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Proceedings of the International Conference on Research in Business, Management and Economics
Vol. 1, Issue. 2, 2024, pp. 50-71
DOI: https://doi.org/10.33422/icrbme.v1i2.1394

ISSN: 3030-0525 online

Analysing Performance of Incubation Firms Using Fuzzy Multi-Criteria Decision Making Approaches

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Abstract

This study proposes a competency model to analyse the entrepreneurship ecosystem and assess the performance of incubation firms in Türkiye. A comprehensive field study is conducted across various incubation firms in the country, utilising a detailed survey to collect data from entrepreneurs. The survey focuses on key dimensions: Customer, Technology, Research and Development (R&D), Competition, Investment, Marketing, Environment & Sustainability, Human Resources (HR) and Commercialisation. The survey responses are compiled into a database for performance analysis. Five experts perform pairwise evaluations to determine each dimension's relative importance. Based on their insights, the Fuzzy Analytic Hierarchy Process (FAHP) approach is employed to assign weights to each decision criterion. The analysis identifies Commercialisation and R&D as the most critical, followed by Technology and Competition. Environment & Sustainability is given the least weight, as it is considered a secondary factor that supports overall performance. The WASPAS (Weighted Aggregated Sum Product Assessment) method is applied to evaluate and rank the performance of incubation firms. High-performing firms align innovative strategies with market demands, leverage R&D, and secure intellectual and industrial property rights. Low-performing firms exhibit weaknesses, particularly in customer, marketing, and technology issues. The analysis highlights that the Marmara Region, particularly Istanbul, is a key hub for high-performing incubation firms. Other regions demonstrate more limited entrepreneurial potential, indicating that regional differences significantly affect the concentration of entrepreneurial activities. Successful firms are predominantly concentrated in the software and information technology sectors. This analysis provides strategic insights to help entrepreneurs and supporting organisations enhance firm performance and entrepreneurship ecosystem.

Keywords: entrepreneurship; incubation firms; decision support system; WASPAS; fuzzy AHP

1. Introduction

Incubation firms play a crucial role in fostering entrepreneurship (Theodoraki et al., 2020), driving innovation (Strobel & Kratzer, 2017), and contributing to economic growth (Liñán et al., 2011; McMullan et al., 1986). These firms facilitate the emergence of new ventures by supporting the development of innovative ideas and business models (Kiran & Bose, 2020). As a result, they contribute not only to individual business success but also to the commercialization of new technologies, regional economic development, and job creation (Groen et al., 2015). The role of incubation firms has become particularly significant in the post-pandemic period, as entrepreneurial activities have increased in many regions in response to the shifting global economic landscape (Dvouletý, 2024). The COVID-19 crisis has accelerated the adoption of digital processes and innovative strategies, positioning incubation firms as central actors in supporting the digital transformation of startups (Szerb et al., 2024).

Measuring the performance of incubation firms presents significant challenges. Their operations involve both tangible and intangible outcomes, which complicates the assessment of their effectiveness. Traditional performance evaluation methods, are often designed for established businesses (Kulkarni et al., 2023; Pugliese et al., 2022), frequently fail to account for the unique characteristics and dynamic nature of newly formed incubation firms. This highlights the need for more comprehensive and tailored evaluation frameworks that consider a broad range of influencing factors in entrepreneurship management (Liguori et al., 2019).

Multi-criteria decision-making (MCDM) methods provide a valuable framework for evaluating the performance of incubation firms. Previous studies have utilised MCDM to assess the performance of startups (Nguyen & Chu, 2023; Lin et al., 2021; Mello et al., 2024) and their competencies in technology and innovation (Quaiser & Srivastava, 2024; Bolukbas & Guneri, 2018; Sharma et al., 2023). These methods are especially useful in contexts where innovation systems are rapidly evolving, such as in many developing countries, where universities and technology development zones (TDZ) are increasingly contributing to entrepreneurship ecosystems and fostering technological innovation (Belousova al., 2024). Given the complex nature of newly established firms, MCDM approaches enable detailed assessments by considering both qualitative and quantitative factors. This structured framework supports the decision-making process and helps stakeholders make informed decisions.

Incorporating fuzzy logic into MCDM enhances its ability to handle uncertainty and subjectivity while relying on expert opinions (Zadeh, 1965). Fuzzy methods provide more flexible and precise models for subjective assessments by converting linguistic evaluations into numerical values. Many studies (Pamucar et al.,2021; Karagoz et al., 2020; Deveci et al., 2018; Yalcin et al., 2012) have improved their analysis by combining fuzzy logic with MCDM.

Among the many MCDM techniques, the Analytic Hierarchy Process (AHP) (Saaty, 1980) has been widely applied for determining the relative importance of decision criteria. In te field of entrepreneurship, AHP has been employed to identify key success factors for startups (Chen et al., 2019; Kasayu et al., 2017). Within incubation programs, it has been used to evaluate the performance of business incubators and assess their effectiveness in supporting entrepreneurial development (Cheng, 2016). Moreover, in the area of technology transfer and knowledge diffusion, AHP has proven useful in determining intangible priority factors for adoption (Lee et al., 2012), identifying and evaluating critical determinants for effective technology transfer (Kumar et al., 2015), and examining infrastructure requirements for building entrepreneurial capacity in rural areas (Krakowiak-Bal et al., 2017).

Despite its broad application, the inherent uncertainty in expert judgments limits the precision of classical AHP in entrepreneurial and innovation environments where subjective evaluations are inevitable. To address this, studies have incorporated Fuzzy Analytic Hierarchy Process (FAHP). For example, it has been used to prioritize enabling factors for the strategic management of university business incubators (Somsuk & Laosirihongthong, 2014) and to model critical success factors in women entrepreneurship (Amrita et al., 2018).

