Fuzzy Multi-Criteria Selection of Science Parks for Start-up Companies

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Abstract

Science parks are crucial for an innovative economic setting since they act as 'development catalysts' driving the startup of newly established high-tech firms. The selection of the appropriate science park becomes a major decision for start-up entrepreneurs since it is a multi-criterion decision problem which includes both qualitative and quantitative factors. The aim of this paper is to identify the important and critical decision criteria for science park selection and develop a decision support system for start-up entrepreneurs. In this study, a fuzzy multi-criteria science park selection model using the fuzzy analytic hierarchy process (FAHP) method is proposed and applied to analytically select the best science park for a start-up company in Turkey.

Keywords: Multi-criteria decision making, Fuzzy AHP, Science park, Start-up company

1. Introduction

Science Parks provide property for knowledge and technology based businesses, whether they are a business start up or a small to medium sized enterprise (SME). In addition, they provide assistance in start-up financing, technology transfer, networking opportunities and marketing programs for entrepreneurs and SMEs developing innovative products and services. Science parks are very crucial for economies since they act as 'development catalysts' driving the startup of newly established high-tech firms and tracing the path for existing firms to process and product innovation.[1] According to the United Kingdom Science Park Association (UKSPA), science parks have three fundamental features.[2] They are designed to foster the creation and growth of R&D-intensive firms, provide an environment that enables large companies to develop relationships with small, high-tech companies, and promote formal and operational links between firms, universities, and other research institutions (e.g., federal research labs). Thus, science parks are expected to provide access to critical human and physical capital for innovative companies. Furthermore, the clustering of high-tech firms should serve to stimulate technology transfer and the acquisition of key business skills, such as the ability to develop new products[3]. In today's competitive industry, competitive conditions change rapidly and the selection of the appropriate science park becomes a major decision for start-up entrepreneurs to conduct business successfully. In this dynamic competitive environment, decisions on selection of the science park can widely influence business strategic planning and operational profit.[4]

The aim of this paper is to identify the important and critical decision criteria for science park selection and develop a decision support system for start-up entrepreneurs. In this study, a fuzzy multi-criteria science park selection model using the fuzzy analytic hierarchy process (FAHP) method is proposed. The model is applied to analytically select the best science park for a start-up company in Turkey. The overall objective of the selection is to identify the potential science park which can stand on the start-up company's specific decision criteria.

In the proposed model, the fuzzy analytic hierarchy process (FAHP) method is used to select the appropriate science park for the start-up company analytically. Although the AHP method is widely used for tackling multi-criteria decision-making problems, it is often criticized for its inability to adequately handle the

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inherent uncertainty and imprecision associated with the mapping of the decision-makers' perceptions to exact numbers. Since some of the evaluation criteria are subjective and qualitative in nature, it is very difficult for the decision maker to express the preferences using exact numerical values and to provide exact pairwise comparison judgments.[5] Therefore the fuzzy AHP (FAHP) method is selected to solve the multi-criteria science park selection problem in this study.

The rest of this paper is organized as follows. Section 2 presents a brief literature review on science parks. Section 3 provides criteria definition for multi-criteria science park selection problem for a start-up company. In Section 4, the proposed model for the problem is presented. In Section 5, the application of the model is included. Conclusions and future research directions are provided in Section 6.

2. Background

In the literature, there are limited efforts on science park evaluation and comparison. Bakouros et al. evaluated the performance of three science parks in terms of interactions take place both within the science park and between the university and firms located in science park.[6] A framework was developed to assess the performance of technology incubators and applied with six cases in Hong Kong Science Park by Chan and Lau.[7] An innovation capacity comparison between two science parks on both sides of the Taiwan Strait was made by Lai and Shyu.[8] Chen analyzed the urban effect on the performance of science park and compared science parks in three different cities of China.[9] Bigliardi et al. proposed a performance evaluation framework and conducted an empirical analysis considering four case studies of science parks located in Italy.[1] In addition to empirical researches for science park evaluation data envelopment analysis (DEA), a mathematical programming methodology, was used by Chen et al. to analyze the comparative performances of the six high-tech industries and select the firm with better efficiency and/or growth potential.[10]

Some researchers also have attempted to investigate the benefits of science park locations to firms. A survey was conducted considering in-science parks and out-science parks firms in the UK and the perceived benefits of selected locations were explored.[11] According to the results; many tenants had selected a science park location in order to benefit from informal as well as formal links with local universities. Westhead and Batstone, also stated that science park can provide managed support for firms in order to ensure rental growth and by linking with a local university, science park firms are able to minimize the direct personal cost (and associated risk) associated with R&D.[12] Moreover, Siegel et al. stated that science park firms are more efficient than non-science park firms in research, in terms of generating new products and patents.[13]

