(x)$ is defined by:

$$\mu_{\emptyset\tilde{A}}(x) = 1 - \mu_{\tilde{A}}(x) \quad x \in X \tag{7}$$

5 FUZZY DECISION-MAKING TECHNIQUES

In this section, hierarchical fuzzy MCDM technique, fuzzy integral and OWA aggregation method are introduced to perform evaluation of potential R&D projects.

5.1 Hierarchical Fuzzy MCDM Method

Decision-making problems in real world like R&D project selection generally need regarding various attributes in a hierarchical structure. Moreover, crisp data are not enough to construct real world solutions. Preferences cannot be estimated with a certain crisp value because human criticism and interpretation considering preferences are generally ambiguous. Using linguistic evaluation might be more reasonable instead of numerical ones, that means to estimate the scoring and weights of the criteria in the issue are valued with the help of linguistic terms (Chen, 2000).

In this study, the hierarchical fuzzy MCDM technique is applied to select the optimal R&D project. The method is determined since the problem includes multi-level criteria structure to direct a more useful analysis. The steps of the technique follows as below (Karsak et al., 2010)

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

Step 2. Specify 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 as below respectively**.**

$$\tilde{x}_{ijkl} = (x^1{}_{ijkl}, x^2{}_{ijkl}, x^3{}_{ijkl}) \tag{8}$$

$$\tilde{w}_{jkl} = (w^1{}_{jkl}, w^2{}_{jkl}, w^3{}_{jkl}) \tag{9}$$

$$\tilde{w}_{jl} = (w^1{}_{jl}, w^2{}_{jl}, w^3{}_{jl}) \tag{10}$$

Perform the aggregated scorings of alternates ($\tilde{x}_{ijk}$), the aggregated importance values of sub-criteria ($\tilde{w}_{jk}$), and the aggregated importance values of criteria ($\tilde{w}_j$).

$$\tilde{x}_{ijk} = \sum_l \nu_l \, \tilde{x}_{ijkl} \tag{11}$$

$$\tilde{w}_{jk} = \sum_l \nu_l \, \tilde{w}_{jkl} \tag{12}$$

$$\tilde{w}_j = \sum_l \nu_l \, \tilde{w}_{jl} \tag{13}$$

where $\nu_l \in [0,1]$ and $\sum_l \nu_l = 1$ **.** Thus, the aggregated scorings of alternates according to each sub-criterion can be performed by means of

$$\tilde{x}_{ijk} = (x^1{}_{ijk}, x^2{}_{ijk}, x^3{}_{ijk}) \tag{14}$$

the aggregated importance values of sub-criteria can be calculated with the help of

$$\tilde{w}_{jk} = (w^1{}_{jk}, w^2{}_{jk}, w^3{}_{jk}) \tag{15}$$

and the aggregated importance values of criteria can be acquired by

$$\tilde{w}_j = (w^1{}_j, w^2{}_j, w^3{}_j) \tag{16}$$

Step 3. 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 (17) taking into account benefit-related sub-criteria (CB_j) as well as cost-related sub-criteria (CC_j).

$$\tilde{r}_{ijk} = \begin{cases} \left(\frac{x_{ijk}^1 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}, \frac{x_{ijk}^2 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}, \frac{x_{ijk}^3 - x_{jk}^-}{x_{jk}^* - x_{jk}^-}\right), k \in CB_j \\ \left(\frac{x_{jk}^* - x_{ijk}^3}{x_{jk}^* - x_{jk}^-}, \frac{x_{jk}^* - x_{ijk}^2}{x_{jk}^* - x_{jk}^-}, \frac{x_{jk}^* - x_{ijk}^1}{x_{jk}^* - x_{jk}^-}\right), k \in CC_j \end{cases} \tag{17}$$

In equation (17), $\tilde{r}_{ijk}$ 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.

Step 4. Aggregate the performance scorings of alternates at the sub-criteria level to criteria level by using equation 18.

$$\tilde{y}_{ij} = (y^1_{ij}, y^2_{ij}, y^3_{ij}) = \frac{\sum_k \tilde{w}'^0_{jk} \otimes \tilde{r}_{ijk}}{\sum_k \tilde{w}'^0_{jk}}, \forall i, j \tag{18}$$

where $\tilde{y}_{ij}$ symbolizes the aggregate performance scoring of alternate i according to criterion j and $\otimes$ represents the fuzzy multiplication operator.

Step 5. The aggregated performance scorings at criteria level are normalized using a linear transformation procedure as follows. If normalization result equals to 1, it is the best value and if normalization result equals to 0, it represents the worst one. The procedure is:

$$\tilde{y}'_{ij} = \left(\frac{y_{ij}^{1} - y_j^{-}}{y_j^{*} - y_j^{-}}, \frac{y_{ij}^{2} - y_j^{-}}{y_j^{*} - y_j^{-}}, \frac{y_{ij}^{3} - y_j^{-}}{y_j^{*} - y_j^{-}} \right), \forall i, j \tag{19}$$

where $y_j^{*} = max_i y_{ij}^{3}$ and $y_j^{-} = min_i y_{ij}^{1}$, and $\tilde{y}'_{ij}$ represents normalized aggregate performance scoring of alternate *i* according to criterion *j*.

Step 6. Set the ideal solution $A^{*} = (r_1^{*}, r_2^{*}, \dots, r_n^{*})$ and the anti-ideal solution $A^{-} = (r_1^{-}, r_2^{-}, \dots, r_n^{-})$ where $r_j^{*} = (1,1,1)$ and $r_j^{-} = (0,0,0)$ for $j = 1, 2, \dots, n$.

Step 7. Calculate the weighted distances from ideal solution and anti-ideal solution (D_i^{*} and D_i^{-}, respectively) for every alternate with the help of

$$D_i^{*} = \sum_j 1/2 \left\{ max\left(w_j^{1} \left| y'^{1}_{ij} - 1 \right|, w_j^{3} \left| y'^{3}_{ij} - 1 \right| \right) + w_j^{2} \left| y'^{2}_{ij} - 1 \right| \right\}, \forall i \tag{20}$$

$$D_i^{-} = \sum_j 1/2 \left\{ max\left(w_j^{1} \left| y'^{1}_{ij} - 0 \right|, w_j^{3} \left| y'^{3}_{ij} - 0 \right| \right) + w_j^{2} \left| y'^{2}_{ij} - 0 \right| \right\}, \forall i \tag{21}$$

Step 8. Perform the adjacency of the alternates to the ideal solution, Ω_i^{*}, by regarding the distances from ideal and anti-ideal solutions as

$$\Omega_i^{*} = \frac{D_i^{-}}{(D_i^{*} + D_i^{-})}, \forall i \tag{22}$$

Step 9. Rank the options with respect to Ω_i^{*} values in diminishing order. Define the option with the highest Ω_i^{*} as the best one.

5.2 Fuzzy Measure 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 λ-measure which the additivity is not required have been proposed for a better assessment of human subjectivity (Ayub, 2009).

Fuzzy measures and integrals were firstly introduced by Choquet (1954), in his paper "Theory of Capacities". In the related study, he submitted 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 (1975) 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 (Alfimtsev & Sakulin, 2017).

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 (Keller & Osborn, 1996).

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 (Keller & Osborn, 1996):

(1) $g(\emptyset) = 0$ and $g(X) = 1$ (23)

(2) $g(A) \leq g(B)\ if\ A \subseteq B$ (24)

(3) If $\{A_i\}$ is an increasing sequence of subsets of X, then

$$\lim_{i\to\infty} g(A_i) = g\left(\bigcup_{i=1}^{\infty} A_i\right) \tag{25}$$

A fuzzy measure g is called as Sugeno measure (g_λ-fuzzy measure), if it also satisfies below property:

(4) For all $A, B \subseteq X$ with $A \cap B = \emptyset$,

$$g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B) \text{ where } \lambda > -1 \tag{26}$$

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 (Keller & Osborn, 1996).

The value of λ for any Sugeno fuzzy measure can be determined by solving following equation (Keller & Osborn, 1996):

$$1 + \lambda = \prod_{i=1}^{n} (1 + \lambda\, g^i) \tag{27}$$

The fuzzy integral is described as:

$$\int_A h(x)og(.) = \sup_{E\subseteq X}\left[min\left(\min_{x\in E} h(x), g(A\cap E)\right)\right] = \sup_{\alpha\in[0,1]}[min(\alpha, g(A\cap F_\alpha)] \qquad (28)$$

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:

$$e = max_{i=1}^{n}[\min((h(x_i), g(A_i))], \text{ where } A_i = \{x_1, \ldots . x_i\} \qquad (29)$$

Sugeno measure, the value of $g(A_i)$ can be iteratively defined as:

$$g(A_1) = g(\{x_1\}) \qquad (30)$$

$$g(A_i) = g^i + g(A_{i-1}) + \lambda g^i g(A_{i-1}), \qquad \text{for } 1 < i \leq n \qquad (31)$$

The process of the fuzzy integral employed in this thesis can be ordered as below (Karsak et al., 2011):

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.

Step 4. Perform the aggregated fuzzy evaluations of options according to sub-criteria ($\tilde{x}_{ijk}$), the aggregated fuzzy importance weights of sub-criteria ($\widetilde{w}_{jk}$), and the aggregated fuzzy importance weights of sub-criteria ($\widetilde{w}_{j}$).

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 (32) taking into account benefit-related sub-criteria (CB_j) as well as cost-related sub-criteria (CC_j).

$$\tilde{r}_{ijk} = \begin{cases} \left(\frac{x_{ijk}^{1} - x_{jk}^{-}}{x_{jk}^{*} - x_{jk}^{-}}, \frac{x_{ijk}^{2} - x_{jk}^{-}}{x_{jk}^{*} - x_{jk}^{-}}, \frac{x_{ijk}^{3} - x_{jk}^{-}}{x_{jk}^{*} - x_{jk}^{-}}\right), k \in CB_j \\ \left(\frac{x_{jk}^{*} - x_{ijk}^{3}}{x_{jk}^{*} - x_{jk}^{-}}, \frac{x_{jk}^{*} - x_{ijk}^{2}}{x_{jk}^{*} - x_{jk}^{-}}, \frac{x_{jk}^{*} - x_{ijk}^{1}}{x_{jk}^{*} - x_{jk}^{-}}\right), k \in CC_j \end{cases} \tag{32}$$

In equation (32), $\tilde{r}_{ijk}$ 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.