On the other hand, the Weighted Aggregated Sum Product Assessment (WASPAS) method (Zavadskas et al., 2012) integrates the Weighted Sum and Weighted Product Models to rank alternatives efficiently while requiring minimal computational effort (Chakraborty et al., 2024). Despite its advantages, the application of WASPAS method in entrepreneurship remains limited. In social entrepreneurship, Fuzzy WASPAS has been used to rank solutions for overcoming barriers faced by emerging social entrepreneurs (Keleş Tayşir et al., 2024). This structured approach helps social entrepreneurs prioritize strategies effectively and reduces the risk of venture failure.

Hybrid MCDM methods aim to combine multiple MCDM techniques to leverage their strengths and overcome their limitations (Li et al, 2020; Hasan et al., 2022). This integration provides decision-makers with more comprehensive insights and supports more informed and reliable choices in complex, multi-dimensional problems (Islam et al., 2017; Hariri et al., 2023). Particularly in uncertain and dynamic environments, such as evaluating the performance of incubation firms, hybrid MCDM methods allow decision-makers to conduct multi-dimensional assessments and accurately prioritize strategic actions. Therefore this study aims to analyse the performance of incubation firms in Türkiye and identify key success factors using a hybrid approach that combines FAHP and WASPAS methods. A comprehensive field study surveying 305 firms was conducted to collect data on various performance dimensions.

There has been no nationwide survey or decision model in the entrepreneurship literature that evaluates the performance of incubation firms in Türkiye. This study aims to fill this gap by providing a comprehensive and robust approach using a hybrid MCDM methodology. Considering the critical role of entrepreneurs in driving economic development, this research provides practical insights for stakeholders to strengthen the entrepreneurial ecosystem, promote regional economic growth, create jobs, and accelerate technological innovation.

The findings from this study enhance our understanding of the entrepreneurial ecosystem and provide valuable guidance for stakeholders, including incubation centres, the Ministry of Industry and Technology, the Small and Medium Enterprises Development Organisation (KOSGEB), and the Scientific and Technological Research Council of Türkiye (TÜBİTAK). By identifying strengths and areas for improvement, this study helps inform policies to promote sustainable incubation management and improve the productivity and economic contribution of incubation centres in Türkiye. Moreover, the study contributes to the growing body of knowledge on entrepreneurship in transition economies and the role of university-led innovation systems in fostering regional economic development (Riwu, Mattunruang, 2024).

The remainder of this paper is structured as follows. Section 2 provides an overview of the performance criteria utilised to evaluate the competency of incubation firms. Section 3 introduces the mathematical methodologies and their steps. Section 4 covers the criteria weights and presents the application of performance evaluation for incubation firms. Finally, the results are discussed with some recommendations for future researches.

2. Performance Criteria

Data for this study are collected through a structured survey based on nine performance criteria: (1) Customer, (2) Technology, (3) Research and Development (R&D), (4) Competition, (5) Investment, (6) Marketing, (7) Environment and Sustainability, (8) Human Resources (H&R), and (9) Commercialization. These dimensions are identified through expert evaluations and a comprehensive review of the literature (Júnior et al., 2023; Cheah & Ho, 2021; Pugliese et al., 2022; Cubero et al., 2021). The 70 questions from the nationwide survey were designed to assess the competencies of 305 incubation firms. Firms respond to the questions using a 1-5 Likert scale. Using MCDM methodologies, the performance of these firms was evaluated. Both the highest and lowest performers were identified. A brief overview of each survey dimension is provided below:

(1) Customer: This dimension centers on a customer-focused approach, considering factors such as customer participation, understanding needs and desires, enhancing customer experience, maintaining regular communication, visiting potential clients, anticipating future needs, driving customer innovation, and building trust.

(2) Technology: This dimension emphasizes the technological infrastructure and processes of firms, focusing on aspects such as the design of functional websites, adoption of advanced technologies, innovative product development, and the effective use of computer-aided design (CAD), manufacturing, and business intelligence tools.

(3) Research and Development: This dimension evaluates the R&D infrastructure, looking at factors like stakeholder collaboration, product quality and variety, intellectual property registration, budget planning, innovation activities, original ideas, technological tracking, prototype development, and R&D projects related to disaster and emergency management.

(4) Competition: This dimension reflects the competitive strategies of firms, focusing on competitor analysis, development of appropriate pricing strategies, ensuring adequate education and experience, addressing societal problems, and formulating strategies for innovative products and services.

(5) Investment: This dimension considers factors like government incentives, economic fluctuation planning, utilization of support funds, openness to risky investments, initiatives to seize new opportunities, mentorship for entrepreneurs, access to financing resources, angel investment networks, and fostering investor trust.

(6) Marketing: This dimension involves a comprehensive marketing approach aimed at reaching target audiences, creating new markets, developing innovative marketing strategies, leveraging social media marketing, building brand value, employing effective presentation techniques, exploiting cost advantages, identifying market opportunities, and analyzing consumer behavior.

(7) Environment and Sustainability: This dimension focuses on activities aimed at protecting the environment and supporting sustainability, including energy efficiency, environmental sensitivity, and sustainable recycling practices.

(8) Human Resources: This dimension considers aspects such as team motivation and confidence, effective communication, harmonious collaboration, distribution of duties and responsibilities, and ensuring sufficient human resources.

(9) Commercialization: This dimension evaluates factors such as exploring radical opportunities, market testing of prototypes, creating new markets, distribution network competence, customer relationship management, refining Minimum Viable Products

(MVP), contributing to the Low Touch Economy, and strengthening commercialization and sales capabilities.