Leyden et al. point out the gap on science park location decisions of start-up firms and the results of the study identified that the decision of firms to locate on a university research park is dependent on its ability to realize innovation externalities from other members in the park including the university. [14] Another empirical research on the firm-level decision to join a science park was conducted by Wright et al. for high technology SME's in China.[15] Chen and Yu explored the main factors effecting the decision to locate in a science park for high-tech firms Taiwan.[4] They identified that cost and benefit factors of network effect dominate the decision-making in selection of location.

Owing to the fact that the study includes FAHP method, it will be meaningful to mention about FAHP and its applications. The FAHP method, with its ability to accommodate both quantitative and qualitative data, has been popularly used to develop and solve different multi criteria decision making problems. Here, some of its applications realized in various fields are presented as follows; Kahraman et al. used fuzzy AHP for the selection among renewable energy alternatives.[16] Kuo et al. proposed a decision support system using the fuzzy AHP to locate new convenience store.[17] Ayağ and Özdemir evaluated machine tool alternatives using the FAHP approach.[18] A personnel selection system based on FAHP was proposed by Gungor et al..[19] Lin developed an evolution model using the fuzzy AHP to evaluate course website quality.[20] Cheng et al. compared technology forecasting methods by a group decision making method based on FAHP.[21] Aydin and Kahraman provided an FAHP based analytical tool for decision support enabling an effective multi-criteria supplier selection process in an air conditioner seller firm.[22] Kaya proposed a multi-attribute e-business website quality evaluation methodology based on a modified fuzzy TOPSIS approach in that the weights of the evaluation criteria are generated by a fuzzy AHP procedure.[23]

When considering the relevant literature, it is revealed that there has not been any published study solving the multi-criteria science park selection problem for a start-up company analytically. This paper aims at filling this gap in the literature by proposing a decision support system for start-up entrepreneurs. In this context, this paper has the originality of presenting a fuzzy AHP model that selects the appropriate science park for a start-up company.

3. Evaluation Criteria

The main objective of this study is the selection of the best science park for a start-up company. After synthesizing the literature review, the important and critical decision criteria are determined with the help of the experts in the respective areas to accomplish this objective. Owing to the large number of factors affecting the science park selection decision, an orderly sequence of steps should be required to tackle it.

The problem defined here has four levels of hierarchy. Application of common criteria to all science park alternatives makes objective comparisons possible. The criteria which are considered here in the selection of the best science park are namely: cost, physical and technical infrastructure, consultancy & services and location characteristics. These criteria can be decomposed into various other attributes. The main criteria and numbers of attributes relevant to science park selection are described below.

The criteria are denoted by C_i, attributes by A_j, and alternatives by S_k (where i, j, k = 1, 2, . . .). The hierarchy of the selection criteria, attributes, and decision alternatives is depicted in Fig. 1. In the hierarchy, the overall objective is placed at level 1, criteria at level 2, attributes at level 3, and the decision alternatives at level 4.

Cost (C_1): The cost criterion is one of the important criteria in assessing the science park for newly established start-up companies with limited financial resources. The initial cost may occur if the company needs to change the existing architectural design of the office. The rental cost is generally paid monthly. The company should also share the general expenses including water supply, electricity, telephone, internet services etc. Hence, this criterion involves three attributes namely, the initial cost (A_1), rental cost (A_2) and general expenses (A_3).

Physical and technical infrastructure (C_2): This criterion is related with buildings and technical infrastructure. Some start-up companies may need lab facilities to develop and test their prototypes. IT infrastructure of the science park should provide a large internet bandwidth, well-performed data infrastructure, network monitoring server, remote support and network security for tenants. And the tenant may need to expand the office area when the business grows. The entrepreneurs of start-up companies generally prefer modern architectural design and new buildings. In this context, the factors (attributes) affecting this criterion can be stated as lab facilities (A_4), IT Infrastructure (A_5), sufficient area for expansion (A_6), architectural structure (A_7), age of building (A_8).

