A Hybrid Fuzzy Model To The Ranking Problem of Companies operating R&D Activities in Technology Innovation Centers

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A Hybrid Fuzzy Model To The Ranking Problem of Companies Operating R&D Activities in Technology Innovation Centers

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Abstract

Technology innovation centers where universities share information with industry collaborations and institutions and have a wide range of companies in its field. Developing technology and competition have forced to make innovations, the companies in technology innovation centers operating Research and Development (R&D) activities have tried to prove themselves by proposing different projects to industrial organizations and making innovations and they are still working since they may get some promotions from the government. A decision for ranking companies has a number of criteria, which range from financial incentives and infrastructure to R&D activities. Most of the criteria are based on linguistic terms that decision makers can express with fuzzy statements. For this reason, in this study, the problem for ranking the companies operating R&D activities is solved by using a hybrid model, combining the Fuzzy Analytic Hierarchy Process and Fuzzy TOPSIS methods. Four different main decision criteria, 16 sub-criteria and three random companies were considered for this study. A network was formed, and surveys were carried out with the opinions of the experts on R&D activities and including experts from some technology development zones of Turkey. The proposed hybrid model was applied successfully to a case study for the ranking the companies operating R&D activities in Çukurova University Technology Development Zone in Turkey. Using actual data, it is showed the applicability of the proposed approach and compare the best alternative obtained by the proposed method for three companies in Çukurova University Technology Development Zone in Turkey.

Keywords: Fuzzy AHP, Fuzzy TOPSIS, Technology Innovation Centers, Ranking Companies, R&D

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1. Introduction

The basis of the infrastructure of the national innovation system is a technology innovation centers, business incubators, technology parks. These centers are called in different names in the countries. They are designed for the rapid transmission of developments in production, development of high-tech and competitive products [1].

Technology innovation centers where universities share information with industry collaborations and institutions and have a wide range of companies in its field. These centers foster university–industry collaboration which targets combining academic and industrial resources to conduct research and development focused on industry-oriented problems and innovation and, additionally, educating a workforce capable of advancing national technological and economic goals [2]. These companies are operating within the technology innovation centers or by providing benefit to the outside institutions and organizations to commercialize their projects. Developing technology and competition have forced to make innovations and it has triggered the collaboration of companies in the technology innovation centers with the industry. When we look at the World, besides the research and the development activities of the companies in Silicon Valley is one of the pioneers in the market. Silicon Valley can be said to lead the technology development regions in the World with different innovative products. The rapidly developing technology and competitiveness of universally developing technology continued to increase the importance of technology innovation centers. Considering the current situation in the World, the determination of the innovative success of the companies within the Technology innovation centers plays an important role both for the companies and the economy. Recently, the most innovative company lists are formed conducting surveys by different global media company such as Forbes. The surveys include different factors from value creation to industry peer review. This list is not exhaustive, and it is possible to consider many other factors. Therefore, determination of the innovative success of companies can be evaluated as a multi-criteria decision-making problem.

Saaty and Ozdemir [3] conclude *"to serve both consistency and redundancy, it is best to keep the number of elements seven or less. It appears that Miller's seven plus or minus two is indeed a limit, a channel capacity on our ability to process information."* This explains why multi-criteria decision-making models are widely used, as they provide an effective method for acquiring solutions to complex decision-making problems. There exists a geometric system that consists of m-points in a n-dimensional space for a decision-making problem where multi-attributes (n) are considered for alternatives (m) [4]. Analytic Hierarchical Model (AHP), fuzzy AHP and fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods are examples of multi-criteria decision-making models. These methods have been used in different areas including alternative selections, marketing decisions, performance assessments, resource allocations, quality management etc., and we refer readers to the study of Mardani et al. [5] for a comprehensive two-decade review (1994 to 2014) on fuzzy multiple criteria decision-making techniques and applications.

In particular, one application area for multi-criteria decision-making models is to find solutions to ranking problems. Ozkan et al. [6] have evaluated the R&D performance of cities in Turkey. They have used the DEMATEL and ANP methods together while determining the performance criteria of cites. They have made a suggestion using the VIKOR method to list the cities. Yu et al. [7] have proposed an integrated supplier selection approach that includes the risk attitude of the decision maker using ANN, AHP and TOPSIS methods. Mashal and Alsaryrah [8] have proposed a fuzzy analytical hierarchy process model for determining suitable internet of things applications for each user. Dincer, [9] has applied integrated multi-criteria decision-making methods to measure the market competition and concentration in the European Banking Sector. Luna et al. [10] have proposed a new solution to the problem in the sector with fuzzy TOPSIS by determining appropriate criteria to solve the excess consumption and management confusion in aquaculture.