These nine dimensions are all critical factors that directly influence the success of incubation firms. Effective management of these dimensions within the entrepreneurial ecosystem is essential for firms to achieve their growth, competitiveness and sustainability goals.

3. Materials and Methods

In this section, we present the key definitions and steps of the applied mathematical methods. We employ the FAHP method to calculate the weights of the competency evaluation dimensions. These dimensions weights and the survey responses related to firm profiles are input data for ranking the incubation firms using the WASPAS method.

3.1 Fuzzy Analytical Hierarchy Process (Fuzzy AHP)

The Analytic Hierarchy Process (AHP), developed by Saaty (1980), provides a method for prioritizing alternatives and assessing the importance of attributes in MCDM problems. However, traditional AHP does not effectively address the uncertainty inherent in human judgment or natural language expression (Yang & Chen, 2004). To address vagueness, ambiguity, and subjectivity in the decision-making process, fuzzy set theory has been introduced (Zadeh, 1965). This approach allows decision-makers to use linguistic scales to express their preferences, which are then converted into fuzzy numbers.

In this study, the weights of the performance criteria for competency assessment of incubation firms are determined using Buckley's (Buckley, 1985a; 1985b) extension of the FAHP approach. This method can be easily adapted to fuzzy cases and provides a unique solution for pairwise comparison matrix. Additionally, the steps involved in Buckley's FAHP are simpler compared to other FAHP methods. The steps algorithm can be summarized as follows:

Step 1. Construct pairwise comparison matrices for all criteria in the hierarchical structure (see Equation 1). Assign linguistic terms, as shown in Equation 2, to the pairwise comparisons by determining which of the two criteria is more important.

$$\tilde{M} = \begin{pmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{pmatrix} = \begin{pmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{pmatrix} \tag{1}$$

$$\tilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9}, & \textit{criterion i has relative importance to criterion j} \\ 1, & i = j \\ \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1}, & \textit{criterion i has less importance to criterion j} \end{cases} \tag{2}$$

Step 2. Use the geometric mean to define the fuzzy geometric mean as follows:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in})^{1/n} \tag{3}$$

where $\tilde{a}_{in}$ is the fuzzy comparison value of the criterion i to criterion n, calculated as the geometric mean of the fuzzy comparison values of the criterion i relative to each criterion.

Step 3. Calculate the fuzzy weights of each criterion using Equation 4:

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1} \tag{4}$$

where $\widetilde{w}_i$ is the fuzzy weight of the criterion, which can be indicated by $\widetilde{w}_i = (lw_i, mw_i, uw_i)$ Here lw_i, mw_i, uw_i and stand for the lower, middle, and upper values of the fuzzy weight of the ith criterion.

Step 4. Utilise the centre of area (COA) method to find out the best non-fuzzy performance (BNP) value (crisp weights) of each criterion by the following equation:

$$BNP\widetilde{w}_i = [(uw_i - lw_i) + (mw_i - lw_i)]/3 + lw_i \quad (5)$$

According to the value of the derived BNP for each of the alternatives, the ranking of each alternative can then be proceed.

3.2 Weighted Aggregated Sum Product Assessment (WASPAS)

The Weighted Aggregated Sum Product Assessment (WASPAS) method was presented by Zavadskas, Turskis, Antucheviciene, and Zakarevicius in 2012. This method combines the strengths of the Weighted Sum Model (WSM) and the Weighted Product Model (WPM) (Zavadskas et al., 2012). The additive and multiplicative relative importance of each attribute are calculated based on the procedural steps of the WASPAS method. The alternatives are then ranked based on these evaluations.

WASPAS is a widely used MCDM approach in the research community due to its strong mathematical foundation and simplicity. It also requires minimal computational effort, making it an efficient tool for decision-making (Chakraborty et al., 2024). The steps used for the WASPAS algorithm can be summarized as follows (Zavadskas et al., 2012):

Step 1. The decision matrix X which shows the performances of different alternatives with respect to various criteria is formed.

$$X = \begin{pmatrix} r_{11} & \cdots & r_{1j} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{i1} & \cdots & r_{ij} & \cdots & r_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mj} & \cdots & r_{mn} \end{pmatrix} \quad ; i = 1, \dots, m, \;\; j = 1, \dots, n \quad (6)$$

where r_{ij} represents the decision matrix for ith alternative in jth attribute. Also, the decision maker provides the weight of the attribute $[w_1, w_{2,\dots,} w_n]$.

Step 2. The decision matrix X is normalised considering the beneficial and non-beneficial attributes.

$$r_{ij}{}^{*} = \frac{r_{ij}}{\max\limits_{i} r_{ij}}; \quad i = 1, \dots, m, j = 1, \dots, n \quad (7)$$

$$r_{ij}{}^{*} = \frac{\min\limits_{i} r_{ij}}{r_{ij}}; \quad i = 1, \dots, m, j = 1, \dots, n \quad (8)$$

where $r_{ij}{}^{*}$ illustrates the normalised value of the decision matrix of ith alternative in jth attribute.

Step 3. The additive relative importance of the weighted normalised data of each alternative is calculated.

$$Q_i^{(1)} = \sum_{j=1}^{n} r_{ij}^{*} . w_j ; \; i = 1, \dots, m \tag{9}$$

where w_j indicates the weight of the attribute $[w_1, w_{2,\dots,} w_n]$ and $Q_i^{(1)}$ indicates the additive relative importance of the ith alternative.