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, $d_{ijk}^{*} = d_v(\tilde{r}_{ijk}, \tilde{P}^{*})$; $wd_{jk}^{*} = d_v(\widetilde{w}_{jk}, \tilde{P}^{*})$; $wd_{j}^{*} = d_v(\widetilde{w}_{j}, \tilde{P}^{*})$; $d_{ijk}^{-} = d_v(\tilde{r}_{ijk}, \tilde{P}^{-})$; $wd_{jk}^{-} = d_v(\widetilde{w}_{jk}, \tilde{P}^{-})$; $wd_{j}^{-} = d_v(\widetilde{w}_{j}, \tilde{P}^{-})$, are calculated regarding the equation which states the distance between the triangular fuzzy numbers.

$$d_v(\tilde{A}, \tilde{B}) = 1/2\{max(|a_1 - b_1|, |a_3 - b_3|) + |a_2 - b_2|\} \tag{33}$$

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

$$RW_{jk} = {wd_{jk}^{-}} \Big/ \left(wd_{jk}^{-} + wd_{jk}^{*}\right) \tag{34}$$

$$RW_{j} = {wd_{j}^{-}} \Big/ \left(wd_{j}^{-} + wd_{j}^{*}\right) \tag{35}$$

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

$$RI_{ijk} = {d_{ijk}^{-}} \Big/ \left(d_{ijk}^{-} + d_{ijk}^{*}\right) \tag{36}$$

Step 9. λ values of fuzzy measures and fuzzy integral values of whole options according to each criterion are calculated with the help of using Equation (27)-(31). The h function is the transformation values of normalized fuzzy evaluations RI_{ijk} and $g(A_1) = g^1 = RW_1$.

Step 10. The ultimate λ values and the ultimate fuzzy integral values of options are computed. The options are ranked with respect to the ultimate fuzzy integral values in decreasing order.

5.3 Aggregation Procedure in Group Decision Making

Weighting of sub-criteria and criteria is a critical step to quantify whole preferences for group decision-making problems. It is required to aggregate ratings of alternative so as to make decisions. One of key points in multi-criteria issues is aggregation of scorings which come from individuals to gain an overall assessment for alternatives. The overall assessment is utilized to choose the best option. Therefore, the procedure to aggregate individuals' scorings for options is needed in group decision making.

Aggregation is simply described as the procedure of unifying a number of scorings according to each sub-criterion and criterion into one representative score by means of an aggregation operator to acquire a universal value. In other words, aggregation is employed for summarization of scorings when multiple experts exist. In MCDM problems, each member possesses her/his idea and might have diverse knowledge about alternatives. It may not straightforward to determine her/his rating with crisp values. Therefore, each option included in the problem might be needed to represent in linguistic terms. Considering these situations, aggregation methodologies are essential to cope with the process to actualize the overall characteristic of group decision making (Mohd & Abdullah, 2017).

Various aggregation techniques have been examined to handle multiplicity characteristics in group decision making. In this thesis, the ordered weighted averaging (OWA) operator is utilized to aggregate decision-makers' assessments. The OWA operator was initially suggested by Yager & Filev (1988). 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 (Karsak et al., 2011).

The concept of OWA can be described as below (Filev & Yager, 1998)

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

$$F\{a_1, a_2, \dots, a_n\} = \boldsymbol{w}\boldsymbol{b}^{\boldsymbol{T}} = \sum_{j=1}^{n} w_j b_j \tag{37}$$

$\boldsymbol{w} = (w_1, w_2, \dots, w_n)$ is a weighting vector where $w_i \in [0,1]$ and $\sum_{i=1}^{n} w_i = 1$

$\boldsymbol{b}$ 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 (Filev & Yager, 1998).

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 (Karsak et al., 2011):

$$w_i = Q\left({}^{i}/_{n}\right) - Q\left({}^{(i-1)}/_{n}\right), \ \ i = 1, \dots, n \tag{38}$$

A non-decreasing relative quantifier *Q* is stated by (Karsak et al., 2011):

$$Q(y) = \begin{cases} 0, & y < a, \\ \dfrac{y-a}{b-a} & a \le y \le b, \\ 1 & y > b, \end{cases} \tag{39}$$

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.

6 METHODOLOGY

Hierarchical fuzzy MCDM method and fuzzy integral method are adopted for R&D project selection problem in this study. These methods have 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 candidate projects. Uncertainty may come from the following reasons: unmeasurable information, partial information, inaccessible information and unfamiliarity (Yang & Hsieh, 2009). To handle these difficultness, fuzzy techniques are performed for the problem.

6.1 Constructing Decision Matrix and Ratings

Eight candidate projects are selected that are to be evaluated. Then, decision-making team who score the criteria and the sub-criteria according to selected projects are determined. Weights of experts are assigned by means of OWA operator. The candidate projects and decision-making team are listed in Table 6.1 and Table 6.2.

Table 6:1: 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

Table 6:2: The decision-making team

No	Team Member
DM_1	General Manager
DM_2	R&D Center Director
DM_3	Design Team Leader
DM_4	Project Manager

Different categorizations of criteria exist in the literature. The criteria and sub-criteria used for this study are derived from several references stated in Table 6.3. To provide a better understanding of project selection criteria, they are categorized as 27 sub-criteria which are aggregated into six main criteria. Titles of main criteria were obtained from (Balachandra & Friar, 1997). and (Karasakal & Aker, 2017). The decision criteria are listed in Table 6.3 and their definitions are introduced below. Also, the scheme for hierarchical structure of the problem is shown in Figure 6.1.

Table 6:3: R&D project selection criteria

Selection Criteria
1. Technological Issues (C_1)
1.1.Innovation of technology (C_{11}) (C. C. Huang et al., 2008)
1.2.Advancement of technology (C_{12}) (C. C. Huang et al., 2008)
1.3.Key of technology (C_{13}) (C. C. Huang et al., 2008)
1.4.Patentability (C_{14}) (M. Lee & Om, 1996), (Balachandra & Friar, 1997)
1.5.Uniqueness of technology/product (C_{15}) (M. Lee & Om, 1996)
1.6.Technological extendibility (C_{16}) (C. C. Huang et al., 2008)
2. Environmental Issues (C_2)
2.1.Safety considerations (C_{21}) (Pillai et al., 2002), (C. C. Huang et al., 2008)
2.2.Benefits for human life (C_{22}) (C. C. Huang et al., 2008)
2.3.Political factors (C_{23}) (Balachandra & Friar, 1997), (Meade & Presley, 2002)
2.4.Job creation opportunity (C_{24}) (Karasakal & Aker, 2017)
2.5.The satisfaction of the employee (C_{25}) (Jin et al., 2019)

Table 6.3: R&D project selection criteria (continued)

Selection Criteria
3. Marketing Issues (C_3)
3.1.Opportunity/probability of market success (C_{31}) (Meade & Presley, 2002), (Pillai et al., 2002), (C. C. Huang et al., 2008)
3.2.Potential size of market (C_{32}) (Huang et al., 2008), (Pillai et al., 2002)
3.3.Degree of competition (C_{33}) (Pillai et al., 2002), (Karasakal & Aker, 2017)
3.4.Opportunity for new technology/market (C_{34}) (M. Lee & Om, 1996)
4. Organizational Issues (C_4)
4.1.Competence and experience on similar projects (C_{41}) (Pillai et al., 2002)
4.2.Knowledge/skills availability (C_{42}) (Pillai et al., 2002)
4.3.Facilities availability (C_{43}) (Pillai et al., 2002)
4.4.Research staff availability (C_{44}) (Pillai et al., 2002)
5. National Advantages Issues (C_5)
5.1.Collaboration of University and Industry (C_{51}) (Karasakal & Aker, 2017)
5.2.Contribution to national economy (C_{52}) (K. Wang et al., 2005)
5.3.Conducting Market Research (C_{53}) (Karasakal & Aker, 2017)
5.4.Contributions to the state of knowledge (C_{54}) (C. C. Huang et al., 2008)
6. Financial Issues (C_6)
6.1.Investment cost (C_{61})
6.2.Outsourced benefits and services cost (C_{62})
6.3.Contribution of profitability (C_{63}) (Jiang & Klein, 1999)
6.4.Risk for development cost (C_{64}) (C. C. Huang et al., 2008)

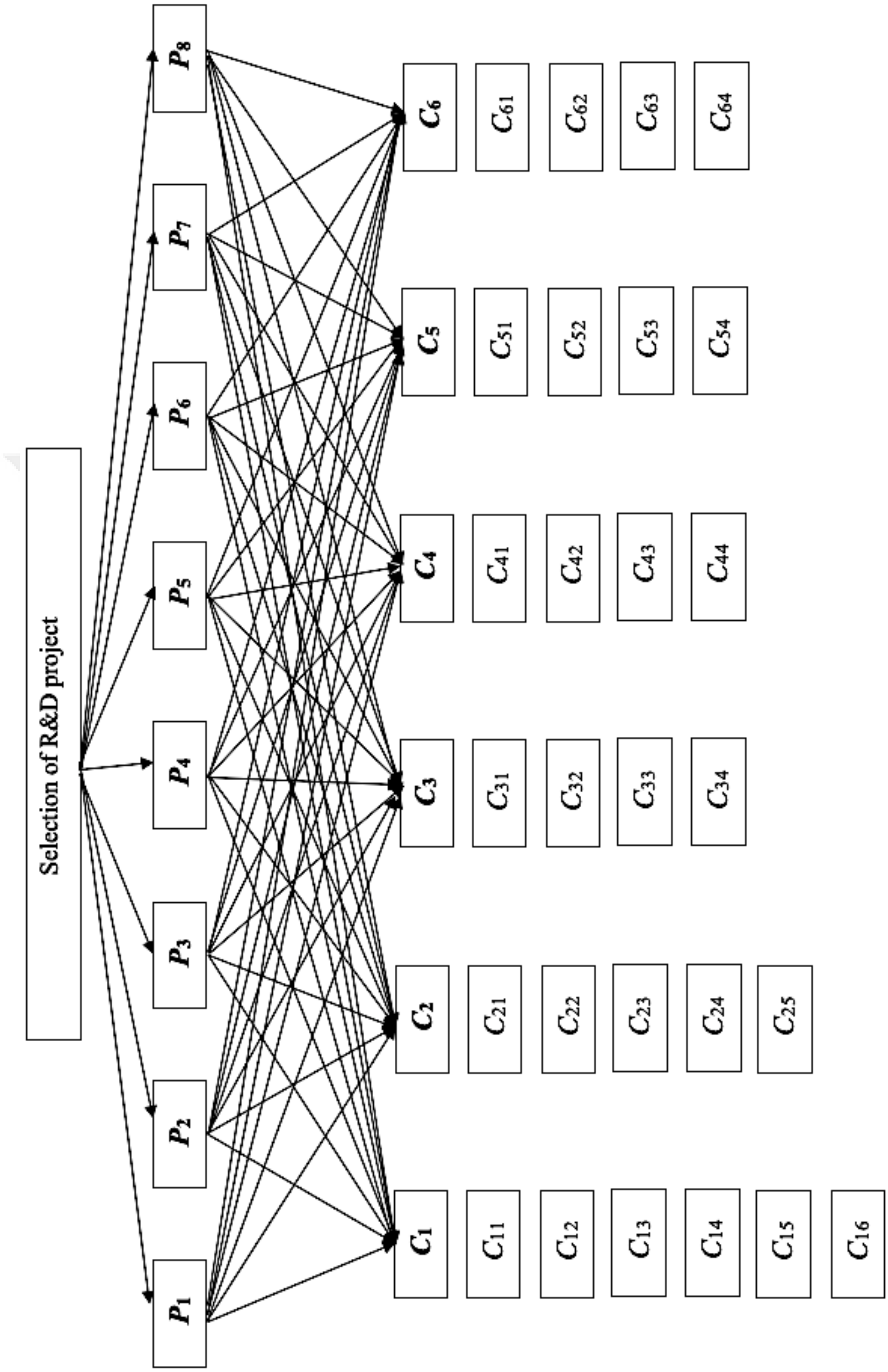

Figure 6.1: Hierarchical structure of the R&D project selection problem

Innovation of technology: Innovation degree of offered technology

Advancement of technology: Advancement level of offered technology compared with current technology

Key of technology: Is the offered technology crucial for product or industry improvement

Patentability: If the offered technology can emerge a patent or utility model

Uniqueness of technology/product: If the offered technology implies any knowledge/technology/method which others do not have.