According to the researchers and the opinion of the experts, it is understood worldwide that there are no certain criteria for companies' innovative success ranking. The aim of this study is to make an objective and quantitative evaluation of the companies operating R&D activities. A decision for ranking companies has a number of criteria, which range from financial infrastructure to R&D activities. Most of the criteria are based on linguistic terms that decision makers can express with fuzzy statements. For this reason, in this study the problem for ranking the companies is solved by using a hybrid model, combining the Fuzzy Analytic Hierarchy Process and Fuzzy TOPSIS methods. To the best knowledge of the authors, the study has the distinction of being the first in this field. Four different main decision criteria, sixteen sub criteria and three random companies were considered for this study. A network was formed, and surveys were carried out with the opinions of the experts on R&D activities and from different technology innovation centers of Turkey. The fuzzy AHP technique, which is one of the MCDM methods, was used to determine the weights and fuzzy TOPSIS method was used for the ranking stage of the companies. After the integration of these methods, several companies operating R&D activities in Çukurova University Technology Development Zone were applied for ranking problems and the results of the method were discussed.

2. Fuzzy sets and fuzzy numbers

Zadeh [11] was the first researcher who had the idea of fuzzy set theory: he proposed such a theory to handle vagueness in human thought and expression. Membership grades constitute the basics of objects found within a fuzzy set class definition. In this definition, each object is given a membership attribute and a membership function sets this attribute between 0 and 1.

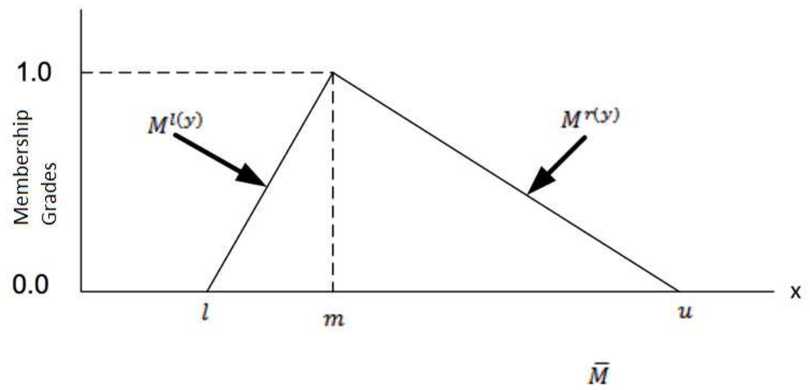

Fig. 1. A triangular fuzzy member

The tilde symbol, '~', is placed above to show that the number represents a fuzzy set. As seen in Fig.1, parameter l represents the smallest possible value, m is the most promising value and u is the largest possible value. A fuzzy event is defined by three parameters $\{l, m, u\}$ and known as a triangular fuzzy number (TFN), $\tilde{M}$.

The membership function of a TFN could be given as;

$$triangle(x; l, m, u) = \begin{cases} 0, & x \le l. \\ \frac{x-l}{m-l}, & l \le x \le m. \\ \frac{u-x}{u-m}, & m \le x \le u. \\ 0, & u \le x \end{cases} \tag{1}$$

A fuzzy number is always characterized using its corresponding left and right membership degrees, where left side and right-side representation of a fuzzy number are denoted by $l(y)$ and $r(y)$, respectively.

$$\begin{aligned} \tilde{M} &= (M^{l(y)}, M^{r(y)}) \\ &= (l + (m-l)y, u + (m-u)y), \quad y \in [0,1] \end{aligned} \tag{2}$$

3. Proposed model

The proposed model was designed to be used in single level multi-attribute decision making (MADM) problems. Fig. 2 shows a general MADM hierarchy when a single decision objective and criteria hierarchies are considered. The goal of the decision-making process is situated on top of the decision hierarchy. In the first stage, criteria set (C), and alternatives (A) are determined according to the context of the decision problem. A common approach to list the alternatives and criteria set is to conduct a market analysis. The method assigns this step to the decision makers, and then the goal is solved through the evaluation of the alternatives according to the criteria provided by the decision makers.