The consultancy and services (C_3): This criterion is an indicator for service quality and diversity in selecting the best science park for a start-up company. The newly

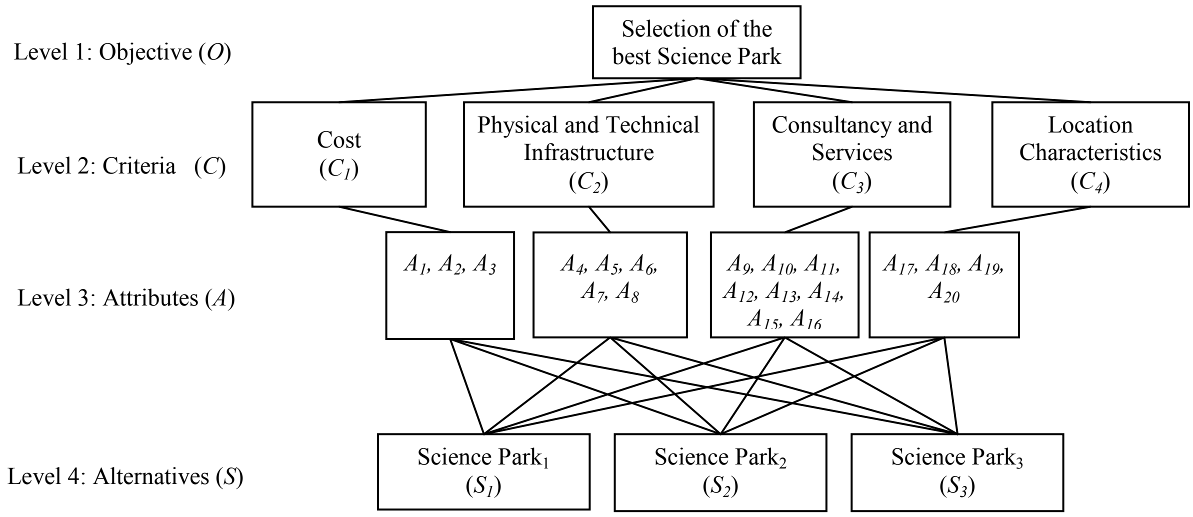

Fig. 1. The hierarchical structure for science park selection

established start-up companies generally need consultancy in management and marketing activities. If a new technology is developed, the company may need intellectual property support to protect and/or transfer the technology. The science park could also consult the start-up companies in finding financial sources and applying for loans or research grants. This factor can be measured in terms of the following attributes: technology transfer consultancy (A_9), finance & accounting consultancy (A_{10}), marketing consultancy (A_{11}), management consultancy (A_{12}), support of preparation of project proposals (A_{13}), venture capital consultancy (A_{14}), intellectual property consultancy (A_{15}) and export & import consultancy (A_{16}).

The location characteristics (C_4): This criterion is another important factor in selecting the best science park for the start-up company. If the start-up company is close to market, better relations are established with the customers. The location of the company is very important factor to be able to recruit qualified human resources and establish better connections with financial institutions. Additionally, the clustering of high-tech firms should serve to stimulate technology transfer and the acquisition of key business skills. In this context, this criterion is analyzed based on the following attributes: closeness to market (A_{17}), closeness to financial institutions (A_{18}), accessibility to qualified human resources (A_{19}), and closeness to related industrial clusters (A_{20}).

4. The Fuzzy AHP Model

Selecting the most appropriate science park for a start-up company can be considered as a multi-criteria decision making problem (MCDM) in the presence of many quantitative and qualitative attributes. The four main criteria and twenty attributes forming the hierarchic structure for the suitable science park selection are defined in the previous section.

In the literature, researchers have studied different multi-criteria decision making (MCDM) problems and proposed various methods such as AHP, TOPSIS, ELECTRE, PROMETHEE.[24] In this paper, AHP firstly described by Saaty,[25] is used for science park selection problem due to the fact that it has been successfully applied in evaluating various kinds of MCDM problems in both academic researches and practices.

AHP enables decision makers to determine the criteria weights and the alternative scores by using comparison matrices. However, since decision makers often provide vague answers rather than precise values, the crisp pair wise comparison in the conventional AHP may not be sufficient to capture the right judgments of the decision-maker on evaluating both selection factors and science park alternatives. Therefore, fuzzy logic[26] is introduced in the pair wise comparison and evaluation of AHP to make up for this deficiency in the conventional AHP. Fuzzy AHP (FAHP) approach can reflect human thinking style and allows a more accurate description of the decision making process.[27]

In this study, a decision support system based on AHP approach combined with Buckley's fuzzy extent analysis method[28] is proposed to evaluate the science park alternatives under multiple attributes. After defining the criteria and constructing the hierarchy, the decision-makers are asked to compare the elements at a given level on a pair wise basis to estimate their relative importance in relation to the element at the immediate proceeding level. Then, a fuzzy multi-criteria decision making analysis which aggregates group decisions is used for the evaluation of different science parks. In order to determine the performance value of each science park, each evaluator defines his/her own rating scale and the corresponding fuzzy numbers within the range of 0-100. For each evaluator with the same importance, this study employed the notion of average value to integrate the judgment values of different evaluators regarding the same evaluation criteria. Finally, alternatives are evaluated according to their total points taken from evaluation criteria one by one.