Step 4. The multiplicative relative importance of the weighted normalised data of each alternative is calculated.

$$Q_i^{(2)} = \prod_{j=1}^{n} (r_{ij}^{*})^{w_j} ; \; i = 1, \dots, m \tag{10}$$

where $Q_i^{(2)}$ demonstrates the multiplicative importance of the ith alternative.

Step 5. The joint generalized criterion (Q) is determined for generalizing and integrating additive and multiplicative methods, defined as Equation 11.

$$Q_i = \lambda \sum_{j=1}^{n} r_{ij}^{*} . w_j + (1 - \lambda) \prod_{j=1}^{n} (r_{ij}^{*})^{w_j} ; \; i = 1, \dots, m \tag{11}$$

Step 6. The joint generalized criterion (Q) values are ranked in descending order, and the highest value gives the highest rank. If the λ value equals 1, the equation is converted into the Weighted Sum Model (WSM) model and if the λ value equals zero, the equation is converted into the Weighted Product Model (WPM) model.

4. Application

A comprehensive field study is conducted across 305 incubation firms in Türkiye, utilising a detailed survey to collect data from entrepreneurs. The survey focused on key dimensions of firm performance, including Customer, Technology, Research and Development, Competition, Investment, Marketing, Environment and Sustainability, Human Resources and Commercialisation. Responses are compiled into a database for competency analysis. To assess the relative importance of each dimension, five experts performed pairwise evaluations.

Based on their insights, we employ Buckley's extension of FAHP approach to assign the weights to each decision criterion. Following the weighting process, we apply the WASPAS method to evaluate and rank the performance of the incubation firms. By comparing the rankings generated by these MCDM approaches, the study identifies common characteristics of top-performing firms, providing valuable insights into the factors that contribute to their success. To summarise, the evaluation procedure in this paper consists of three main steps:

Step 1. Identify the performance criteria based on literature research and expert opinions. Prepare survey questions associated with these criteria and create a database.

Step 2. Calculate the weights of performance criteria using Buckley's extension of the FAHP method.

Step 3. Conduct the WASPAS method to determine the final ranking of incubation firms in Türkiye.

4.1 Fuzzy Weights of Performance Criteria

The weights of the nine performance evaluation criteria are determined by using the FAHP method. The performance criteria are assessed by five experts in the fields of entrepreneurship management and SME (Small and Medium-sized Enterprise) analysis. Each expert used the linguistic terms presented in Table 1 while conducting the pairwise comparison matrices.

Table 1. Linguistic scale for Buckley's FAHP

Linguistic definition	Fuzzy numbers
Absolutely low importance (ALI)	(1/9, 1/9, 1/7)
Very low importance (VLI)	(1/9, 1/7, 1/5)
Low importance (LI)	(1/7, 1/5, 1/3)
Weakly low importance (WLI)	(1/5, 1/3, 1)
Equal importance (EI)	(1, 1, 1)
Weakly high importance (WHI)	(1, 3, 5)
High importance (HI)	(3, 5, 7)
Very high importance (VHI)	(5, 7, 9)
Absolutely high importance (AHI)	(7, 9, 9)

Table 2 demonstrates an example of the linguistic comparison between performance criteria. According to decision expert 1, Technology is weakly high important (WHI) over Customer. For all other comparisons, green and red tone coloring is used to provide visualization in Table 2.

Table 2. Pairwise comparison example for decision expert 1

Evaluation Matrix	Customer	Technology	R&D	Competition	Investment	Marketing	Environment	Human Resources	Commercialisation
Customer	1	1/WHI	1/VHI	1/WHI	WHI	WHI	VHI	1/WHI	1/VHI
Technology	WHI	1	1/HI	WHI	HI	WHI	HI	1/WHI	1/WHI
R&D	VHI	HI	1	VHI	AHI	HI	AHI	WHI	WHI
Competition	WHI	1/WHI	1/VHI	1	WHI	1/EI	HI	1/WHI	1/HI
Investment	1/WHI	1/HI	1/AHI	1/WHI	1	1/WHI	1/EI	1/HI	1/VHI
Marketing	1/WHI	1/WHI	1/HI	EI	WHI	1	WHI	1/HI	1/VHI
Environment	1/VHI	1/HI	1/AHI	1/HI	EI	1/WHI	1	1/VHI	1/AHI

Human Resources	WHI	WHI	1/WHI	WHI	HI	HI	VHI	1	1/WHI
Commercialisation	VHI	WHI	1/WHI	HI	VHI	VHI	AHI	WHI	1

The Consistency Ratio (CR) values for the pairwise comparison matrices for experts and the aggregated matrix for the overall CR are shown in Table 3. The consistency of calculation process is evaluated by analysing the overall CR, which is determined through geometric mean of the numerical scale values assigned to the linguistic terms used by all experts.

Table 3. Consistency ratio values for experts

Decision Experts	CR Values
E1	0.078
E2	0.050
E3	0.086
E4	0.057
E5	0.076
Overall CR	0.028*

According to the evaluations of five experts, Table 4 presents the fuzzy weights of the performance criteria and their BNP values. Based on these evaluations, the most important dimension is Research and Development, with a weight of 0.127. This is followed closely by Commercialisation at 0.124 and Technology at 0.115 value. Competition criterion ranks fourth with a weight of 11.3%.

Table 4. Fuzzy weights of the performance criteria

Performance Criteria	BNP
1. Research and Development	0.127
2. Commercialisation	0.124
3. Technology	0.115
4. Competition	0.114
5. Customer	0.113
6. Marketing	0.107
7. Human Resources	0.105
8. Investment	0.104
9. Environment and Sustainability	0.095

Additionally, Environment and Sustainability provide the least support to overall performance, with a weight of only 9.5%.