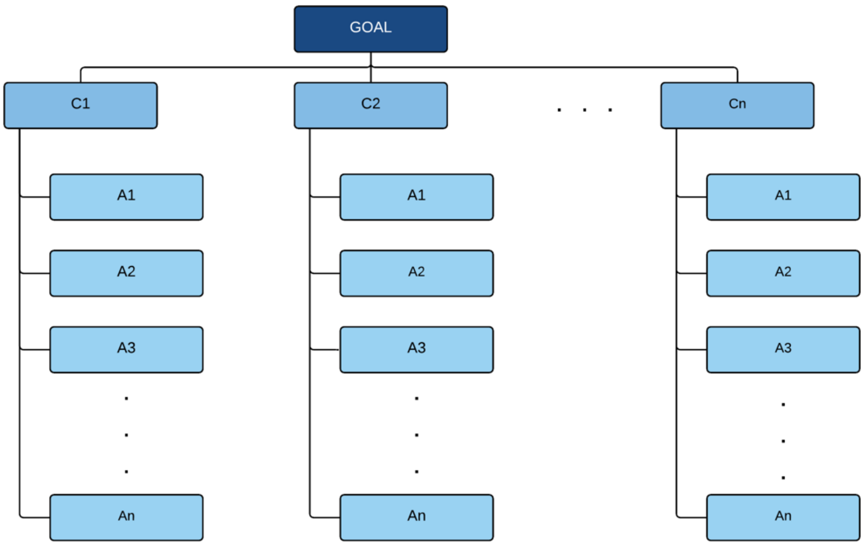

Fig. 2. Criteria and goal hierarchy

In the second stage, Chang's extent analysis model [12] is used in order to calculate criteria weights. Ranking of the alternatives are obtained in the third stage of the model by using fuzzy TOPSIS method. In order to solve MADM, our hybrid model combines theoretical fundamentals from Chang’s extent analysis with fuzzy TOPSIS. Fig. 3 shows the activity diagram for the proposed hybrid model.

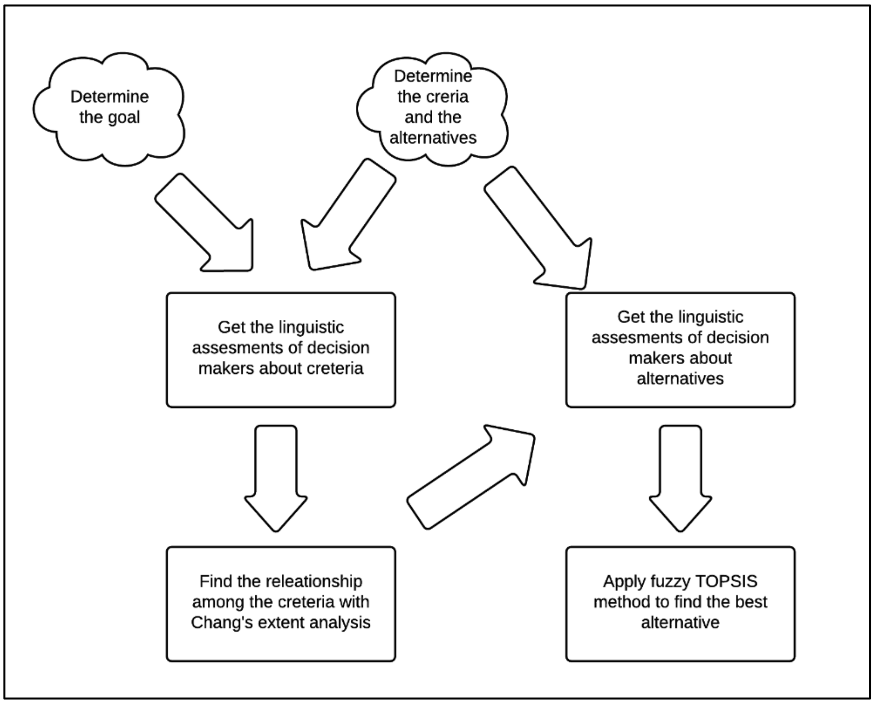

Fig. 3. Hybrid model activity diagram

3.1. Fuzzy analytic hierarchy process for criteria weights

The root of FAHP is extended to fuzzy set theory, which was proposed by Zadeh [11]. Instead of using crisp values, Buckley [13] utilized fuzzy ratios. By doing so, Buckley [13] introduced hierarchical structures analysis environment.