Technological extendibility: If the offered technology has a potentiality for further technology improvement regarding project outcomes

Safety considerations: If the safety management of offered technology is essential in work environment

Benefits for human life: The offered technology can have favorable outcomes in terms of human health or quality of human life

Political factors: The effects of political factors (tax policies and other government policies, elections, trade reforms etc.) in the country on the offered technology/product

Job creation opportunity: If the project can emerge new job opportunities for the industry

The satisfaction of the employee: The project team members can enhance their skills and collaboration abilities during life cycle of a project.

Opportunity/probability for market success: The potential of market success of the offered technology/product

Potential size of market: The potential growth of market for the proposed technology/product.

Degree of competition: The level of competition of the proposed technology/product compared with other alternatives and market values in industry.

Opportunity for new technology/market: If the offered technology can pioneer a new technology can pioneer to place in a new market.

Competence and experience on similar projects: The level of experience/knowledge on identical projects.

Knowledge/skills availability: The degree of knowledge/skills of project team.

Facilities availability: The level of facilities available (like physical capacity of company, degree of existing technology, number of staff, etc.) to construct a project.

Research staff availability: If number of existing employees and the quality of project team are adequate to conduct associated project.

Collaboration of University and Industry: The potential of the project to enable the persistence of industry and university collaboration.

Contribution to national economy: The potential or national level of the project to promote national economy.

Conducting Market Research: The potential of the project to find an international market when the project outcomes are considered.

Contributions to the state of knowledge: The scope of contributions of offered technology to current level of technical knowledge.

Contribution of profitability: The degree of contribution of the project for company's profitability.

Risk for development cost: The risk for developing prototype regarding financial cost.

After determining team members, alternatives, criteria and sub-criteria, each decision maker is entailed to rate from 1 to 5 for each sub-criterion, each main criterion and sub-criterion according to each project. Their scorings are transformed into linguistic terms and their corresponding fuzzy values. The corresponding fuzzy values are represented by triangular fuzzy numbers stated as 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) (Karsak & Dursun, 2015). Scorings of decision makers are indicated in Table 6.4 - 6.15.

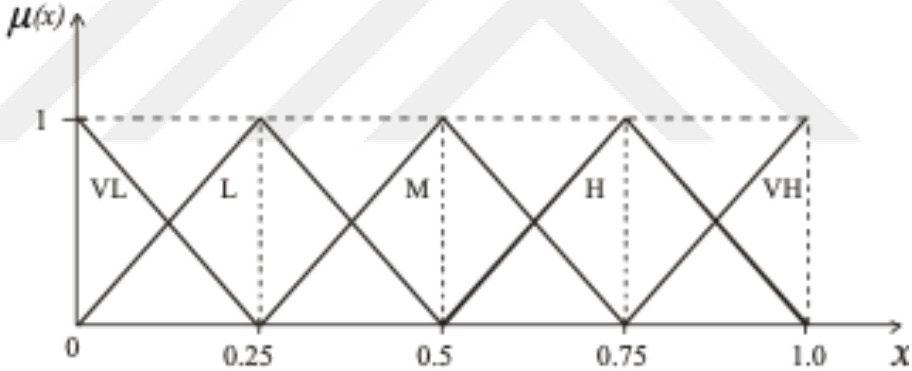

Figure 6.2: Fuzzy linguistic term set

Table 6:4: Importance weights of DM_1 for each project wrt sub-criteria ($\tilde{x}_{ijk1}$)

Sub-Criterion	P_1	P_2	P_3	P_4
C_{11}	VH	M	VH	M
C_{12}	VH	H	VH	H
C_{13}	VH	L	H	M
C_{14}	VH	VL	H	L
C_{15}	VH	M	H	L
C_{16}	VH	H	H	M
C_{21}	VH	VH	VH	VH
C_{22}	VH	H	VH	M
C_{23}	H	H	H	H
C_{24}	L	L	L	L
C_{25}	VH	L	H	L
C_{31}	VH	L	H	M
C_{32}	VH	M	VH	L
C_{33}	VH	H	VH	H
C_{34}	VH	VH	VH	M
C_{41}	VH	M	VH	L
C_{42}	H	H	H	H
C_{43}	H	H	H	H
C_{44}	VH	L	H	L
C_{51}	H	VL	H	VL
C_{52}	VH	M	VH	M
C_{53}	VH	M	VH	M
C_{54}	VH	L	VH	L
C_{61}	(450,530,550)	(420,450,500)	(460,480,510)	(150,200,250)
C_{62}	(20,25,30)	(10,13,15)	(20,25,30)	(10,15,20)
C_{63}	VH	H	VH	M
C_{64}	H	M	H	M

Table 6.4: Importance weights of DM_1 for each project wrt sub-criteria ($\tilde{x}_{ijk1}$) (continued)

Sub-Criterion	P_5	P_6	P_7	P_8
C_{11}	H	H	H	H
C_{12}	VH	H	M	H
C_{13}	H	VH	H	H
C_{14}	VH	H	VH	H
C_{15}	VH	VH	L	H
C_{16}	H	H	H	H
C_{21}	VH	VH	VH	VH
C_{22}	L	H	H	L
C_{23}	H	H	H	H
C_{24}	L	L	L	L
C_{25}	VH	VH	M	H
C_{31}	H	H	H	H
C_{32}	H	M	M	H
C_{33}	VH	VH	H	VH
C_{34}	VH	H	VH	H
C_{41}	VH	VH	M	H
C_{42}	H	H	H	H
C_{43}	H	H	H	H
C_{44}	VH	VH	M	VH
C_{51}	M	H	L	H
C_{52}	VH	H	VH	H
C_{53}	VH	H	VH	H
C_{54}	VH	VH	M	VH
C_{61}	(1000,1200,1400)	(720,758,800)	(360,390,410)	(1200,1300,1500)
C_{62}	(45,56,60)	(15,18,20)	(10,12,15)	(40,44,50)
C_{63}	VH	VH	VH	H
C_{64}	H	H	M	H

Table 6:5: Importance weights of DM_1 for each sub-criterion ($\widetilde{w}_{jk1}$)

Sub-Criterion	Importance Weight
C_{11}	VH
C_{12}	H
C_{13}	M
C_{14}	H
C_{15}	H
C_{16}	H
C_{21}	VH
C_{22}	H
C_{23}	L
C_{24}	H
C_{25}	H
C_{31}	VH
C_{32}	H
C_{33}	VH
C_{34}	VH
C_{41}	VH
C_{42}	H
C_{43}	H
C_{44}	H
C_{51}	M
C_{52}	H
C_{53}	VH
C_{54}	VH
C_{61}	VH
C_{62}	M
C_{63}	VH
C_{64}	M

Table 6:6: Importance weights of DM_1 for each criterion ($\widetilde{w}_{j1}$)

Main Criterion	Importance Weight
C_1	H
C_2	H
C_3	VH
C_4	H
C_5	H
C_6	VH

Table 6:7: Importance weights of DM_2 for each project wrt sub-criteria ($\tilde{x}_{ijk2}$)

Sub-Criterion	P_1	P_2	P_3	P_4
C_{11}	VH	M	VH	L
C_{12}	VH	L	VH	L
C_{13}	VH	H	VH	M
C_{14}	VH	VL	H	L
C_{15}	VH	L	H	VL
C_{16}	VH	H	H	L
C_{21}	VH	VH	VH	VH
C_{22}	VH	H	VH	M
C_{23}	M	M	M	M
C_{24}	H	L	H	L
C_{25}	VH	M	H	L
C_{31}	VH	M	VH	H
C_{32}	VH	M	VH	L
C_{33}	VH	H	VH	H
C_{34}	VH	L	VH	VL
C_{41}	VH	M	VH	L
C_{42}	H	H	H	H
C_{43}	H	H	H	H
C_{44}	VH	M	VH	M
C_{51}	VH	VL	H	VL
C_{52}	VH	M	VH	H
C_{53}	VH	H	VH	M
C_{54}	VH	M	VH	L
C_{61}	(450,530,550)	(420,450,500)	(460,480,510)	(150,200,250)
C_{62}	(20,25,30)	(10,13,15)	(20,25,30)	(10,15,20)
C_{63}	VH	L	VH	L
C_{64}	H	L	H	M

Table 6.7: Importance weights of DM_2 for each project wrt sub-criteria ($\tilde{x}_{ijk2}$) (continued)

Sub-Criterion	P_5	P_6	P_7	P_8
C_{11}	H	VH	VH	H
C_{12}	H	H	M	H
C_{13}	VH	VH	VH	H
C_{14}	VH	VH	VH	H
C_{15}	VH	H	H	H
C_{16}	VH	H	VH	H
C_{21}	VH	VH	VH	VH
C_{22}	L	VH	L	M
C_{23}	M	M	M	M
C_{24}	H	H	VH	H
C_{25}	VH	VH	H	VH
C_{31}	VH	H	VH	H
C_{32}	VH	H	VH	H
C_{33}	VH	VH	VH	VH
C_{34}	VH	VH	VH	H
C_{41}	VH	VH	H	H
C_{42}	H	H	H	H
C_{43}	H	H	H	H
C_{44}	VH	VH	H	H
C_{51}	VH	VH	L	H
C_{52}	VH	VH	VH	VH
C_{53}	VH	H	VH	VH
C_{54}	VH	VH	H	VH
C_{61}	(1000,1200,1400)	(720,758,800)	(360,390,410)	(1200,1300,1500)
C_{62}	(45,56,60)	(15,18,20)	(10,12,15)	(40,44,50)
C_{63}	VH	VH	VH	H
C_{64}	VH	H	M	H

Table 6:8: Importance weights of DM_2 for each sub-criterion ($\widetilde{w}_{jk2}$)

Sub Criterion	Importance Weight
C_{11}	VH
C_{12}	H
C_{13}	H
C_{14}	VH
C_{15}	H
C_{16}	H
C_{21}	VH
C_{22}	H
C_{23}	L
C_{24}	H
C_{25}	VH
C_{31}	M
C_{32}	M
C_{33}	H
C_{34}	M
C_{41}	VH
C_{42}	VH
C_{43}	VH
C_{44}	VH
C_{51}	H
C_{52}	H
C_{53}	M
C_{54}	VH
C_{61}	H
C_{62}	L
C_{63}	L
C_{64}	H

Table 6:9: Importance weights of DM_2 for each criterion ($\widetilde{w}_{j2}$)

Main Criterion	Importance Weight
C_1	VH
C_2	M
C_3	L
C_4	H
C_5	H
C_6	VH

Table 6:10: Importance weights of DM_3 for each project wrt sub-criteria ($\tilde{x}_{ijk3}$)