4.2 Ranking Incubation Firms

The weights of the performance evaluation criteria (determined in the FAHP method) are utilized in the WASPAS method. The calculation steps of the WASPAS method are applied to the decision matrix of 305 incubation firms in Türkiye and the Additive Relative Importance Q(1), Multiplicative Relative Importance Q(2), and the Joint Generalized

Criterion Q values of alternatives are determined. Finally, the rankings are obtained by sorting the Q value for λ=0.5 in descending order as shown in Table 5.

Table 5. Results of the WASPAS method for λ=0.5

Firms	$Q^{(1)}$	$Q^{(2)}$	Q	Ranking
F 195	0.999	0.995	0.997	1
F 190	0.994	0.990	0.992	2
F 7	0.993	0.989	0.991	3
F 230	0.993	0.989	0.991	4
F 247	0.990	0.986	0.988	5
F 199	0.985	0.981	0.983	6
F 14	0.981	0.977	0.979	7
F 249	0.975	0.969	0.972	8
F 61	0.968	0.963	0.966	9
F 279	0.963	0.958	0.961	10
…	…	…	…	...
F 99	0.607	0.575	0.591	296
F 83	0.635	0.529	0.582	297
F 41	0.581	0.566	0.574	298
F 86	0.588	0.557	0.573	299
F 136	0.572	0.558	0.565	300
F 31	0.529	0.497	0.513	301
F 246	0.390	0.385	0.388	302
F 82	0.212	0.208	0.210	303
F 81	0.210	0.206	0.208	304
F 123	0.207	0.204	0.206	305

We conduct sensitivity analysis to observe the effects of different λ values on the Joint Generalized Criterion, Q. While the rankings of the best-performed incubation firms remain unchanged, some variations are observed among the worst-performed firms, as illustrated in Figure 1. Based on the ranking results, while the alpha value causes some changes in worst-performing firms, it has no effect on best performing firms. In other words, the successful firms' rankings are robust in the method.

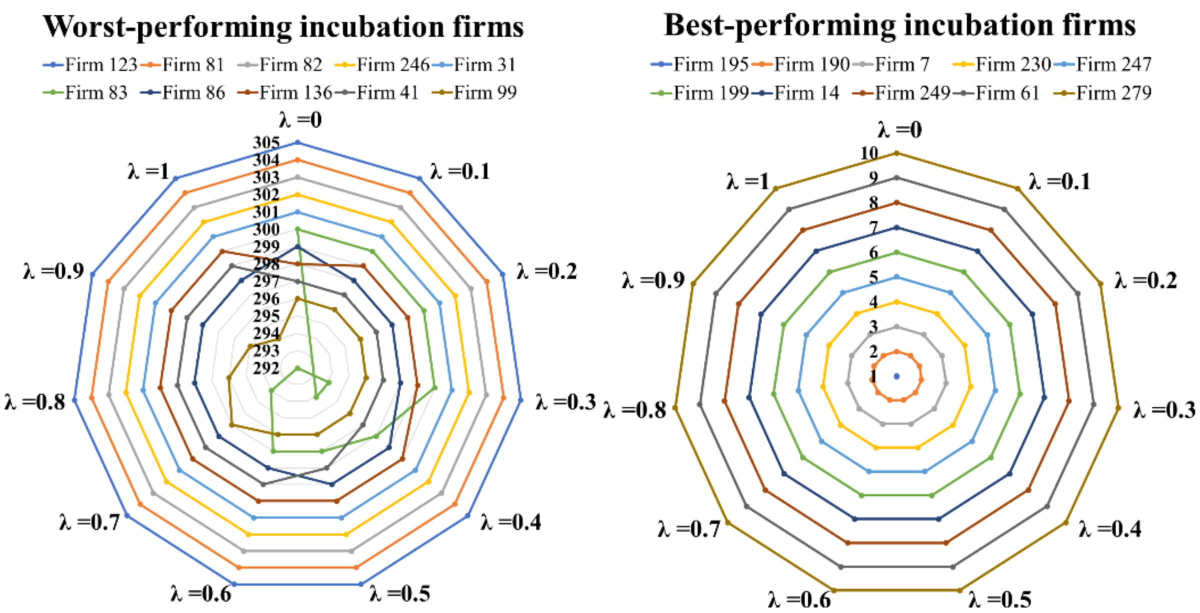

Figure 1. Effect of λ values on the joint generalized criterion (Q) and firm rankings

5. Discussion

This study evaluates incubation firm performance using MCDM method and offers important insights into various dimensions of the entrepreneurial ecosystem. The findings provide a concrete roadmap for developing countries to review and strengthen their entrepreneurship policies, develop specific strategies for universities and technology development zones, and make more effective and flexible investment decisions. Table 6 presents key attributes of the top 10 firms identified through Fuzzy AHP and WASPAS.

Table 6. The ten best-performing incubation firms

No	Firm ID	City	Affiliated Institution	Graduation Level	Activity Duration (Months)	Field	Completed R&D Projects	Patents
1	195	Kastamonu	State University	Post-PhD	8	Software	5	2
2	190	İstanbul	R&D University	B.Sc.	4	Energy	1	3
3	7	Van	State University	B.Sc.	6	Software	3	4
4	230	Kocaeli	State University	B.Sc.	1	Energy	2	3
5	247	İstanbul	Private University	B.Sc.	8	Software	5	2
6	199	Kastamonu	State University	Post-PhD	5	IT	1	2
7	14	Van	State University	M.Sc	50	IT	4	5
8	249	Niğde	State University	M.Sc	5	Food	5	2
9	61	Manisa	State University	B.Sc.	22	Health	1	3
10	279	İstanbul	Private University	B.Sc.	5	Health	5	2

In Table 6, incubator firms with Firm IDs 7 (Van), 230 (Kocaeli), and 249 (Niğde) accelerated their entrepreneurial activities by receiving funding from other institutions and organizations. The remaining seven firms with successful profiles were found to be unaware of these funding opportunities. In fact, this could be considered a significant input for strengthening financial resources.