In the following sub-sections, the Fuzzy AHP methodology is presented after the description of basic concepts of fuzzy numbers and algebraic operations.

4.1. *Fuzzy AHP Ranking Model*

The AHP is a popular tool for multiple criteria decision-making. The purpose of AHP is to capture the human's knowledge when multi-person and multi-attribute decision making problems are considered. However, the traditional AHP may not fully reflect a style of human judgment and preferences because of several pitfalls associated with the technique.[29] In real world, decision makers usually feel more confident to express their judgments in the form natural language expressions instead of assigning exact numerical values to the comparison judgments.[30] As a result, FAHP, a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems.

In this study, a fuzzy multiple criteria decision making procedure based on AHP approach combined with Buckley's fuzzy extent analysis method[28] is used to facilitate the selection of the most appropriate to realize a hierarchical structure and effectively solve vague assessment of a science park having different dimensions. The hierarchical structure adopted in this study to deal with the problems of science park selection for a start-up company is shown in Fig 1.

FAHP methodology is applied to determine the priority weights of each dimension and criteria and to determine a score of a science park among criteria. The steps of the prioritization of criteria and evaluation of a science park can be summarized in the following sub-sections.[31]

1.2.1. *Prioritization of criteria*

Step 1: Decision makers are asked to express relative importance of two decision elements in the same level by the linguistic scale given in Table 1. Let $\tilde{d}_{ij}^k$ be a set of the k^{th} decision maker's preference of one attribute over another then; construct the pair-wise comparison matrices such as

$$A^k = \begin{bmatrix} \tilde{d}_{11}^k & \tilde{d}_{12}^k & \dots & \tilde{d}_{1n}^k \\ \tilde{d}_{21}^k & \dots & \dots & \tilde{d}_{2n}^k \\ \dots & \dots & \dots & \dots \\ \tilde{d}_{n1}^k & \tilde{d}_{n2}^k & \dots & \tilde{d}_{nn}^k \end{bmatrix} \tag{1}$$

where n is the number of the related elements at this level and $\tilde{d}_{ij}^k = 1/\tilde{d}_{ji}^k$. Also, $\tilde{d}_{ij}^k = (1,\ 1,\ 1)\ \forall i = j$.

Table 1. Linguistic variables for comparison of two criteria.[31]

Linguistic Scale		Fuzzy Numbers
Equally Important	(E)	(1, 1, 1)
Weakly Important	(W)	(1, 3, 5)
Fairly Important	(F)	(3, 5, 7)
Very Strongly Important	(VS)	(5, 7, 9)
Absolutely Important	(A)	(7, 9, 9)

Step 2: The fuzzy judgment values of K decision makers are integrated by using the arithmetic mean method, that is;

$$\tilde{d}_{ij} = \frac{\sum_{k=1}^{K} \tilde{d}_{ij}^k}{K} \tag{2}$$

$\tilde{d}_{ij}$ denotes the average value of the preferences of the decision makers and can be indicated by a triangular fuzzy number.

Step 3: Obtain the fuzzy weights of each criterion of synthetic pair-wise comparison matrix by using the geometric mean method suggested by Buckley:[28]

First, find the geometric mean of fuzzy comparison value of criterion i to each criterion.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij} \right)^{1/n}, \quad i=1, 2,..., n \tag{3}$$

Then, obtain the fuzzy weight of the ith criterion indicated by a triangular fuzzy number.

$$\begin{aligned} \tilde{w}_i &= \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1} \\ &= (lw_i, mw_i, uw_i) \end{aligned} \tag{4}$$

Step 4: Obtain the nonfuzzy values of each criterion N_i by utilizing a defuzzification process which converts a fuzzy number into a crisp value. At first, fuzzy numbers will be defuzzified into crisp values by Centre of Area (COA) method and then the normalization procedure will be applied.[31] Eq. (5) presents both defuzzification and normalization procedures in one formula.

$$N_i = \frac{lw_i + mw_i + uw_i}{\sum_{j=1}^{n} lw_j + \sum_{j=1}^{n} mw_j + \sum_{j=1}^{n} uw_j} \tag{5}$$

where N_i is a crisp number and n is the number of criteria.