Sub-Criterion	P_1	P_2	P_3	P_4
C_{11}	VH	M	VH	L
C_{12}	VH	L	VH	L
C_{13}	VH	H	VH	M
C_{14}	VH	VL	VH	L
C_{15}	VH	VL	VH	L
C_{16}	VH	H	H	M
C_{21}	VH	VH	VH	VH
C_{22}	VH	H	VH	H
C_{23}	L	L	L	L
C_{24}	H	H	H	H
C_{25}	VH	M	VH	L
C_{31}	H	L	H	M
C_{32}	VH	VL	VH	L
C_{33}	VH	VL	H	M
C_{34}	VH	M	VH	M
C_{41}	VH	L	H	L
C_{42}	H	H	H	H
C_{43}	H	H	H	H
C_{44}	H	H	H	H
C_{51}	H	VL	H	VL
C_{52}	VH	M	VH	M
C_{53}	VH	H	VH	M
C_{54}	VH	VH	VH	VH
C_{61}	(450,530,550)	(420,450,500)	(460,480,510)	(150200,250)
C_{62}	(20,25,30)	(10,13,15)	(20,25,30)	(10,15,20)
C_{63}	H	L	H	L
C_{64}	VH	VL	VH	L

Table 6.10: Importance weights of DM_3 for each project wrt sub-criteria ($\tilde{x}_{ijk3}$) (continued)

Sub-Criterion	P_5	P_6	P_7	P_8
C_{11}	H	VH	VH	VH
C_{12}	VH	VH	H	H
C_{13}	VH	VH	VH	VH
C_{14}	H	H	VH	H
C_{15}	VH	VH	M	H
C_{16}	H	H	VH	H
C_{21}	VH	VH	VH	VH
C_{22}	L	VH	L	H
C_{23}	L	L	L	L
C_{24}	H	H	H	H
C_{25}	H	VH	M	H
C_{31}	H	M	H	H
C_{32}	VH	M	H	H
C_{33}	VH	H	VH	H
C_{34}	H	VH	VH	VH
C_{41}	VH	VH	M	H
C_{42}	H	H	H	H
C_{43}	H	H	H	H
C_{44}	H	H	H	H
C_{51}	H	VH	L	H
C_{52}	VH	H	VH	VH
C_{53}	VH	H	VH	H
C_{54}	VH	VH	VH	VH
C_{61}	(1000,1200,1400)	(720,758,800)	(360,390,410)	(1200,1300,1500)
C_{62}	(45,56,60)	(15,18,20)	(10,12,15)	(40,44,50)
C_{63}	H	H	H	H
C_{64}	VH	H	L	VH

Table 6:11: Importance weights of DM_3 for each sub-criterion ($\widetilde{w}_{jk3}$)

Sub Criterion	Importance Weight
C_{11}	VH
C_{12}	VH
C_{13}	VH
C_{14}	VH
C_{15}	H
C_{16}	H
C_{21}	VH
C_{22}	H
C_{23}	L
C_{24}	L
C_{25}	L
C_{31}	M
C_{32}	L
C_{33}	VH
C_{34}	M
C_{41}	VH
C_{42}	VH
C_{43}	VH
C_{44}	VH
C_{51}	M
C_{52}	H
C_{53}	H
C_{54}	VH
C_{61}	M
C_{62}	VL
C_{63}	L
C_{64}	VH

Table 6:12: Importance weights of DM_3 for each criterion ($\widetilde{w}_{j3}$)

Main Criterion	Importance Weight
C_1	VH
C_2	H
C_3	L
C_4	H
C_5	L
C_6	H

Table 6:13: Importance weights of DM_4 for each project wrt sub-criteria ($\tilde{x}_{ijk4}$)

Sub-Criterion	P_1	P_2	P_3	P_4
C_{11}	H	L	H	VL
C_{12}	M	M	M	M
C_{13}	M	M	M	M
C_{14}	L	L	L	L
C_{15}	L	L	L	L
C_{16}	H	L	H	M
C_{21}	VH	VH	VH	VH
C_{22}	VH	H	VH	H
C_{23}	L	L	L	L
C_{24}	L	L	L	L
C_{25}	H	L	H	M
C_{31}	VH	M	H	H
C_{32}	VH	M	VH	L
C_{33}	VH	M	VH	L
C_{34}	VH	M	VH	L
C_{41}	VH	M	VH	L
C_{42}	H	H	H	H
C_{43}	H	H	H	H
C_{44}	H	H	H	H
C_{51}	H	VL	H	VL
C_{52}	VH	H	VH	M
C_{53}	VH	H	VH	M
C_{54}	VH	M	H	M
C_{61}	(450,530,550)	(420,450,500)	(460,480,510)	(150,200,250)
C_{62}	(20,25,30)	(10,13,15)	(20,25,30)	(10,15,20)
C_{63}	H	H	H	H
C_{64}	VH	L	H	L

Table 6.13: Importance weights of DM_4 for each project wrt sub-criteria ($\tilde{x}_{ijk4}$) (continued)

Sub-Criterion	P_5	P_6	P_7	P_8
C_{11}	H	H	H	H
C_{12}	M	M	M	M
C_{13}	M	M	M	M
C_{14}	L	L	L	L
C_{15}	L	L	L	L
C_{16}	H	H	H	H
C_{21}	VH	VH	VH	VH
C_{22}	L	VH	M	H
C_{23}	L	L	L	L
C_{24}	L	L	L	L
C_{25}	H	VH	H	VH
C_{31}	H	H	H	H
C_{32}	VH	VH	VH	H
C_{33}	VH	VH	VH	VH
C_{34}	VH	VH	VH	H
C_{41}	VH	VH	H	VH
C_{42}	H	H	H	H
C_{43}	H	H	H	H
C_{44}	H	H	H	H
C_{51}	VH	VH	M	H
C_{52}	VH	VH	VH	VH
C_{53}	VH	H	VH	H
C_{54}	VH	VH	H	H
C_{61}	(1000,1200,1400)	(720,758,800)	(360,390,410)	(1200,1300,1500)
C_{62}	(45,56,60)	(15,18,20)	(10,12,15)	(40,44,50)
C_{63}	H	H	H	H
C_{64}	VH	VH	M	H

Table 6:14: Importance weights of DM_4 for each sub-criterion ($\widetilde{w}_{jk4}$)

Sub Criterion	Importance Weight
C_{11}	M
C_{12}	M
C_{13}	M
C_{14}	L
C_{15}	L
C_{16}	H
C_{21}	VH
C_{22}	VH
C_{23}	L
C_{24}	VL
C_{25}	M
C_{31}	H
C_{32}	H
C_{33}	H
C_{34}	H
C_{41}	H
C_{42}	VH
C_{43}	VH
C_{44}	VH
C_{51}	L
C_{52}	H
C_{53}	H
C_{54}	VH
C_{61}	H
C_{62}	M
C_{63}	VH
C_{64}	VH

Table 6:15: Importance weights of DM_4 for each criterion ($\widetilde{w}_{j4}$)

Main Criterion	Importance Weight
C_1	H
C_2	H
C_3	M
C_4	M
C_5	M
C_6	VH

6.2 Application of OWA Aggregation Method

Determining weights of decision makers' and aggregation of ratings are achieved with the help of OWA aggregation method.

Weights of OWA operator are calculated by employing the non-decreasing relative quantifier Q stated in Equation 38 and Equation 39. Also, (0.3, 0.8)- the "most" parameter- is chosen for (a,b) to execute the calculations.

For i = 1; Equation 38 equals to

$w_1 = Q(1/4) - Q((1-1)/4)) = Q(0.25) - Q(0)$

By applying Equation 39;

$w_1 = 0$

For i = 2; Equation 38 equals to

$w_2 = Q(2/4) - Q((2-1)/4)) = Q(0.5) - Q(0.25)$

By applying Equation 39;

$w_2 = 0.4$

For i = 3; Equation 38 equals to

$w_3 = Q(3/4) - Q((3-1)/4)) = Q(0.75) - Q(0.5)$

By applying Equation 39;

$w_3 = 0.5$

For i =4; Equation 38 equals to

$w_4 = Q(4/4) - Q((4-1)/4)) = Q(1) - Q(0.75)$

By applying Equation 39;

$w_4 = 0.1$

Aggregation of scorings is executed through the instrument of Equation 37. Scorings of projects according to each sub-criterion which come from all decision makers are reordered from the biggest one to smallest one and aggregated values ($\tilde{x}_{ijk}$)are computed.

Sample calculation for aggregation can be shown as below:

Advancement of technology (C_{12}):

Table 6:16: Scorings of projects according to C_{12}

Project	DM_1	DM_2	DM_3	DM_4
P_1	VH	VH	VH	M
P_2	H	L	L	M
P_3	VH	VH	VH	M
P_4	H	L	L	M
P_5	VH	H	VH	M
P_6	H	H	VH	M
P_7	M	M	H	M
P_8	H	H	H	M

Below table is obtained by reordering scorings.

Table 6:17: Reordering of scorings according to C_{12}

Project	DM_1	DM_2	DM_3	DM_4
P_1	VH	VH	VH	M
P_2	H	M	L	L
P_3	VH	VH	VH	M
P_4	H	M	L	L
P_5	VH	VH	H	M
P_6	VH	H	H	M
P_7	H	M	M	M
P_8	H	H	H	M

By using Equation 37 and **w** = (0.0, 0.4, 0.5, 0.1), the aggregated value for P_2 is:

$$\tilde{x}_{212} = ((0*0.5),(0*0.75),(0*1))\oplus((0.4*0.25),(0.4*0.5),(0.4*0.75))\oplus((0.5*0),(0.5*0.25),(0.5*0.5))\oplus((0.1*0),(0.1*0.25),(0.1*0.5))$$

$$\tilde{x}_{212} = (0.100, 0.350, 0.600)$$

The same procedure is applied to aggregate importance values of criteria and sub-criteria. The aggregated values are shown in Table 6.18 - 6.20.