In the second stage of the proposed model, the weights of criteria are calculated by using Chang's extent analysis. Initially, we define $X = \{x_1, x_2, x_3, ..., x_n\}$ *and* $G = \{u_1, u_2, u_3, ..., u_m\}$ as an object set, and as a goal set, respectively. According to the principles of Chang's extent analysis [12], each object is taken correspondingly, and extent analysis for each of the goal, g_i is implemented in order to obtain the values of *m* extent analyses with the following signs:

$$M_{g_i}^1 M_{g_i}^2, ..., M_{g_i}^m, \; i = 1, 2, ..., n \tag{3}$$

where $M_{g_i}^j \; (j = 1, 2, ..., m)$ are triangular fuzzy numbers. After these assumptions are defined, Chang's extent analysis includes four main steps:

Step 1: The value of fuzzy synthetic extent with respect to the i[th] object is defined as,

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1} \tag{4}$$

where $\otimes$ sign represents the multiplication operation on fuzzy numbers. Fuzzy addition operation of *m* extent analysis values is performed for particular matrixes such that:

$$\sum_{j=1}^{n} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{5}$$

$$\sum_{i=1}^{n} \sum_{i=1}^{m} M_{g_i}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{6}$$

$$\left[\sum_{i=1}^{n} \sum_{i=}^{m} M_{g_i}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{7}$$

Step 2: The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1$ is defined as

$V(M_1 \geq M_2) = \sup_{x \geq y} \lfloor \min(\mu_{M_1}(x), \mu_{M_2}(y)) \rfloor$ and it can be denoted as:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_1}(d)$$
$$= \begin{cases} 1, & if \;\; m_2 \geq m_1, \\ 0, & if \;\; l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise, \end{cases} \tag{8}$$

where $hgt(M_1 \cap M_2)$ stands for the height of a fuzzy set and it is the supremum (maximum) of the membership grades of $(M_1 \cap M_2)$ and d is the ordinate of the highest intersection point between μ_{M_1} and μ_{M_2}. The values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ are needed in order to compare accordingly.

Step 3: The degree possibility for a convex fuzzy number to be greater than *k* convex fuzzy numbers M_i $(i = 1, 2, \ldots, k)$ can be defined by

$$V(M \geq M_1, M_2, \ldots M_k) = V[(M \geq M_1) \; and \; (M \geq M_2) \ldots \; and (M \geq M_k)] \tag{9}$$

$$= \min V(M \geq M_i), i = 1,2,3, \ldots k$$

Assume that, $d(A_i) = \min \;\; V(S_i \geq S_k), \; for = 1,2,3,\cdots n; \; k \neq i.$ Then, the weight vector is given by $W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T$, where $A_i \left(i = 1,2,3,\cdots n\right)$ are *n* elements.

Step 4: *N*ormalized weight vectors $W = (d(A_1), d(A_2), \ldots, d(A_n))^T$ are obtained after normalization. W is a nonfuzzy number that represents priority weights of attributes [12].

3.2. Fuzzy TOPSIS for alternative ranking

In the third stage of the proposed model, the alternatives are ranked using fuzzy TOPSIS method. There are numerous techniques in order to sort the alternatives based on a criterion set such as fuzzy ELECTRE, fuzzy TOPSIS, fuzzy AHP, fuzzy PROMETHEE and fuzzy MCDM approaches [4, 14, 15]. TOPSIS method was first proposed by Hwang and Yoon [16]. TOPSIS method is built on the shortest distance and longest distance mechanism. A preferable solution should have a short distance to the positive-ideal solution and long distance to negative ideal solution. Therefore, in order to be ranked first an alternative must have both shortest distance to positive ideal solution and farthest distance to negative ideal solution at the same time. The term *Ideal solution* is used to show the best criteria value, which is attainable from the alternatives in consideration. *Negative ideal solution* is used to indicate the opposite: worst criteria value which is attainable from the alternatives in consideration [17]. However, it is not generally feasible to get direct value from a decision maker about any criteria in a typical decision problem.