Step 5: After obtaining the local weights of each criterion, calculate the global weights of all criteria W_i by multiplying the local weights of criteria by the weights of the related dimension.

1.2.2. *Evaluation of alternatives*

After determining the weights of each criterion by pair-wise comparisons in FAHP, a fuzzy multi-criteria decision making (FMCDM) analysis which aggregates group decisions is used for the evaluation of science parks. The performance scores of science parks can be obtained by synthesizing individual experts' opinions. The following will be the method and procedures of the scoring method;[31]

Step 1: In order to determine the performance value of each science park, each decision makers can define his/her own individual range for the linguistic variables according to his/her subjective judgments within the range of 0-100. These linguistic terms can be expressed via triangular fuzzy numbers.

Step 2: Decision makers evaluate the science park based on each criterion and conduct their subjective judgments by using linguistic variables. Take $\tilde{e}_i^k$ to indicate the fuzzy performance value of decision maker *k* under criterion *i*.

Step 3: To integrate the fuzzy assessment values of *K* evaluators, use the notation of average value, that is;

$$\tilde{e}_i = \frac{\sum_{k=1}^{K} \tilde{e}_i^k}{K} \tag{6}$$

$\tilde{e}_i$ shows the average fuzzy number of the assessment of decision makers, which can be displayed by a triangular fuzzy number as; $\tilde{e}_i = (le_i, me_i, ue_i)$.

Step 4: Obtain the final weighted fuzzy assessment value $\tilde{p}$ of the science park by the formula;

$$\tilde{p} = \sum_{i=1}^{m} \tilde{e}_i \times W_i \tag{7}$$

where *m* is the number of criteria in the hierarchy.

The criteria weights W_i are derived by pair-wise comparisons of criteria, whereas the assessment values $\tilde{e}_i$ are obtained from the ranking method under *m* criteria.

Step 4: Lastly, the fuzzy number $\tilde{p}$ is converted into a nonfuzzy number "Score of a Science Park" *Sp* by the COA method.

5. Application

A Turkish start-up company operating less than two years in the field of automatic identification systems plans to maintain its business operations in a science park by 2010 summer. A group of three managers of the company is constituted for the evaluation. The science parks alternatives determined as S_1 in Ankara, S_2 and S_3 in Istanbul, will be evaluated according to the predetermined criteria by the fuzzy AHP methodology. The whole hierarchy of the selection of best science park can be easily visualized from Fig. 1. After the construction of the hierarchy, the priority weights of each criteria, attributes and alternatives are calculated using the FAHP approach.

Firstly, the group is asked to make pair-wise comparisons in order to obtain the priority weights for the main and sub-attributes. The evaluation matrices relevant to the goal are given below;

$$A^1 = \begin{bmatrix} E & FS & FS & W \\ & E & W & W \\ & & E & LW \\ & & & E \end{bmatrix} \quad A^2 = \begin{bmatrix} E & E & E & FS \\ & E & E & W \\ & & E & W \\ & & & E \end{bmatrix}$$

$$A^3 = \begin{bmatrix} E & W & FS & FS \\ & E & W & W \\ & & E & E \\ & & & E \end{bmatrix}$$

where *L*=less.

Through the triangular fuzzy number aggregation by Eq. (2), the average value of the preferences of three decision makers are obtained. For $\tilde{d}_{12}$ as an example;

$$\tilde{d}_{12} = \frac{\sum_{k=1}^{3} \tilde{d}_{12}^k}{3} = \frac{(3,5,7) \oplus (1,1,1) \oplus (1,3,5)}{3}$$
$$= (1.67, 3.00, 4.33)$$

We can obtain the remaining aggregated weights $\tilde{d}_{ij}$ by the same computational procedure; therefore, the synthetic pairwise comparison matrix of the three evaluators is as follows;

$$\tilde{A} = \begin{bmatrix} (1.00,1.00,1.00) & (1.67,3.00,4.33) & (2.33,3.67,5.00) & (3.00,5.00,7.00) \\ (0.45,0.51,0.78) & (1.00,1.00,1.00) & (2.33,3.67,1.00) & (1.00,3.00,5.00) \\ (0.43,0.47,0.56) & (0.47,0.56,1.00) & (1.00,1.00,1.00) & (0.73,1.44,2.33) \\ (0.14,0.20,0.33) & (0.20,0.33,1.00) & (0.73,1.44,2.33) & (1.00,1.00,1.00) \end{bmatrix}$$