Table 6:18: The aggregated scorings of projects according to sub-criteria ($\tilde{x}_{ijk}$)

Sub-Criterion	P_1	P_2	P_3	P_4
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
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)
C_{61}	(450,530,550)	(420,450,500)	(460,480,510)	(150,200,250)
C_{62}	(20,25,30)	(10,13,15)	(20,25,30)	(10,15,20)
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)
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)

Table 6.18: The aggregated scorings of projects according to each sub-criterion ($\tilde{x}_{ijk}$) (continued)

Sub-Criterion	P_5	P_6	P_7	P_8
C_{11}	(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}	(0.575,0.825,0.975)	(0.475,0.725,0.975)	(0.250,0.500,0.750)	(0.475,0.725,0.975)
C_{13}	(0.575,0.825,0.975)	(0.700,0.950,0.975)	(0.575,0.825,0.975)	(0.475,0.725,0.975)
C_{14}	(0.550,0.800,0.950)	(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)	(0.550,0.800,0.950)	(0.100,0.350,0.600)	(0.450,0.700,0.950)
C_{16}	(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)
C_{22}	(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)
C_{24}	(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}	(0.600,0.850,1.000)	(0.750,1.000,1.000)	(0.350,0.600,0.850)	(0.600,0.850,1.000)
C_{31}	(0.500,0.750,1.000)	(0.475,0.725,0.975)	(0.500,0.750,1.000)	(0.500,0.750,1.000)
C_{32}	(0.725,0.975,1.000)	(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)	(0.725,0.975,1.000)	(0.725,0.975,1.000)	(0.725,0.975,1.000)
C_{34}	(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)	(0.750,1.000,1.000)	(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)
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)
C_{44}	(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}	(0.575,0.825,0.975)	(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)	(0.600,0.850,1.000)	(0.750,1.000,1.000)	(0.725,0.975,1.000)
C_{53}	(0.750,1.000,1.000)	(0.500,0.750,1.000)	(0.750,1.000,1.000)	(0.500,0.750,1.000)
C_{54}	(0.750,1.000,1.000)	(0.750,1.000,1.000)	(0.475,0.725,0.975)	(0.725,0.975,1.000)
C_{61}	(1000,1200,1400)	(720,758,800)	(360,390,410)	(1200,1300,1500)
C_{62}	(45,56,60)	(15,18,20)	(10,12,15)	(40,44,50)
C_{63}	(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}	(0.725,0.975,1.000)	(0.500,0.750,1.000)	(0.225,0.475,0.725)	(0.500,0.750,1.000)

Table 6:19: The aggregated importance values of sub-criteria ($\tilde{w}_{jk}$)

Sub-Criterion	Aggregated Values
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_{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_{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_{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_{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_{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 6:20: The aggregated importance values of criteria ($\tilde{w}_{j}$)

Main Criterion	Aggregated Values
C_1	(0.600,0.850,1.000)
C_2	(0.475,0.725,0.975)
C_3	(0.100,0.350,0.600)
C_4	(0.475,0.725,0.975)
C_5	(0.325,0.575,0.825)
C_6	(0.725,0.975,1.000)

6.3 Application of Hierarchical Fuzzy MCDM Method

Step 1. The decision-making team, alternates, main criteria and sub-criteria are settled (see tables 6.1 - 6.3).

Step 2. The scorings of each alternate according to each sub-criterion, importance value of each sub-criterion and importance value of each main criterion are accomplished by each decision maker (see tables 6.4 – 6.15).

The aggregated scorings of each alternate according to each sub-criterion, the aggregated importance values of each sub-criterion and, the aggregated importance values of each main criterion are also achieved (see tables 6.18-6.20).

Step 3. The aggregated values in Table 6.18 are normalized by using equation 17. Calculations are shown for P_1 and the other normalized results are listed in Table 6.21.

Innovation of technology (C_{11}): $x_{11}^{*} = \max_i x_{i11}^{3}$= 1.000 and $x_{11}^{-} = \min_i x_{i11}^{1}$ = 0.000

$$\tilde{r}_{111} = \left(\frac{0.725 - 0.00}{1.00 - 0.00}, \frac{0.975 - 0.00}{1.00 - 0.00}, \frac{1.00 - 0.00}{1.00 - 0.00}\right) = (0.725, 0.975, 1.000)$$

Advancement of technology (C_{12}): $x_{12}^{*} = \max_i x_{i12}^{3}$= 0.975 and $x_{12}^{-} = \min_i x_{i12}^{1}$ = 0.100

$$\tilde{r}_{112} = \left(\frac{0.70 - 0.10}{0.975 - 0.100}, \frac{0.95 - 0.10}{0.975 - 0.1003}, \frac{0.975 - 0.10}{0.975 - 0.100}\right) = (0.686, 0.971, 1.000)$$

Key of technology (C_{13}): $x_{13}^{*} = \max_i x_{i13}^{3}$= 0.975 and $x_{13}^{-} = \min_i x_{i13}^{1}$ = 0.250

$$\tilde{r}_{113} = \left(\frac{0.70 - 0.25}{0.975 - 0.250}, \frac{0.95 - 0.25}{0.975 - 0.250}, \frac{0.975 - 0.25}{0.975 - 0.250}\right) = (0.621, 0.966, 1.000)$$

Patentability (C_{14}): $x_{14}^{*} = \max_i x_{i14}^{3}$= 0.950 and $x_{14}^{-} = \min_i x_{i14}^{1}$ = 0.000

$$\tilde{r}_{114} = \left(\frac{0.675-0.00}{0.95-0.00}, \frac{0.925-0.00}{0.95-0.00}, \frac{0.950-0.00}{0.95-0.00}\right) = (0.711, 0.974, 1.000)$$

Uniqueness of technology/product (C_{15}): $x^*_{15} = \max_i x^3_{i15} = 0.950$ and $x^-_{15} = \min_i x^1_{i15} = 0.000$

$$\tilde{r}_{115} = \left(\frac{0.675-0.00}{0.95-0.00}, \frac{0.925-0.00}{0.95-0.00}, \frac{0.950-0.00}{0.95-0.00}\right) = (0.711, 0.974, 1.000)$$

Technological extendibility (C_{16}): $x^*_{16} = \max_i x^3_{i16} = 1.000$ and $x^-_{16} = \min_i x^1_{i16} = 0.225$

$$\tilde{r}_{116} = \left(\frac{0.725-0.225}{1.00-0.225}, \frac{0.975-0.225}{1.00-0.225}, \frac{1.00-0.225}{1.00-0.225}\right) = (0.645, 0.968, 1.000)$$

Safety considerations (C_{21}): $\max_i x^3_{i21} = 1.000$ and $x^-_{21} = \min_i x^1_{i21} = 0.750$

$$\tilde{r}_{121} = \left(\frac{0.75-0.75}{1.00-0.75}, \frac{1.00-0.75}{1.00-0.75}, \frac{1.00-0.75}{1.00-0.75}\right) = (0.000, 1.000, 1.000)$$

Benefits for human life (C_{22}): $\max_i x^3_{i22} = 1.000$ and $x^-_{22} = \min_i x^1_{i22} = 0.000$

$$\tilde{r}_{122} = \left(\frac{0.75-0.00}{1.00-0.00}, \frac{1.00-0.00}{1.00-0.00}, \frac{1.00-0.00}{1.00-0.00}\right) = (0.750, 1.000, 1.000)$$

Political factors (C_{23}): $\max_i x^3_{i23} = 0.600$ and $x^-_{23} = \min_i x^1_{i23} = 0.100$

$$\tilde{r}_{123} = \left(\frac{0.60-0.60}{0.60-0.10}, \frac{0.60-0.35}{0.60-0.10}, \frac{0.60-0.10}{0.60-0.10}\right) = (0.000, 0.500, 1.000)$$

Job creation opportunity (C_{24}): $\max_i x^3_{i24} = 0.70$ and $x^-_{24} = \min_i x^1_{i24} = 0.00$

$$\tilde{r}_{124} = \left(\frac{0.20-0.00}{0.70-0.00}, \frac{0.45-0.00}{0.70-0.00}, \frac{0.70-0.00}{0.70-0.00}\right) = (0.286, 0.643, 1.000)$$

The satisfaction of the employee (C_{25}): $\max_i x_{i25}^3$= 1.000 and $x_{25}^- = \min_i x_{i25}^1$ = 0.000

$\tilde{r}_{125} = \left(\frac{0.725 - 0.00}{1.00 - 0.00}, \frac{0.975 - 0.00}{1.00 - 0.00}, \frac{1.00 - 0.00}{1.00 - 0.00}\right)$ = (0.725, 0.975, 1.000)

Opportunity/prob. of market success (C_{31}): $\max_i x_{i31}^3$= 1.000 and $x_{31}^- = \min_i x_{i31}^1$ = 0.100

$\tilde{r}_{131} = \left(\frac{0.725 - 0.10}{1.00 - 0.10}, \frac{0.975 - 0.10}{1.00 - 0.10}, \frac{1.00 - 0.10}{1.00 - 0.10}\right)$ = (0.694, 0.972, 1.000)

Potential size of market (C_{32}): $\max_i x_{i32}^3$= 1.000 and $x_{32}^- = \min_i x_{i32}^1$ = 0.000

$\tilde{r}_{132} = \left(\frac{0.75 - 0.00}{1.00 - 0.00}, \frac{1.00 - 0.00}{1.00 - 0.00}, \frac{1.00 - 0.00}{1.00 - 0.00}\right)$ = (0.750, 1.000, 1.000)

Degree of competition (C_{33}): $\max_i x_{i33}^3$= 1.000 and $x_{33}^- = \min_i x_{i33}^1$ = 0.325

$\tilde{r}_{133} = \left(\frac{0.75 - 0.325}{1.00 - 0.325}, \frac{1.00 - 0.325}{1.00 - 0.325}, \frac{1.00 - 0.325}{1.00 - 0.325}\right)$ = (0.630, 1.000, 1.000)

Opportunity for new tech. / market (C_{34}): $\max_i x_{i34}^3$= 1.000 and $x_{34}^- = \min_i x_{i34}^1$ = 0.100

$\tilde{r}_{134} = \left(\frac{0.75 - 0.10}{1.00 - 0.10}, \frac{1.00 - 0.10}{1.00 - 0.10}, \frac{1.00 - 0.10}{1.00 - 0.10}\right)$ = (0.722, 1.00, 1.00)

Competence and experience on similar projects (C_{41}): $\max_i x_{i41}^3$= 1.000 and $x_{41}^- = \min_i x_{i41}^1$ = 0.000

$\tilde{r}_{141} = \left(\frac{0.75 - 0.00}{1.00 - 0.00}, \frac{1.00 - 0.00}{1.00 - 0.00}, \frac{1.00 - 0.00}{1.00 - 0.00}\right)$ = (0.750, 1.000, 1.000)

Knowledge/skills availability (C_{42}): $\max_i x_{i42}^3$= 1.000 and $x_{42}^- = \min_i x_{i42}^1$ = 0.500

$\tilde{r}_{142} = \left(\frac{0.50 - 0.50}{1.00 - 0.50}, \frac{0.75 - 0.50}{1.00 - 0.50}, \frac{1.00 - 0.50}{1.00 - 0.50}\right)$ = (0.000, 0.500, 1.000)

Facilities availability (C_{43}): $\max_i x_{i43}^3$= 1.000 and x_{43}^- = $\min_i x_{i43}^1$ = 0.500

$$\tilde{r}_{143} = \left(\frac{0.50 - 0.50}{1.00 - 0.50}, \frac{0.75 - 0.50}{1.00 - 0.50}, \frac{1.00 - 0.50}{1.00 - 0.50}\right) = (0.000, 0.500, 1.000)$$

Research staff availability (C_{44}): $\max_i x_{i44}^3$= 1.000 and x_{44}^- = $\min_i x_{i44}^1$ = 0.325

$$\tilde{r}_{144} = \left(\frac{0.60 - 0.325}{1.00 - 03.25}, \frac{0.85 - 0.325}{1.00 - 0.325}, \frac{1.00 - 0.325}{1.00 - 0.325}\right) = (0.407, 0.778, 1.000)$$