The geographical distribution of the ten highest-performing incubation firms highlights their valuable contributions to innovation and entrepreneurship across various regions. Notably, the Marmara Region, and Istanbul in particular, serves as a hub for top performing entrepreneurs. However, the leading firm in Kastamonu demonstrates that success can also be achieved outside major metropolitan areas. Similarly, Van stands out in the Eastern Anatolia Region with its remarkable performance. The presence of successful firms in less developed regions such as Kastamonu, Van, Nigde, Kocaeli, and Manisa cities underscores the entrepreneurial ecosystem is spread over a wide geographical area as shown in Figure 2.

The geographic distribution of incubation centers demonstrates that the entrepreneurial ecosystem is not limited to global centers like Istanbul; competitive companies can also emerge in Anatolian cities. This demonstrates the need for decision-makers and policymakers to expand entrepreneurship support and programs, taking into account regional development differences across countries, and to support the development of innovative ventures not only in economic centers but also in various regions of the country. This contribution will support regional development, revitalize the local economy, and ensure the sustainability of the entrepreneurial ecosystem.

Figure 2. The geographical distribution of the best-performing incubation firms

Most of the companies are affiliated with state universities, emphasizing the critical role of these institutions in supporting the innovation and entrepreneurship ecosystem. Additionally, the presence of two companies in Istanbul linked to private universities highlights the significant impact of private sector-supported institutions in fostering entrepreneurship. The majority of incubation firm founders hold undergraduate degrees. However, firms established by individuals with master's or post-doctoral education levels also demonstrate notable contributions. The operating periods of the companies range from 1 to 50 months. In particularly, the firm in Van (Firm ID: 14), which has been active for 50 months shows that success can be achieved in long-term incubation processes. This firm has completed four R&D projects and obtained five patents, demonstrating a significant performance in this process.

Firms' founder profiles, talents, and duration of operations influence firm competence and, consequently, the performance of incubators. The competence of incubators also has a significant impact on entrepreneurial performance. The rapid success of firms founded by young entrepreneurs, mostly undergraduates, demonstrates that some incubators provide significant support to entrepreneurs at early stages. The fact that an incubator with a long history of operations in a low-development region stands out with both R&D projects and patents demonstrates the necessity of long-term support mechanisms for sustainable success. This demonstrates the need for both short-term accelerator support and long-term capacity building programs within the entrepreneurial ecosystem.

The activity fields of the companies are primarily concentrated in the software, energy and information technology (IT) sectors. High-performing incubation firms significantly contribute to the entrepreneurship ecosystem with their expertise and innovative approaches in advanced technology fields. Companies in the software and IT sectors achieve a competitive advantage by providing solutions tailored to user needs and promoting technological innovation. In the energy sector, firms focusing on renewable energy and energy efficiency adopt innovative approaches to ensure sustainable energy production and management. These firms develop dynamic business models and strong strategies to address market demands and secure a strategic advantage.

The contributions of entrepreneurs operating in software and information technologies to artificial intelligence and digitalization processes, and the activities of enterprises in the energy sector in renewable energy and energy efficiency, demonstrate that national strategic priority issues are supported through entrepreneurship. This finding is important for investors in identifying strategic issues and sectors where resources can be directed.

The number of R&D projects completed by the companies generally ranges from 1 to 5. Notably, the company in Nigde (Firm ID: 249) has completed five (5) R&D projects, highlighting its success in this field. Similarly, the company in Van (Firm ID: 14) stands out with five (5) patents. The completed projects and registered patents not only reflect the innovation capacities of these companies but also reveal their potential to lead advancements in technology.

Receiving funding support can be regarded as a key success indicator in entrepreneurship processes. Three companies, based in Istanbul, Van, and Nigde, have secured funding support, suggesting a higher commercial potential for these firms. The majority of incubation firms operate without financial support from national or international sources. However, some have benefitted from national funding programs such as TÜBİTAK, KOSGEB, and the Ministry of Industry and Technology. The limited access to international funding emerges as a significant area for improvement. Implementing strategies to enhance access to international funding opportunities, strengthen commercialization efforts, and expand collaboration and networking opportunities will increase the global competitiveness of these firms and accelerate their innovation processes.

Financial support mechanism is a determining factor in entrepreneurship development and scalability. While the effective utilization of national support programs by some incubators is a positive development, limited access to international funding is a significant shortcoming in the global integration of the entrepreneurial ecosystem. Encouraging and expanding access to international funding will enhance entrepreneurs' global competitiveness and accelerate technology transfer.