The fuzzy weights of the matrix are found by applying Eq. (3) and Eq. (4).

$$\tilde{r}_1 = \left(\prod_{j=1}^{4} \tilde{d}_{1j} \right)^{1/4} = \left(\tilde{d}_{11} \otimes \tilde{d}_{12} \otimes \tilde{d}_{13} \otimes \tilde{d}_{14} \right)^{1/4}$$
$$= \begin{pmatrix} (1 \times 1.67 \times 2.33 \times 3.00)^{1/4}, (1 \times 3 \times 3.67 \times 5)^{1/4}, \\ (1 \times 4.33 \times 5 \times 7)^{1/4} \end{pmatrix}$$
$$= (1.85, 2.72, 3.51)$$

We can obtain the remaining $\tilde{r}_i$, that is;

$$\tilde{r}_2 = (0.82, 1.38, 1.94)$$
$$\tilde{r}_3 = (0.62, 0.78, 1.07)$$
$$\tilde{r}_4 = (0.38, 0.56, 0.94)$$

Then, the fuzzy weight of each dimension can be obtained;

$$\tilde{w}_1 = \tilde{r}_1 \otimes \left(\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4\right)^{-1}$$
$$= (1.85, 2.72, 3.51)$$
$$\otimes \begin{pmatrix} 1/(3.51+1.94+1.07+0.94), \\ 1/(2.72+1.38+0.78+0.56), \\ 1/(1.85+0.82+0.62+0.38) \end{pmatrix}$$
$$= (0.25, 0.50, 0.96)$$

Likewise, we can obtain the remaining $\widetilde{w}_i$, that is;

$$\tilde{w}_2 = (0.11, 0.25, 0.53)$$
$$\tilde{w}_3 = (0.08, 0.14, 0.29)$$
$$\tilde{w}_4 = (0.05, 0.10, 0.26)$$

The normalized crisp values of each criterion are found by COA method;

$$N_1 = \frac{0.25+0.50+0.96}{0.49+1.00+2.03} = 0.48$$

The remaining N_i can be obtained similarly, that is;
N_2= 0.25
N_3= 0.15
N_4= 0.12

The remaining matrices of pair-wise comparisons are given in Appendix A.

Overall attribute weights W_i are then computed by multiplying local weight of the attribute with the interdependent weights of the criteria to which it belongs. The final W_i values are listed in Table 2.

In the next step, after obtaining the weights of criteria, the alternatives are evaluated by the managers group. The linguistic variables and the corresponding fuzzy numbers defined and used by each manager (*MNG*) to express their own judgments on alternatives are given in Table 3.

Table 3. The subjective fuzzy scale and linguistic expression for ranking alternatives

Linguistic Variable	MNG 1	MNG 2	MNG 3
Very poor VP	(0, 0, 25)	(0, 0, 30)	(0, 0, 30)
Poor P	(20, 35, 50)	(25, 35, 45)	(25, 35, 45)
Fair F	(45, 60, 75)	(45, 60, 75)	(40, 55, 70)
Good G	(70, 80, 90)	(70, 80, 90)	(65, 75, 85)
Very good VG	(85, 100, 100)	(80, 100, 100)	(80, 100, 100)

Each of the decision makers evaluates the science park based on each criterion and conducts their subjective judgments by using the linguistic variables. The fuzzy performance value $\widetilde{e}_i^k$ of alternatives given by three decision makers under all criteria is presented in Table 4.

Table 2. Weights of evaluation criteria.

Criteria	Local Weight	Attribute	Local Weight	Overall Weight
Cost	0.48	First cost	0.21	0.10
		Rental cost	0.51	0.25
		General expenses	0.28	0.14
Physical and Technical Infrastructure	0.25	Lab facilities	0.39	0.10
		IT Infrastructure	0.32	0.08
		Sufficient area for expansion	0.15	0.04
		Architectural structure	0.09	0.02
		Age of building	0.05	0.01
Consultancy & Services	0.15	Technology transfer	0.17	0.02
		Finance & Accounting	0.11	0.02
		Marketing	0.15	0.02
		Management Consultancy	0.08	0.01
		Preparation of Project Proposals	0.14	0.02
		Venture Capital	0.21	0.03
		Intellectual Property, Patent, Trademark	0.09	0.01
		Export & Import	0.05	0.01
Location Characteristics	0.12	Market	0.30	0.03
		Financial institutions	0.11	0.01
		Human resources	0.34	0.04
		Industrial clusters	0.25	0.03

To integrate the fuzzy/vague judgment values of different experts regarding the same evaluation criteria, the method of average value is employed. For the science park S_1 as an example, the average fuzzy assessment values of the first cost from experts' judgment can be obtained as follows:

$$\tilde{e}_1 = \frac{\sum_{k=1}^{3} \tilde{e}_1^k}{3} = \frac{(70,80,90) \oplus (70,80,90) \oplus (40,55,70)}{3}$$
$$= (60, 71.7, 83.3)$$

The complete results of all alternatives are shown in Table 4.