Collaboration of University and Industry (C_{51}): $\max_i x_{i51}^3$= 1.00 and x_{51}^- = $\min_i x_{i51}^1$ = 0.00

$$\tilde{r}_{151} = \left(\frac{0.50 - 0.00}{1.00 - 0.00}, \frac{0.75 - 0.00}{1.00 - 0.00}, \frac{1.00 - 0.00}{1.00 - 0.00}\right) = (0.500, 0.750, 1.000)$$

Contribution to national economy (C_{52}): $\max_i x_{i52}^3$= 1.000 and x_{52}^- = $\min_i x_{i52}^1$ = 0.250

$$\tilde{r}_{152} = \left(\frac{0.75 - 0.25}{1.00 - 0.25}, \frac{1.00 - 0.25}{1.00 - 0.25}, \frac{1.00 - 0.25}{1.00 - 0.25}\right) = (0.667, 1.000, 1.000)$$

Conducting Market Research (C_{53}): $\max_i x_{i53}^3$= 1.000 and x_{53}^- = $\min_i x_{i53}^1$ = 0.250

$$\tilde{r}_{153} = \left(\frac{0.75 - 0.25}{1.00 - 0.25}, \frac{1.00 - 0.25}{1.00 - 0.25}, \frac{1.00 - 0.25}{1.00 - 0.25}\right) = (0.667, 1.000, 1.000)$$

Contributions to the state of knowledge (C_{54}): $\max_i x_{i54}^3$= 1.00 and x_{54}^- = $\min_i x_{i54}^1$ = 0.10

$$\tilde{r}_{154} = \left(\frac{0.75 - 0.10}{1.00 - 0.10}, \frac{1.00 - 0.10}{1.00 - 0.10}, \frac{1.00 - 0.10}{1.00 - 0.10}\right) = (0.722, 1.000, 1.000)$$

Investment Cost (C_{61}): $\max_i x_{i61}^3$= 1500 and x_{61}^- = $\min_i x_{i61}^1$ = 150

$$\tilde{r}_{161} = \left(\frac{1500 - 550}{1500 - 150}, \frac{1500 - 530}{1500 - 150}, \frac{1500 - 450}{1500 - 150}\right) = (0.704, 0.719, 0.778)$$

Outsourced benefits and services cost (C_{62}): $\max_i x_{i62}^3$= 60 and x_{62}^- = $\min_i x_{i62}^1$ = 10

$$\tilde{r}_{162} = \left(\frac{60-30}{60-10}, \frac{60-25}{60-10}, \frac{60-20}{60-10}\right) = (0.600, 0.700, 0.800)$$

Contribution of profitability (C_{63}): $\max_i x_{i63}^3$= 1.000 and x_{63}^- = $\min_i x_{i63}^1$ = 0.100

$$\tilde{r}_{163} = \left(\frac{0.60-0.10}{1.00-0.10}, \frac{0.85-0.10}{1.00-0.10}, \frac{1.00-0.10}{1.00-0.10}\right) = (0.556, 0.833, 1.000)$$

Risk for development cost (C_{64}): $\max_i x_{i64}^3$= 1.000 and x_{64}^- = $\min_i x_{i64}^1$ = 0.000

$$\tilde{r}_{164} = \left(\frac{1.00-1.00}{1.00-0.00}, \frac{1.00-0.85}{1.00-0.00}, \frac{1.00-0.60}{1.00-0.00}\right) = (0.000, 0.150, 0.400)$$

Table 6:21: Normalized values related with the problem ($\tilde{r}_{ijk}$)

Sub-Criterion	P_1	P_2	P_3	P_4
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)
C_{12}	(0.686,0.971,1.000)	(0.000,0.286,0.571)	(0.686,0.971,1.000)	(0.000,0.286,0.571)
C_{13}	(0.621,0.966,1.000)	(0.103,0.448,0.793)	(0.448,0.793,1.000)	(0.000,0.345,0.690)
C_{14}	(0.711,0.974,1.000)	(0.000,0.026,0.289)	(0.474,0.737,1.000)	(0.000,0.263,0.526)
C_{15}	(0.711,0.974,1.000)	(0.000,0.237,0.500)	(0.474,0.737,1.000)	(0.000,0.237,0.500)
C_{16}	(0.645,0.968,1.000)	(0.290,0.613,0.935)	(0.355,0.677,1.000)	(0.000,0.323,0.645)
C_{21}	(0.000,1.000,1.000)	(0.000,1.000,1.000)	(0.000,1.000,1.000)	(0.000,1.000,1.000)
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)
C_{23}	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)
C_{24}	(0.286,0.643,1.000)	(0.000,0.357,0.714)	(0.286,0.643,1.000)	(0.000,0.357,0.714)
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)
C_{31}	(0.694,0.972,1.000)	(0.000,0.278,0.556)	(0.444,0.722,1.000)	(0.278,0.556,0.833)
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)
C_{33}	(0.630,1.000,1.000)	(0.000,0.333,0.704)	(0.593,0.963,1.000)	(0.000,0.370,0.741)
C_{34}	(0.722,1.000,1.000)	(0.319,0.417,0.694)	(0.722,1.000,1.000)	(0.000,0.250,0.528)
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)
C_{42}	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)
C_{43}	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)
C_{44}	(0.407,0.778,1.000)	(0.000,0.370,0.741)	(0.259,0.630,1.000)	(0.000,0.370,0.741)
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)
C_{52}	(0.667,1.000,1.000)	(0.033,0.367,0.700)	(0.667,1.000,1.000)	(0.000,0.333,0.667)
C_{53}	(0.667,1.000,1.000)	(0.300,0.633,0.967)	(0.667,1.000,1.000)	(0.000,0.333,0.667)
C_{54}	(0.722,1.000,1.000)	(0.139,0.417,0.694)	(0.694,0.972,1.000)	(0.000,0.278,0.556)
C_{61}	(0.704,0.719,0.778)	(0.741,0.778,0.800)	(0.733,0.756,0.770)	(0.926,0.963,1.000)
C_{62}	(0.600,0.700,0.800)	(0.900,0.940,1.000)	(0.600,0.700,0.800)	(0.800,0.900,1.000)
C_{63}	(0.556,0.833,1.000)	(0.111,0.389,0.667)	(0.556,0.833,1.000)	(0.000,0.278,0.556)
C_{64}	(0.000,0.150,0.400)	(0.525,0.775,1.000)	(0.000,0.250,0.500)	(0.400,0.650,0.900)

Table 6.21: Normalized values related with the problem ($\tilde{r}_{ijk}$) (continued)

Sub-Criterion	P_5	P_6	P_7	P_8
C_{11}	(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}	(0.543,0.829,1.000)	(0.429,0.714,1.000)	(0.171,0.457,0.743)	(0.429,0.714,1.000)
C_{13}	(0.448,0.793,1.000)	(0.621,0.966,1.000)	(0.448,0.793,1.000)	(0.310,0.655,1.000)
C_{14}	(0.579,0.842,1.000)	(0.474,0.737,1.000)	(0.711,0.974,1.000)	(0.474,0.737,1.000)
C_{15}	(0.711,0.974,1.000)	(0.579,0.842,1.000)	(0.105,0.368,0.632)	(0.474,0.737,1.000)
C_{16}	(0.355,0.677,1.000)	(0.355,0.677,1.000)	(0.484,0.806,1.000)	(0.355,0.677,1.000)
C_{21}	(0.000,1.000,1.000)	(0.000,1.000,1.000)	(0.000,1.000,1.000)	(0.000,1.000,1.000)
C_{22}	(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}	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)
C_{24}	(0.286,0.643,1.000)	(0.286,0.643,1.000)	(0.286,0.643,1.000)	(0.286,0.643,1.000)
C_{25}	(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}	(0.444,0.722,1.000)	(0.417,0.694,0.972)	(0.444,0.722,1.000)	(0.444,0.722,1.000)
C_{32}	(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}	(0.630,1.000,1.000)	(0.593,0.963,1.000)	(0.593,0.963,1.000)	(0.593,0.963,1.000)
C_{34}	(0.694,0.972,1.000)	(0.694,0.972,1.000)	(0.722,1.000,1.000)	(0.444,0.722,1.000)
C_{41}	(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}	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)
C_{43}	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)	(0.000,0.500,1.000)
C_{44}	(0.407,0.778,1.000)	(0.407,0.778,1.000)	(0.222,0.593,0.963)	(0.259,0.630,1.000)
C_{51}	(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}	(0.667,1.000,1.000)	(0.467,0.800,1.000)	(0.667,1.000,1.000)	(0.633,0.967,1.000)
C_{53}	(0.667,1.000,1.000)	(0.333,0.667,1.000)	(0.667,1.000,1.000)	(0.333,0.667,1.000)
C_{54}	(0.722,1.000,1.000)	(0.722,1.000,1.000)	(0.417,0.694,0.972)	(0.694,0.972,1.000)
C_{61}	(0.074,0.222,0.370)	(0.519,0.550,0.578)	(0.807,0.822,0.844)	(0.000,0.148,0.222)
C_{62}	(0.000,0.080,0.300)	(0.800,0.840,0.900)	(0.900,0.960,1.000)	(0.200,0.320,0.400)
C_{63}	(0.556,0.833,1.000)	(0.556,0.833,1.000)	(0.556,0.833,1.000)	(0.444,0.722,1.000)
C_{64}	(0.000,0.025,0.275)	(0.000,0.250,0.500)	(0.275,0.525,0.775)	(0.000,0.250,0.500)

Step 4. Sub-criteria are aggregated to criteria level with the help of equation 18. Calculations are indicated for P_1 and the other results are listed in Table 6.22.

$\tilde{y}_{11} = (y^1{}_{11}, y^2{}_{11}, y^3{}_{11})$

$$= \frac{((0.73,0.98,1.00)\otimes(0.70,0.95,0.98))\oplus((0.69,0.97,1.00)\otimes(0.48,0.73,0.98))\oplus((0.62,0.97,1.00)\ \otimes(0.35,0.60,0.85))}{(0.70,0.95,0.98)\oplus(0.48,0.73,0.98)\oplus(0.35,0.60,0.85)\oplus(0.55,0.80,0.95)\oplus(0.45,0.70,0.95)\oplus(0.50,0.75,1.00)}$$

$$+ \frac{((0.71,0.97,1.00)\otimes(0.56,0.80,0.95))\oplus((0.71,0.97,1.00)\otimes(0.45,0.70,0.95))}{(0.70,0.95,0.98)\oplus(0.48,0.73,0.98)\oplus(0.35,0.60,0.85)\oplus(0.55,0.80,0.95)\oplus(0.45,0.70,0.95)\oplus(0.50,0.75,1.00)}$$

$$+ \frac{((0.65,0.97,1.00)\otimes(0.50,0.75,1.00))}{(0.70,0.95,0.98)\oplus(0.48,0.73,0.98)\oplus(0.35,0.60,0.85)\oplus(0.55,0.80,0.95)\oplus(0.45,0.70,0.95)\oplus(0.50,0.75,1.00)}$$