When decision maker evaluations are vague, fuzzy logic substitutes as a good method to be used in solving MADM problems. When fuzzy theory is used along with TOPSIS method then it is called fuzzy TOPSIS. Fuzzy TOPSIS is developed as an extension of TOPSIS in order to encapsulate linguistic evaluations of alternatives and criteria. A great number of applications for fuzzy TOPSIS could be found in the literature [4,5,18-22].

3.2.1. Alternative set definition and obtaining decision maker linguistic assessment

At the beginning of the Fuzzy TOPSIS method, the alternatives are assessed with respect to each criterion using linguistic values given in Table 1, accordingly.

Table 1. Saaty's 1–9 linguistic scale [23]

Linguistic terms	Triangular fuzzy numbers	Intensity of importance
Equal	$\tilde{1}$	(1,1,1)
Weak	$\tilde{3}$	(2/3,1,3/2)
Fairly strong	$\tilde{5}$	(3/2,2,5/2)
Very strong	$\tilde{7}$	(5/2,3,7/2)
Absolutely	$\tilde{9}$	(7/2,4,9/2)

The fuzzy assessment values are held in $\widetilde{\mathrm{Y}}$ matrix. $\tilde{\mathrm{y}}_{\mathrm{ij}}$ holds the specific assessment of the decision maker for alternative i according to criteria j where $(i = 1,2, \dots, k), (j = 1,2, \dots, l)$ and k is the number of alternatives and l is the number of criteria at the lowest level of the decision hierarchy.

3.2.2. Normalizing fuzzy assessment matrix

Normalized value $\tilde{n}_{ij} = (n_{ij,l},\ n_{ij,m},\ n_{ij,u})$ for alternative *i* according to criteria *j* is calculated as;

$$\tilde{n}_{ij} = \frac{\tilde{x}_{ij}}{\sqrt{\sum_{i=1}^{m}(s(\tilde{x}_{ij},0)^2)}} \quad , j = 1, \dots, n \tag{10}$$

where; $s(\tilde{x}_{ij}, 0) = \frac{1}{4}(x_{ij,l} + 2x_{ij,m} + x_{ij,u})$

3.2.3. Calculating the weighted normalized decision matrix

The weights found in section 3.1 are used while calculating $\tilde{v}_{ij}$. The weighted matrix $\tilde{v}_{ij} = (v_{ij,l}, v_{ij,m}, v_{ij,u})$ is calculated as;

$$\tilde{v}_{ij} = \mathrm{w_j} * \tilde{n}_{ij} \tag{11}$$

3.2.4. Determining the positive ideal solutions and negative ideal solutions

The set of positive ideal solutions and negative ideal solutions are given as follows;

$$\mathrm{A}^+ = \{\tilde{v}_1^+, \tilde{v}_2^+, \dots, \tilde{v}_n^+ = \{(\tilde{v}_{uj} | j \in J), (\tilde{v}_{dj} | j \in J')\} \tag{12}$$

$$\mathrm{A}^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-\} = \{(\tilde{v}_{dj} | j \in J), (\tilde{v}_{uj} | j \in J')\} \tag{13}$$

where *J* is associated with the positive criteria while J' is associated with the negative criteria.

3.2.5. Positive and negative distance calculations of alternatives

Each distance is calculated according to following equations;

$$d_i^+ = \sqrt{\sum_{j=1}^{\mathrm{n}}(s(\tilde{v}_{\mathrm{j}}^+, \tilde{v}_{ij})^2)}, i = 1,2, \dots, m ; \tag{14}$$

$$d_i^- = \sqrt{\sum_{j=1}^{\mathrm{n}}(s(\tilde{v}_{\mathrm{j}}^-, \tilde{v}_{ij})^2)}, i = 1,2, \dots, m) \tag{15}$$

3.2.6. Calculating the relative distances and alternative ranking

Relative distances are computed according to following equations;

$$cl_i^+ = \frac{d_i^+}{d_i^+ + d_i^-}, i = 1, 2, \dots, k \tag{16}$$

$$cl_i^- = \frac{d_i^-}{d_i^+ + d_i^-}, i = 1, 2, \dots, k \tag{17}$$

As mentioned before, in classical TOPSIS method, the most preferred alternative should simultaneously have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution, which also certainly reflects the rational of human choice. Finally, the best alternative could be determined by using cl_i^+ and cl_i^- parameters.