From the global average criteria weights of three decision makers obtained by pair-wise comparisons (Table 2) and the average fuzzy assessment values of each criterion of experts for each science park (Table 4), the final weighted fuzzy assessment value $\tilde{p}$ can then be processed.

$$\tilde{p}_{S_1} = \sum_{i=1}^{m} \tilde{e}_i \times W_i = (60,\ 71.7,\ 83.3) \times 0.10$$
$$\oplus (43.3,\ 58.3,\ 73.3) \times 0.25 \oplus ...$$
$$\oplus (51.7,\ 65,\ 78.3) \times 0.03$$
$$= (45.9, 58.5, 71.6)$$
$$\tilde{p}_{S_2} = (49.6, 61, 73.9)$$
$$\tilde{p}_{S_3} = (45.7, 59.6, 69.8)$$

The fuzzy number $\tilde{p}$ is then converted into a nonfuzzy number "Score of a Science Park" *Sp* by the method explained in Eq. (5).

$$Sp_1 = 58.7$$
$$Sp_2 = 61.5$$
$$Sp_3 = 58.3$$

The highest score of the science park gives the idea about the most appropriate science park for the company. The important results about the scores of each alternative with respect to the main criteria are presented in Table 5.

Table 5. The weights of criteria and the final scores of science parks.

Criteria	Weight	S_1	S_2	S_3
Overall	1.00	58.7	61.5	58.3
Cost	0.48	27.3	19.7	20.6
Physical & Tech. Infrastructure	0.25	17.2	19.8	21.0
Consultancy & Services	0.15	8.6	11.9	6.5
Location Characteristics	0.12	5.6	10.0	10.2

According to Table 5, the ranking of alternatives is determined as S_2 - S_1 - S_3, and alternative S_2 located in Istanbul is determined as the best science park to operate in for the start-up company.

Table 4. Average fuzzy assessment values of each criterion for each science park.

Attribute	S_1	S_2	S_3
First cost	(60, 71.7, 83.3)	(60, 71.7, 83.3)	(23.3, 35, 46.7)
Rental cost	(43.3, 58.3, 73.3)	(6.7, 11.7, 36.7)	(35, 50, 65)
General expenses	(28.3, 41.7, 55)	(43.3, 58.3, 73.3)	(23.3, 35, 46.7)
Lab facilities	(71.7, 85, 91.7)	(73.3, 85, 91.7)	(81.7, 100, 100)
IT Infrastructure	(36.7, 50, 63.3)	(63.3, 78.3, 86.7)	(78.3, 93.3, 96.7)
Sufficient area for expansion	(43.3, 58.3, 73.3)	(51.7, 63.3, 75)	(35, 50, 65)
Architectural structure	(65, 78.3, 86.7)	(73.3, 85, 91.7)	(60, 71.7, 83.3)
Age of building	(73.3, 86.7, 93.3)	(78.3, 93.3, 96.7)	(68.3, 78.3, 88.3)
Technology transfer	(60, 71.7, 83.3)	(78.3, 93.3, 96.7)	(15, 23.3, 41.7)
Finance & Accounting	(60, 71.7, 83.3)	(60, 71.7, 83.3)	(51.7, 63.3, 75)
Marketing	(0, 0, 28.3)	(43.3, 58.3, 73.3)	(28.3, 41.7, 55)
Management Consultancy	(76.7, 91.7, 95)	(78.3, 93.3, 96.7)	(60, 71.7, 83.3)
Preparation of Project Proposals	(78.3, 93.3, 96.7)	(81.7, 100, 100)	(15, 23.3, 41.7)
Venture Capital	(15, 23.3, 41.7)	(73.3, 85, 91.7)	(36.7, 50, 63.3)
Intellectual Property. Patent. Trademark	(68.3, 78.3, 88.3)	(68.3, 78.3, 88.3)	(28.3, 41.7, 55)
Export & Import	(76.7, 93.3, 96.7)	(78.3, 93.3, 96.7)	(38.3, 50, 61.7)
Market	(8.3, 11.7, 33.3)	(73.3, 85, 91.7)	(73.3, 85, 91.7)
Financial institutions	(6.7, 11.7, 36.7)	(78.3, 93.3, 96.7)	(78.3, 93.3, 96.7)
Human resources	(60, 71.7, 83.3)	(81.7, 100, 100)	(76.7, 91.7, 95)
Industrial clusters	(51.7, 65, 78.3)	(68.3, 78.3, 88.3)	(81.7, 100, 100)