$\tilde{y}_{11} = (0.689,0.972,1.000)$

$\tilde{y}_{12} = (y^1{}_{12}, y^2{}_{12}, y^3{}_{12})$

$$= \frac{((0.00,1.00,1.00)\otimes(0.75,1.00,1.00)\ )\oplus((0.75,1.00,1.00)\otimes(0.50,0.075,1.00))\oplus((0.00,0.50,1.00)\ \otimes(0.00,0.25,0.50))}{(0.75,1.00,1.00)\oplus(0.50,0.75,1.00)\oplus(0.00,0.25,0.50)\oplus(0.20,0.43,0.68)\oplus(0.33,0.58,0.83)}$$

$$+ \frac{((0.29,0.64,1.00)\otimes(0.20,0.43,0.68))\oplus((0.73,0.98,1.00)\otimes(0.33,0.58,0.83))}{(0.75,1.00,1.00)\oplus(0.50,0.75,1.00)\oplus(0.00,0.25,0.50)\oplus(0.20,0.43,0.68)\oplus(0.33,0.58,0.83)}$$

$\tilde{y}_{12} = (0.376,0.903,1.000)$

$\tilde{y}_{13} = (y^1{}_{13}, y^2{}_{13}, y^3{}_{13})$

$$= \frac{((0.69,0.97,1.00)\otimes(0.35,0.60,0.85))\oplus((0.75,1.00,1.00)\otimes(0.33,0.58,0.83))\oplus((0.63,1.00,1.00)\otimes(0.60,0.85,1.00))}{(0.35,0.60,0.85)\oplus(0.33,0.58,0.83)\oplus(0.60,0.85,1.00)\oplus(0.35,0.60,0.85)}$$

$$+ \frac{((0.72,100,1.00)\otimes(0.35,0.60,0.85))}{(0.35,0.60,0.85)\oplus(0.33,0.58,0.83)\oplus(0.60,0.85,1.00)\oplus(0.35,0.60,0.85)}$$

$\tilde{y}_{13} = (0.688,0.994,1.000)$

$\tilde{y}_{14} = (y^1{}_{14}, y^2{}_{14}, y^3{}_{14})$

$$= \frac{((0.75,1.00,1.00)\otimes(0.73,0.98,1.00))\oplus((0.00,0.50,1.00)\otimes(0.73,0.98,1.00))\oplus((0.00,0.50,1.00)\otimes(0.73,0.98,1.00))}{(0.73,0.98,1.00)\oplus(0.73,0.98,1.00)\oplus(0.73,0.98,1.00)\oplus(0.73,0.98,1.00)}$$

$$+ \frac{((0.41,0.78,1.00)\otimes(0.73,0.98,1.00))}{(0.73,0.98,1.00)\oplus(0.73,0.98,1.00)\oplus(0.73,0.98,1.00)\oplus(0.73,0.98,1.00)}$$

$\tilde{y}_{14}$ = (0.289,0.694,1.000)

$\tilde{y}_{15} = (y^1{}_{15}, y^2{}_{15}, y^3{}_{15})$

$$= \frac{\big((0.50,0.75,1.00)\otimes(0.23,0.48,0.73)\big)\oplus\big((0.67,1.00,1.00)\otimes(0.50,0.75,1.00)\big)\oplus\big((0.67,1.00,1.00)\otimes(0.48,0.73,0.98)\big)}{(0.23,0.48,0.73)\oplus(0.50,0.75,1.00)\oplus(0.48,0.73,0.98)\oplus(0.75,1.00,1.00)}$$

$$+ \frac{\big((0.72,1.00,1.00)\otimes(0.75,1.00,1.00)\big)}{(0.23,0.48,0.73)\oplus(0.50,0.75,1.00)\oplus(0.48,0.73,0.98)\oplus(0.75,1.00,1.00)}$$

$\tilde{y}_{15}$ = (0.669,0.960,1.000)

$\tilde{y}_{16} = (y^1{}_{16}, y^2{}_{16}, y^3{}_{16})$

$$= \frac{\big((0.70,0.72,0.78)\otimes(0.48,0.73,0.98)\big)\oplus\big((0.60,0.70,0.80)\otimes(0.10,0.33,0.58)\big)\oplus\big((0.56,0.83,1.00)\otimes(0.30,0.55,0.70)\big)}{(0.48,0.73,0.98)\oplus(0.10,0.33,0.58)\oplus(0.30,0.55,0.70)\oplus(0.58,0.83,0.98)}$$

$$+ \frac{\big((0.00,0.15,0.40)\otimes(0.58,0.83,0.98)\big)}{(0.48,0.73,0.98)\oplus(0.10,0.33,0.58)\oplus(0.30,0.55,0.70)\oplus(0.58,0.83,0.98)}$$

$\tilde{y}_{16}$ = (0.387,0.549,0.716)

Table 6:22: Aggregated values from sub-criteria level to criteria level ($\tilde{y}_{ij}$)

Main Criterion	P_1	P_2	P_3	P_4
C_1	(0.689,0.972,1.000)	(0.112,0.348,0.636)	(0.543,0.822,1.000)	(0.000,0.275,0.566)
C_2	(0.376,0.903,1.000)	(0.159,0.680,0.869)	(0.335,0.860,1.000)	(0.099,0.624,0.811)
C_3	(0.688,0.994,1.000)	(0.075,0.365,0.665)	(0.620,0.925,1.000)	(0.060,0.359,0.655)
C_4	(0.289,0.694,1.000)	(0.056,0.461,0.866)	(0.246,0.651,1.000)	(0.000,0.405,0.810)
C_5	(0.669,0.960,1.000)	(0.135,0.390,0.681)	(0.658,0.950,1.000)	(0.000,0.261,0.555)
C_6	(0.387,0.549,0.716)	(0.536,0.710,0.867)	(0.397,0.594,0.744)	(0.517,0.693,0.873)

Table 6.22: Aggregated values from sub-criteria level to criteria level ($\tilde{y}_{ij}$) (continued)

Main Criterion	P_5	P_6	P_7	P_8
C_1	(0.522,0.807,1.000)	(0.509,0.794,1.000)	(0.442,0.720,0.895)	(0.434,0.715,1.000)
C_2	(0.142,0.691,0.875)	(0.374,0.901,1.000)	(0.124,0.669,0.869)	(0.234,0.773,0.956)
C_3	(0.623,0.925,1.000)	(0.528,0.824,0.958)	(0.585,0.886,0.994)	(0.510,0.806,1.000)
C_4	(0.289,0.694,1.000)	(0.289,0.694,1.000)	(0.143,0.548,0.953)	(0.190,0.595,1.000)
C_5	(0.677,0.972,0.995)	(0.562,0.863,1.000)	(0.494,0.776,0.895)	(0.568,0.860,1.000)
C_6	(0.139,0.275,0.466)	(0.340,0.551,0.703)	(0.551,0.742,0.885)	(0.106,0.336,0.507)

Step 5. A linear normalization procedure is applied to the aggregated performance scorings at criteria level by means of equation 19. Calculations are indicated for P_1 and the other results are listed in Table 6.23.

Technological Issues (C_1): $y_1^* = 1.00$ and $y_1^- = 0.00$

$$\tilde{y}'_{11} = \left(\frac{0.689 - 0.00}{1.00 - 0.00}, \frac{0.972 - 0.00}{1.00 - 0.00}, \frac{1.00 - 0.00}{1.00 - 0.00}\right) = (0.689, 0.972, 1.000)$$

Environmental Issues (C_2): $y_2^* = 1.00$ and $y_2^- = 0.099$

$$\tilde{y}'_{12} = \left(\frac{0.376 - 0.099}{1.00 - 0.099}, \frac{0.903 - 0.099}{1.00 - 0.099}, \frac{1.00 - 0.099}{1.00 - 0.099}\right) = (0.308, 0.892, 1.000)$$

Marketing Issues (C_3): $y_3^* = 1.00$ and $y_3^- = 0.06$

$$\tilde{y}'_{13} = \left(\frac{0.688 - 0.06}{1.00 - 0.06}, \frac{0.994 - 0.06}{1.00 - 0.06}, \frac{1.00 - 0.06}{1.00 - 0.06}\right) = (0.668, 0.993, 1.000)$$

Organizational Issues (C_4): $y_4^* = 1.00$ and $y_4^- = 0.00$

$$\tilde{y}'_{14} = \left(\frac{0.289 - 0.00}{1.00 - 0.00}, \frac{0.694 - 0.00}{1.00 - 0.00}, \frac{1.00 - 0.00}{1.00 - 0.00}\right) = (0.289, 0.694, 1.000)$$

National Advantages Issues (C_5): $y_5^* = 1.00$ and $y_5^- = 0.00$

$$\tilde{y}'_{15} = \left(\frac{0.669 - 0.00}{1.00 - 0.00}, \frac{0.96 - 0.00}{1.00 - 0.00}, \frac{1.00 - 0.00}{1.00 - 0.00}\right) = (0.669, 0.960, 1.000)$$

Financial Issues (C_6): $y_6^* = 0.855$ and $y_6^- = 0.106$

$$\tilde{y}'_{16} = \left(\frac{0.387 - 0.106}{0.855 - 0.106}, \frac{0.549 - 0.106}{0.855 - 0.106}, \frac{0.716 - 0.106}{0.855 - 0.106}\right) = (0.361, 0.568, 0.783)$$

Table 6:23: Normalized values of aggregated scorings at criteria level ($\tilde{y}'_{ij}$)

Main Criterion	P_1	P_2	P_3	P_4
C_1	(0.689,0.972,1.000)	(0.112,0.348,0.638)	(0.543,0.822,1.000)	(0.000,0.275,0.566)
C_2	(0.308,0.892,1.000)	(0.067,0.645,0.855)	(0.262,0.844,1.000)	(0.000,0.582,0.791)
C_3	(0.668,0.993,1.000)	(0.016,0.325,0.644)	(0.596,0.920,1.000)	(0.000,0.318,0.633)
C_4	(0.289,0.694,1.000)	(0.056,0.461,0.866)	(0.246,0.651,1.000)	(0.000,0.405,0.810)
C_5	(0.669,0.960,1.000)	(0.135,0.390,0.681)	(0.658,0.950,1.000)	(0.000,0.261,0.555)
C_6	(0.361,0.568,0.783)	(0.552,0.776,0.977)	(0.373,0.626,0.819)	(0.528,0.753,0.985)

Table 6.23: Normalized values of aggregated performance scorings at criteria level ($\tilde{y}'_{ij}$) (continued)

Main Criterion	P_5	P_6	P_7	P_8
C_1	(0.522,0.807,1.000)	(0.509,0.794,1.000)	(0.442,0.720,0.895)	(0.434,0.715,1.000)
C_2	(0.048,0.658,0.861)	(0.305,0.891,1.000)	(0.029,0.632,0.855)	(0.150,0.748,0.951)
C_3	(0.599,0.920,1.000)	(0.498,0.813,0.956)	(0.559,0.879,0.994)	(0.479,0.794,1.000)
C_4	(0.289,0.694,1.000)	(0.289,0.694,1.000)	(0.143,0.548,0.953)	(0.190,0.595,1.000)
C_5	(0.677,0.972,0.995)	(0.562,0.863,1.000)	(0.494,0.776,0.895)	(0.568,0.860,1.000)
C_6	(0.043,0.217,0.462)	(0.301,0.571,0.767)	(0.571,0.817,1.000)	(0.000,0.296,0.515)