4. Application of the proposed hybrid model to the ranking problem of the companies operating R&D activities

The aim of this study is to determine the success rankings of companies R&D activities by using hybrid method using fuzzy AHP and fuzzy TOPSIS methods. First of all, 4 steps of fuzzy AHP method were applied to this problem and weights were obtained for performance criteria. In the second stage of the study, the fuzzy TOPSIS method was applied with these weights.

4.1. Stage 1: Goal, criteria and hierarchy determination

In this stage, the criteria and their hierarchy were determined. The goal definition for the proposed selection problem was given as; "***Select the most innovative company among three different companies operating in Cukurova Technology Development Zone of Turkey***''. In order to gather the required information pertaining to the selection problem, meetings were held with experts on R&D, including experts from different technology development zones of Turkey. During these meetings, the selection criteria were determined. As a result of the study, the criteria were established under 4 main criteria. These main criteria (MC) are the status of the companies about Financial Infrastructure (MC_1), R&D Activities (MC_2), Institutionalization Sustainability and Ecosystem Development Activities (MC_3) and Intellectual Property (MC_4), respectively. Sub-criteria are also determined for Each main criterion, resulting a hierarchal diagram. there are 3 sub-criteria of the financial incentives and infrastructure main criteria: the share of the staff income tax exemption in the total income (C_{11}), the share of the social security institution tax in the total personnel expense (C_{12}) and the share of corporate tax exemption in total income (C_{13}). The number of sub-criteria related to R&D activities is seven. These criteria include the share of R&D personnel in total staff (C_{21}), the share of R&D expenses in total income (C_{22}), the share of completed projects in the number of ongoing projects (C_{23}), the share of government supported projects in the total number of projects (C_{24}) , The ratio of the budget of government supported projects to the total budget (C_{25}), the ratio of the budget of domestic supported projects to the total budget (C_{26}), the share of the budget of the international supported projects in the total budget (C_{27}). The number of sub-criteria for institutionalization sustainability and ecosystem development activities is three. These criteria are the share of previous year in income of last year income (C_{31}), the share of export revenue in total income (C_{32}), and the share of R & D income in total domestic income (C_{33}). The number of sub-criteria for the last main criterion, Intellectual Property, is three as well. These criteria are the share of the number of registered domestic patent applications in the total number of patent applications (C_{41}), the share of the total number of international patent applications in the total number of patent applications (C_{42}), the share of the registered utility model number in the total utility model applications (C_{43}).

4.2. Stage 2: Finding criteria weights

After determining criteria, the evaluation table was created after a series of meetings with the experts where they outlined their opinions about criteria based on the scale given in Table 2. During these meetings, a consensus shown in Table 3 is reached about criteria.

Table 2. Pair wise comparison scale

Linguistic expression	Triangular Fuzzy Numbers	
	Number	Equivalent of the number
Equally important	(1,1,1)	(1,1,1)
Poorly more important	(2/3, 1, 3/2)	(2/3, 1, 3/2)
Fairly more important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Highly more important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Extremely more important	(7/2, 4, 9/2)	(2/9, 1/4, 2/7)

Table 3. Pairwise Comparison Matrix for Main Criteria

	MC_1	MC_2	MC_3	MC_4
MC_1	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
MC_2	(1,1,1)	(1,1,1)	(1.5, 2,2.5)	(0.4,0.5,0.67)
MC_3	(1,1,1)	(0.4,0.5,0.67)	(1,1,1)	(0.67,1,1.5)
MC_4	(1.5, 2,2.5)	(1,1,1)	(0.67,1,1.5)	(1,1,1)

After applying Step 1 procedures of Chang's methodology to Table 3, the following fuzzy synthetic extent values (S) for each of main criteria were calculated accordingly.