Conclusion

Science parks meet the start-up companies' requirements, compensate their weaknesses and help them to survive in the early stages. Hence, the selection of a science park is a strategic decision having a vital importance to start-up companies. Many factors should be considered to evaluate the science parks and make the appropriate decision. In this study, a multi-criteria decision making methodology is presented to select the best science park for a start-up company. The alternative science parks are evaluated by a fuzzy MCDM technique which improves the degree of judgments of the decision maker. The proposed model discussed in this paper is proved to be simple, less time taking and having less computational expense as compared to other existing decision making systems.[32] Finally, a case study in Turkey was presented to illustrate the applicability of the proposed approach. The case study has demonstrated the thoughtfulness, flexibility, and efficiency of the proposed model to directly tap the subjectivity and preferences of the decision makers.[5] In the future research, a decision support system can be developed for science park selection.

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Appendix A. Pair-wise Comparisons of Attributes

Pair-wise comparisons of attributes related to cost;

$$A^1 = \begin{bmatrix} E & LW & E \\ & E & W \\ & & E \end{bmatrix} \quad A^2 = \begin{bmatrix} E & LW & W \\ & E & FS \\ & & E \end{bmatrix}$$

$$A^3 = \begin{bmatrix} E & LW & LW \\ & E & W \\ & & E \end{bmatrix}$$

Pair-wise comparisons of attributes related to physical and technical infrastructure;

$$A^1 = \begin{bmatrix} E & E & W & FS & VS \\ & E & W & A & A \\ & & E & FS & FS \\ & & & E & W \\ & & & & E \end{bmatrix}$$

$$A^2 = \begin{bmatrix} E & W & W & FS & VS \\ & E & E & W & FS \\ & & E & W & FS \\ & & & E & E \\ & & & & E \end{bmatrix}$$

$$A^3 = \begin{bmatrix} E & E & VS & FS & VS \\ & E & VS & FS & VS \\ & & E & LW & E \\ & & & E & W \\ & & & & E \end{bmatrix}$$

Pair-wise comparisons of attributes related to consultancy & services;

$$A^1 = \begin{bmatrix} E & FS & W & W & W & E & E & FS \\ & E & LW & LW & LFS & LVS & LFS & E \\ & & E & W & LW & LFS & LW & W \\ & & & E & LW & LFS & LFS & W \\ & & & & E & LW & LW & FS \\ & & & & & E & FS & VS \\ & & & & & & E & VS \\ & & & & & & & E \end{bmatrix}$$

$$A^2 = \begin{bmatrix} E & LFS & TFS & FS & FS & W & FS & W \\ & E & E & FS & FS & W & FS & W \\ & & E & A & VS & FS & VS & W \\ & & & E & W & LW & LW & LW \\ & & & & E & LW & E & LW \\ & & & & & E & W & E \\ & & & & & & E & LW \\ & & & & & & & E \end{bmatrix}$$

$$A^3 = \begin{bmatrix} E & W & W & E & LW & LW & FS & FS \\ & E & E & LW & LFS & LFS & W & W \\ & & E & LW & LFS & LFS & W & W \\ & & & E & LW & LW & FS & FS \\ & & & & E & E & FS & FS \\ & & & & & E & FS & FS \\ & & & & & & E & E \\ & & & & & & & E \end{bmatrix}$$

Pair-wise comparisons of attributes related to physical and technical infrastructure;

$$A^1 = \begin{bmatrix} E & FS & W & VS \\ & E & LFS & W \\ & & E & A \\ & & & E \end{bmatrix} A^2 = \begin{bmatrix} E & W & LW & LW \\ & E & LW & LW \\ & & E & E \\ & & & E \end{bmatrix}$$

$$A^3 = \begin{bmatrix} E & W & LW & LW \\ & E & LW & LW \\ & & E & LW \\ & & & E \end{bmatrix}$$