Table 7. Performance criteria values of the ten best-performing incubation firms

Performance Criteria	Firm ID									
	195	**190**	**7**	**230**	**247**	**199**	**14**	**249**	**61**	**279**
1-Research and Development	5	5	5	4.8	4.7	5	5	5	5	4.1
2-Commercialisation	5	5	5	5	5	5	4.8	4	5	5
3-Technology	4.5	4.3	4.5	4.4	4.4	4.3	4.5	4.4	4.3	4.5
4-Competition	5	5	5	5	5	4.7	5	5	5	4.5
5-Customer	4.5	4.5	4.6	4.6	4.5	4.5	4.3	4.6	4	4.3
6-Marketing	5	5	5	5	5	5	4.9	5	4.6	5
7-Human Resources	5	5	5	5	5	5	5	5	5	5
8-Investment	5	5	5	5	5	5	5	5	4.8	5
9-Environment	5	5	4.7	5	5	5	4.8	5	5	5

Table 7 presents the average responses of the ten (10) best-performing firms to survey questions across various evaluation dimensions. The survey scores range from 4.3 to 5.00 on a scale of 1-5, reflecting consistently high performance. The analysis reveals that these top performing incubation firms generally excel in each performance criterion. Human Resources, Commercialization, Marketing, Competition and Investment criteria reflect the strongest aspects of these companies. However, lower scores in criteria like Technology, Customer, and R&D suggest areas for development and focus.

The general characteristics of the ten (10) worst-performing firms, obtained using the FAHP and WASPAS methods, are summarized in Table 8. Most of these companies operate under state universities, although it is noteworthy that some firms in Istanbul, linked to R&D and private universities, also underperform. This suggests that the affiliation with institutions may not always positively impact the success of entrepreneurial firms. The education levels of the founders of the company vary across the undergraduate, graduate, doctoral and postdoctoral levels. The operating periods of underperforming firms range from 2 months to 50 months. While short operational durations can explain poor performance, the existence of long operating firms with low performance highlights that activity duration alone is not a sufficient success indicator.

It is considered that education level is not the sole determinant of entrepreneurial performance. The existence of low-performing firms with short and long operating periods similarly demonstrates that operating period alone does not guarantee success. Therefore, along with education level and operating period, the founders' competencies, experience, and personality traits, a strong network, financial literacy, and the ability to develop unique strategies tailored to market dynamics, all have significant impacts on entrepreneurial performance. Entrepreneurs' relationships with incubation centers (incubators) require not only infrastructure and location support, but also the development of effective mentoring, networking, and strategic guidance mechanisms.

The worst-performing firms operate in different sectors such as software, healthcare, IT, PC gaming, and agriculture. Their completed R&D projects typically range from 1 to 5, with patent numbers usually limited to 2. Despite having some R&D initiatives and national or international patents, these efforts are insufficient to translate into successful outcomes. Only two of these firms received funding support. The worst performance of these firms despite receiving fund support suggests that there may be inadequacy in fund management or utilization.

The concentration of high-performing entrepreneurial firms in software, energy, and information technology demonstrates the strategic importance of these sectors and their alignment with global trends. Conversely, the presence of low-performing firms in diverse sectors such as software, healthcare, IT, PC games, and agriculture suggests that entrepreneurial success is not solely dependent on sector selection. The key difference here is that high-performing firms develop innovative approaches and adapt to the market, while low-performing firms fail to keep up with technological developments, invest in innovation, and develop customer-focused strategies.

While high-performing entrepreneurial firms stand out with a higher number of patents and projects, the relatively low number of R&D projects and limited patent holdings in low-performing firms are noteworthy. The failure of some low-performing firms to achieve success despite holding patents demonstrates that innovation outputs alone are not sufficient, and that innovative outputs cannot translate into economic success unless supported by commercialization and strategic management. This result highlights the critical importance for entrepreneurs of not only conducting R&D but also bringing these outputs to market according to customer needs. The fact that some companies, despite receiving funding, rank near the bottom of the performance rankings demonstrates that the presence of funding alone does not guarantee success. Critical factors here are effective management of funds, investment in the right areas, and implementation of sustainable strategies.

Limited access to international funding poses a barrier for both high- and low-performing companies. This finding suggests that policymakers and experts at incubators should provide entrepreneurs with capacity-building support and mentoring on accessing international funding and managing it.

Table 8. The ten worst-performing incubation firms

No	Firm ID	City	Affiliated Institution	Graduation Level	Activity Duration (Month)	Field	Completed R&D Projects	Patents
1	99	Istanbul	R&D University	B.Sc.	11	PC Games	1	3
2	83	Samsun	StateUniversity	M.Sc.	10	Health	5	2
3	41	Adana	R&D University	Post-PhD	24	Agriculture	3	4
4	86	Samsun	State University	B.Sc.	38	Software	5	2
5	136	Malatya	State University	M.Sc.	50	Health	3	2
6	31	İstanbul	R&D University	PhD	30	PC	1	2
7	246	İstanbul	Private	B.Sc.	2	PC Games	4	2
8	82	Samsun	State University	Post-PhD	5	IT	5	2
9	81	Samsun	State University	B.Sc.	15	Software	5	2
10	123	Konya	State University	B.Sc.	19	Health	1	2

In Table 8, incubator firms with firm IDs 41 (Adana) and 123 (Konya) strengthened their entrepreneurial activities by receiving funding from other institutions and organizations. It was determined that the remaining eight companies could not receive such financial support.

The worst-performing firms are primarily concentrated in Samsun and Istanbul. Samsun stands out as the most represented city, with four companies, followed by Istanbul with three. Other underperforming firms are located in regions such as Adana, Malatya, and Konya as shown in Figure 3.

Figure 3. The geographical distribution of the worst-performing incubation firms

The fact that the lowest performing entrepreneurs are concentrated in cities with medium-high development levels shows that entrepreneurial success can not be explained only by geographical location, but the quality of the local ecosystem, the effectiveness of support mechanisms, firm profile and internal strategies of incubation firms are also critical determinants.

Table 9 presents the average responses of the ten (10) worst-performing firms across performance dimensions in the survey. The results, based on a 1-5 scale, indicate that the evaluation scores for these firms are notably low. Firm ID 123, in particular, received the lowest scores across almost all criteria. This indicates the need for substantial improvements in the firm's overall performance, as well as increased resources and support. Such assessments provide valuable insights, enabling firms to identify their weaknesses and take strategic steps to address them.