S_{MC1} (4, 4, 4) x (1/19.34, 1/17, 1/15.14) = (0.21, 0.24, 0.26)

S_{MC2} (3.9, 4.5, 5.17) x (1/19.34, 1/17, 1/15.14) = (0.20, 0.26, 0.34)

S_{MC3} (3.07, 3.5, 4.17) x (1/19.34, 1/17, 1/15.14) = (0.16, 0.21, 0.28)

S_{MC4} (4.17, 5, 6) x (1/19.34, 1/17, 1/15.14) = (0.22, 0.29, 0.40)

Based on the previously calculated fuzzy synthetic extent values and procedures in Step 3, the following V(Si>Sj) values were obtained. Values are found as explained in step two of Chang's methodology.

Table 4. Degree of possibility fuzzy number assessment for main criteria

$V(S_i>S_j)$	S_{MC1}	S_{MC2}	S_{MC3}	S_{MC4}
S_{MC1}	-	0.80	1.00	1.00
S_{MC2}	0.44	-	0.70	1.00
S_{MC3}	1	1	-	1.00
S_{MC4}	1	1	0.42	-

Next, the weight for each criterion was calculated by applying the following equation to Table 4;

$d(A_i) = \min V(S_i \geq S_k)$. Therefore, the minimum values of rows were used for calculating W_G. Then, W_G values were normalized between 0 and 1.

$W_G =$ (0.44 0.80 0.42 1.00)

Normalized $W_G =$ (0.16 0.30 0.16 0.38)

Weights give the decision makers the importance of the criteria. Thus, criteria importance depends on the magnitude of such criteria weight. According to calculated weights, MC_4 (Intellectual Property) is the most important criteria among them.

4.2.1 Finding sub criteria weights

After determining sub-criteria for all main criteria, calculations were created based on applying procedures of Chang's methodology. Table 5 shows the weights of the main criteria and the weights obtained by integrating the weights of the sub criteria in accordance with the hierarchical structure formed after the weights of each sub-criterion have been found.

Table 5. Integration of Main Criteria Weights to Lower Criteria Weights

Main Criteria	Main Criteria Weights	Sub-Criteria	Sub-Criteria Weights	Integration of Weight of Main Criteria and Sub-Criteria
MC_1	0.16	C_{11}	0.68	0.11
		C_{12}	0.16	0.02
		C_{13}	0.16	0.02
MC_2	0.30	C_{21}	0.26	0.08
		C_{22}	0.21	0.06
		C_{23}	0.21	0.06
		C_{24}	0.14	0.04
		C_{25}	0.14	0.04
		C_{26}	0.14	0.04
		C_{27}	0.09	0.03
MC_3	0.16	C_{31}	0.46	0.07
		C_{32}	0.23	0.04
		C_{33}	0.53	0.08
MC_4	0.38	C_{41}	0.29	0.11
		C_{42}	0.24	0.09
		C_{43}	0.47	0.18

If the first three rankings of the sub-criteria are to be made; Institutionalization Regarding the main criterion of Sustainability and Ecosystem Development Activity, stating the ratio of R&D revenue to total domestic income C_{33} takes first place. In the second place, C_{41}, stating the ratio of the number of registered domestic patents of the intellectual property main criterion to the total number of patents, and C_{42} stating the ratio of the number of registered patents of the intellectual property main criterion to the total number of patent applications. Other criteria are from small to large respectively; C_{27}, C_{24}, C_{26}, C_{25}, C_{23}, C_{22}, C_{21}, C_{31}, C_{12}, C_{13}, C_{11}, C_{31}, C_{43}, C_{33}. The lowest criterion is C_{27}, which is the ratio of the budget of the projects supported abroad to the total budget of all projects.

4.3. Stage 3: Applying Fuzzy TOPSIS

At this stage of the study, a case study was performed on three random companies operating R&D activities in Çukurova University Technology Development Zone using fuzzy TOPSIS method. The experts evaluated these three alternative companies with regards to the evaluation criteria using linguistic terms. The linguistic terms were converted to fuzzy values using Table 1. After getting fuzzy values for the port site selection problem, the normalized fuzzy assessment table was derived. Weights obtained were used in order to find weighted normalized decision matrix, given in Table 6.