Step 6. The ideal and the anti-ideal solution are defined.

$$A^* = r_j^* = ((1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1))$$

$$A^- = r_j^- = ((0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0))$$

Step 7. The weighted distances from ideal solution and anti-ideal solution are calculated for each option by using equation 20 and 21.

$$\begin{aligned} D_1^* = {} & 1/2\{\max(0.60 * |0.689-1|, 1.00 * |1.00-1|) + 0.85 * |0.972-1|\} \\ & + 1/2\{\max(0.475 * |0.308-1|, 0.975 * |1.00-1|) + 0.725 * |0.892-1|\} \\ & + 1/2\{\max(0.10 * |0.668-1|, 0.60 * |1.00-1|) + 0.35 * |0.993-1|\} \\ & + 1/2\{\max(0.475 * |0.289-1|, 0.975 * |1.00-1|) + 0.725 * |0.694-1|\} \\ & + 1/2\{\max(0.325 * |0.669-1|, 0.825 * |1.00-1|) + 0.575 * |0.960-1|\} \\ & + 1/2\{\max(0.725 * |0.361-1|, 1.00 * |0.783-1|) + 0.975 * |0.568-1|\} \\ & = 1.11 \end{aligned}$$

$D_2^* = 2.13$

$D_3^* = 1.26$

$D_4^* = 2.37$

$D_5^* = 1.68$

$D_6^* = 1.35$

$D_7^* = 1.45$

$D_8^* = 1.80$

$$D_1^- = 1/2\{\max(0.60 * |0.689 - 0|, 1.00 * |1.00 - 0|) + 0.85 * |0.972 - 0|\}$$
$$+ 1/2\{\max(0.475 * |0.308 - 0|, 0.975 * |1.00 - 0|) + 0.725 * |0.892 - 0|\}$$
$$+ 1/2\{\max(0.10 * |0.668 - 0|, 0.60 * |1.00 - 0|) + 0.35 * |0.993 - 0|\}$$
$$+ 1/2\{\max(0.475 * |0.289 - 0|, 0.975 * |1.00 - 0|) + 0.725 * |0.694 - 0|\}$$
$$+ 1/2\{\max(0.325 * |0.669 - 0|, 0.825 * |1.00 - 0|) + 0.575 * |0.960 - 0|\}$$
$$+1/2\{\max(0.725 * |0.361 - 0|, 1.00 * |0.783 - 0|) + 0.975 * |0.568 - 0|\}$$
$$= 4.03$$

$$D_2^- = 3.13$$

$$D_3^- = 3.96$$

$$D_4^- = 2.87$$

$$D_5^- = 3.46$$

$$D_6^- = 3.88$$

$$D_7^- = 3.73$$

$$D_8^- = 3.47$$

Step 8. The adjacency of the options to the ideal solution, Ω_i^*, are performed by regarding the distances from ideal and anti-ideal solutions by using equation 22.

$$\Omega_1^* = 4.03/(1.11 + 4.03) = 0.78$$

$$\Omega_2^* = 3.13/(2.13 + 3.13) = 0.60$$

$$\Omega_3^* = 3.96/(1.26 + 3.96) = 0.76$$

$$\Omega_4^* = 2.87/(2.37 + 2.87) = 0.55$$

$$\Omega_5^* = 3.46/(1.68 + 3.46) = 0.67$$

$$\Omega_6^* = 3.88/(1.35 + 3.88) = 0.74$$

$$\Omega_7^* = 3.73/(1.45 + 3.73) = 0.72$$

$$\Omega_8^* = 3.47/(1.80 + 3.47) = 0.66$$

Step 9. The options are ranked with respect to Ω_i^* values in diminishing order in Table 6.24. P_1 is the best option according to the ranking.

Table 6:24: Rankings of projects

Project	Ω_{i}^*	Ranking
P_1	0.7834	1
P_2	0.5955	7
P_3	0.7580	2
P_4	0.5478	8
P_5	0.6733	5
P_6	0.7417	3
P_7	0.7199	4
P_8	0.6580	6

6.4 Application of Fuzzy Integral

Step 1. The decision-making team, alternates, main criteria and sub-criteria are settled (see tables 6.1 - 6.3).

Step 2. The scorings of each alternate according to each sub-criterion, importance value of each sub-criterion and importance value of each main criterion are accomplished by each decision maker (see tables 6.4 – 6.15).

Step 3. The OWA weights are computed as stated in Section 6.2. The weights are obtained as **w** = (0.0, 0.4, 0.5, 0.1).

Step 4. The aggregated scorings of each alternate according to each sub-criterion, the aggregated importance values of each sub-criterion and, the aggregated importance values of each main criterion are also achieved (see tables 6.18-6.20).

Step 5. The aggregated values in Table 6.18 are normalized by using equation 32. Calculations are shown for P_1 and the other normalized results are listed in Table 6.21.

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, $d^*_{ijk} = d_v(\tilde{r}_{ijk}, \tilde{P}^*)$; $wd^*_{jk} = d_v(\tilde{w}_{jk}, \tilde{P}^*)$; $wd^*_j = d_v(\tilde{w}_j, \tilde{P}^*)$; $d^-_{ijk} = d_v(\tilde{r}_{ijk}, \tilde{P}^-)$; $wd^-_{jk} = d_v(\tilde{w}_{jk}, \tilde{P}^-)$; $wd^-_j = d_v(\tilde{w}_j, \tilde{P}^-)$, are calculated regarding the Equation 33.

$$d^*_{111} = 1/2(\max(|0.725 - 1|, |1.000 - 1|) + |0.975 - 1|) = 0.150$$

$$wd^*_{11} = 1/2(\max(|0.700 - 1|, |0.975 - 1|) + |0.950 - 1|) = 0.175$$

$$wd^*_1 = 1/2(\max(|0.600 - 1|, |1.000 - 1|) + |0.850 - 1|) = 0.275$$

$$d^-_{111} = 1/2(\max(|0.725 - 0|, |1.000 - 0|) + |0.975 - 0|) = 0.988$$

$wd_{11}^{-} = 1/2(\max(|0.700 - 0|, |0.975 - 0|) + |0.950 - 0|) = 0.963$

$wd_{1}^{-} = 1/2(\max(|0.600 - 0|, |1.000 - 0|) + |0.850 - 0|) = 0.925$

Step 7. The transformation values of fuzzy weights of criteria and sub-criteria are calculated by using Equation 34-35. The results are listed in Table 6.25 - 6.26.

Table 6:25: The transformation values of sub-criteria (RW_{jk})

Sub Criterion	RW_{jk}
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_{21}	0.889
C_{22}	0.700
C_{23}	0.300
C_{24}	0.444
C_{25}	0.560
C_{31}	0.580
C_{32}	0.560
C_{33}	0.771
C_{34}	0.580
C_{41}	0.868
C_{42}	0.868
C_{43}	0,868
C_{44}	0.868
C_{51}	0.480
C_{52}	0.700
C_{53}	0.680
C_{54}	0.889
C_{61}	0.680
C_{62}	0.364
C_{63}	0.521
C_{64}	0.750

Table 6:26: The transformation values of criteria (RW_j)

Main Criterion	RW_j
C_1	0.771
C_2	0.680
C_3	0.380
C_4	0.680
C_5	0.560
C_6	0.868

Step 8. The transformation values of normalized fuzzy evaluations are calculated by means of Equation 36. The results are listed in Table 6.27.

Table 6:27: 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

Step 9. λ values of fuzzy scales and FI values of entire options according to each criterion are calculated by means of Equation 27, 30 and 31 by setting $g(A_1) = g^1 = RW_1$. The results are listed in Table 6.28.

Calculations for Technological Issues (C_1) and P_1:

- λ calculation

$1 + \lambda = (1+(\lambda*0.846))*(1+(\lambda*0.68))*(1+(\lambda*0.58))*(1+(\lambda*0.729))*(1+(\lambda*0.66))$

$\lambda = -0.99942$

- g(K_j) calculation: RI_{ijk} values are reordered before computing g(K_j).

$$g(K_1) = g^1 = 0.846$$

$$g(K_2) = 0.846 + 0.729 + (-0.99942 * 0.846 * 0.729) = 0.959$$

$$g(K_3) = 0.959 + 0.660 + (-0.99942 * 0.959 * 0.660) = 0.986$$

$$g(K_4) = 0.986 + 0.680 + (-0.99942 * 0.986 * 0.680) = 0.996$$

$$g(K_5) = 0.996 + 0.700 + (-0.99942 * 0.996 * 0.700) = 0.999$$

$$g(K_6) = 0.999 + 0.580 + (-0.99942 * 0.999 * 0.580) = 1.000$$

Table 6:28: λ values of fuzzy scales and FI values

	Technical	Environmental	Marketing	Organizational	National Adv.	Financial
λ	-0.99942	-0.99383	-0.97935	-0.99969	-0.99400	-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

Step 10. Final FI values are calculated, and options are ranked according to final FI values in decreasing order. The results are listed in Table 6.29.

Table 6:29: Final FI values and ranking

Project	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

7 DISCUSSION AND CONCLUSION

Choosing the most appropriate project that match up with the organization's goals is getting much more importance under restricted resources. The main reason is that 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 will provide strategic way for the organization. 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. It can be predicted that a considerable effort needs to select the best alternative. For this reasons, decision-maker require a scientific guide to select and evaluate R&D projects.

In this study, hierarchical fuzzy MCDM method and fuzzy integral method are implemented to select the best R&D project in a company which has a R&D center authorized by T.C: Ministry of Industry and Technology. Selection criteria are determined by means of literature. A hierarchical structure for criteria including 6 main criteria and 27 sub-criteria are constructed. 4 decision-makers and 8 projects take part for selection process. Decision-makers are asked to rate from 1 to 5 (from very low importance to very high importance) projects according to each sub criteria. They were also entailed to rate each main criterion and each sub-criterion with same scale. These ratings are converted into corresponding linguistic terms and then corresponding fuzzy values with the help of triangular fuzzy numbers. OWA aggregation technique is applied to weight decision makers and aggregate their ratings.

After aggregation step, hierarchical fuzzy MCDM method and fuzzy integral method are applied separately. The ranking obtained by hierarchical fuzzy MCDM methodology is $P_1 \succ P_3 \succ P_6 \succ P_7 \succ P_5 \succ P_8 \succ P_2 \succ P_4$ whereas the ranking acquired by fuzzy integral is $P_3 \succ P_6 \succ P_1 \succ P_5 \succ P_7 \succ P_4 \succ P_8 \succ P_2$.

When the rankings are examined, P_1, P_3 and P_6 can be thought as the most appropriate projects considering technical, financial and national issues. If P_5 and P_8 are taken into account, they were expected to be in higher position in ranking since they have high scorings. Their rankings can be explained by investment cost criteria. Both P_5 and P_8 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.

The factors which has a potential to affect the result can be also taken into account when evaluating the final result. Ratings of criteria without conflict and prejudice is hard in various real-world multi-criteria project selections. Many decision makers attempt to achieve this goal according to her/his own preference and her/his own past experiences. Nevertheless, such individual knowledge is hard 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.

In conclusion, 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.

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