Table 6. Weighted normalized decision matrix

Criterion	A1	A2	A3	Criterion	A1	A2	A3
C_{11}	(0.1, 0.1, 0.1)	(0.0, 0.1, 0.1)	(0.0, 0.0, 0.0)	C_{26}	(0.1, 0.1, 0.1)	(0.1, 0.1, 0.1)	(0.1, 0.1, 0.1)
C_{12}	(0.0, 0.0, 0.1)	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	C_{27}	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)
C_{13}	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	C_{31}	(0.0, 0.0, 0.1)	(0.1, 0.1, 0.1)	(0.0, 0.0, 0.1)
C_{21}	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	C_{32}	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)
C_{22}	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	C_{33}	(0.4, 0.5, 0.5)	(0.3, 0.3, 0.4)	(0.4, 0.5, 0.5)
C_{23}	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	C_{41}	(0.1, 0.1, 0.1)	(0.1, 0.1, 0.1)	(0.1, 0.1, 0.1)
C_{24}	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	C_{43}	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)	(0.0, 0.0, 0.0)
C_{25}	(0.3, 0.4, 0.6)	(0.3, 0.4, 0.6)	(0.3, 0.4, 0.6)	C_{43}	(0.0, 0.1, 0.1)	(0.0, 0.1, 0.1)	(0.0, 0.1, 0.1)

Positive and negative ideal solutions were found after finding the weighted normalized matrix. A+ and A^- sets were found as follows;

A^+= {(0.07, 0.09, 010),(0.02, 0.02, 0.02),(0.01, 0.02, 0.02),(0.03, 0.04, 0.05),(0.03, 0.04, 0.04), …., (0.05, 0.06, 0.07)}

A^-={(0.02,0.03,0.04),(0.00,0.00,0.01),(0.01,0.02,0.02),(0.05,0.05,0.06),(0.03,0.04,0.04),….,(0.00,0.00,0.00)}

Table 7 presents the positive and negative distances to the ideal solution based on the fuzzy TOPSIS method.

Table 7. Distance values of each alternative from the positive and negative ideal solutions

Alternative	d^+	d^-
A1	0.037298	0.182848
A2	0.051695	0.033387
A3	0.062093	0.189333

Based on the positive and negative distances to the ideal solution, relative distances were calculated by using the equations (16). Table 8 shows the relative distances (Equations 17) to the ideal solution for given three alternative determination of performance index of companies and the best choice. After we examined the results, we could conclude that A2 is the best determination of performance index of companies a cl^+ value of 0.60 and a cl^- value of 0.39. A3 takes second determination of performance index of companies in the preferred order and A1 is the last choice.

Table 8. Relative distances

Alternative	cl^{+}	cl^{-}
A1	0.169425	0.830575
A2	0.607593	0.392407
A3	0.246965	0.753035

5. Conclusion

In recent years, the performance rankings have been among the important issues for almost all areas of our daily life and different industries such as universities and accordingly, the companies operating R&D activities have been affected from this. At the same time, it is thought that the performance rankings of companies can increase the competition and the encouragement between them. For this reason, it is necessary to list the performance ranks of the companies operating R&D activities especially in the Technology Innovation Centers and to reveal the growth-contraction states within themselves. In this study, first of all, criteria for evaluating companies have been established. Then, objective and quantitively results were obtained by applying fuzzy AHP and fuzzy TOPSIS methods. As a result, the most important main criteria on for evaluating companies is found as intellectual property with 0.38.

In this study, it has been tried to increase the objectivity of the survey results by applying quantitative method. The aim is to determine the criteria using the opinions of experts, improve the survey and develop a method that can reach more accurate results by using scaling method. With this study companies will be able to see the competition with other companies about their current situation and at the same time they will be able to encourage themselves for further studies. The proposed approach can be applied to all companies operating R&D activities that cover the criteria. However, the first limitation of the study is considered to be the number and content of the criteria included. Some criteria may not apply to companies located in some countries. These criteria should be updated according to the conditions and needs of each country. In the following studies, the results can be compared by using the fuzzy MCDM having different methods.

Compliance with ethical standards

Conflicts of interest The authors declare no conflict of interest. No conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication.

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Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent N/A.

Authorship contributions

All the authors contributed to the development, analysis, and writing: Conceptualization, C.Ş. and K.T.A.; methodology, K.T.A.; validation, C.Ş. and K.T.A.,; formal analysis, C.Ş. and K.T.A.; investigation, K.T.A.; writing—original draft preparation, K.T.A.; writing—review and editing, C.Ş. and K.T.A.; visualization, K.T.A.; All authors have read and agreed to the published version of the manuscript.

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