Table 9. Performance criteria values of the ten worst-performing incubation firms

Performance Criteria	**Firm ID**									
	99	**83**	**41**	**86**	**136**	**31**	**246**	**82**	**81**	**123**
1-Research and Development	3.4	1.0	3.4	2.8	2.7	1.8	2.2	1.0	1.0	1.0
2-Commercialisation	3.5	1.0	2.5	3.0	2.0	3.8	1.8	1.0	1.0	1.0
3-Technology	2.8	1.2	2.3	3.1	3.2	2.7	2.0	1.3	1.3	1.1
4-Competition	2.8	5.0	3.5	3.2	3.2	2.5	2.0	1.0	1.0	1.0
5-Customer	2.6	4.5	2.9	2.7	2.4	2.5	1.8	0.9	0.9	1.0
6-Marketing	3.2	4.4	2.8	3.7	3.3	2.6	2.0	1.0	1.0	1.0
7-Human Resources	1.0	4.0	1.7	1.0	3.3	1.0	1.7	1.0	1.0	1.0
8-Investment	4.0	4.0	3.3	2.5	2.0	2.5	2.0	1.0	1.0	1.0
9-Environment	3.1	3.4	3.1	3.6	3.0	3.6	1.7	1.0	1.0	1.0

The worst-performing firms demonstrate deficiencies across multiple dimensions, including Customer, Technology, Research and Development, Competition, Investment, Marketing, Environment and Sustainability, Human Resources, and Commercialization. These firms, which rank lower in the performance competency analysis, require significant improvements in these areas. These firms may not have followed technological developments closely, invested enough in innovation, and as a result, lost their competitiveness in the sector. Developing their capabilities in a wide range of areas, such as customer centric strategies, marketing techniques, team management, and sustainability practices, will help these incubators improve their performance and strengthen their position in the market. Lack of financial resources reinforces this situation, and they cannot benefit from national and international support sufficiently. Therefore, strategic planning, fund management, marketing and the development of cooperation networks are critical for low performing firms to become more competitive in the sector. The results obtained in this section indicate that incubation centers should increase capacity building and mentoring services for low performing firms. It is assessed that entrepreneurs need more support and guidance to improve their innovation processes.

This study provides a comprehensive roadmap for decision-makers by considering different dimensions of the entrepreneurial ecosystem. It demonstrates the need for policymakers to develop regional and sector-focused strategies. For private institutions and universities, incubation centers are not only places where space and infrastructure support are provided, but also special incentive zones where effective mentoring, networking, and strategic guidance are provided to entrepreneurs. For investors, it demonstrates that the focus should not only be on sectoral trends but also on firms' innovation capacity, customer focus, and fundraising skills. The findings from high-performing firms demonstrate the importance of efficient resource utilization, international collaborations, and strategic management for entrepreneurial success. Thus, the study not only contributes to the academic literature but also offers innovative strategies for developing countries to ensure the sustainability, competitiveness, and global integration of the entrepreneurial ecosystem.

6. Conclusion

This study proposes an integrated approach that combines a comprehensive field study using surveys with the MCDM methods as FAHP and WASPAS to evaluate the performance competency of incubation firms across Türkiye. The FAHP method effectively determines the weights of various performance dimensions, while the WASPAS method offers a robust yet simple mathematical foundation for ranking the performance of these firms.

According to FAHP results, Research and Development leads with a weight of 0.127, highlighting its key role in driving innovation. Commercialisation follows closely at 0.124, stressing the need to turn ideas into marketable products. Technology (0.115), Competition (0.114), and Customer (0.113) highlight the importance of advanced skills, market awareness, and customer focus for growth. Marketing (0.107) and Human Resources (0.105) underline the need for effective audience engagement and a skilled workforce. Investment (0.104) points to the necessity of financial resources. Environment and Sustainability (0.095), while the lowest, is still an important area for strategic focus.

According to the WASPAS results, the top ten incubation firms out of 305 demonstrate a holistic strategic approach across performance dimensions. Firms that invest in patent registration and R&D projects are stronger in terms of innovation, which is reflected positively in their performance. Many of the best-performing firms have national and international patent registrations. Particularly, those receiving financial support from organisations such as KOSGEB, TÜBİTAK, EU, UN, and the OECD tend to be more successful. This financial backing and patent ownership enable firms to invest in innovative projects and grow. Furthermore, Research and Development activities are identified as strategic priorities for these high-performing firms.

The majority of the lowest-performing firms have not benefited from financial support. They have some R&D projects and national or international patent registrations. These firms exhibit deficiencies in Customer, Technology, Research and Development, Competition, Investment, Marketing, Environment and Sustainability, Human Resources and Commercialisation dimensions. Ranked lower in the performance competency analysis, they require substantial improvements in these areas. These firms may not have been able to follow technological developments closely, have not invested sufficiently in innovation and consequently lost their competitive power in the sector. Improving a wide range of capabilities, including customer-focused strategies, marketing techniques, team management, and sustainability practices, will help these incubation firms increase their performance and strengthen their position in the market.

The geographical distribution of the top-performing incubation firms indicates their valuable contributions to innovation and entrepreneurship across various regions. The analysis highlights that the Marmara Region, particularly Istanbul, serves as a key hub for high-performance incubation firms. Interestingly, the leading firm in Kastamonu demonstrates that success can also be achieved outside major urban centres. Additionally, Van stands out for its notable performance among incubator firms in the Eastern Anatolia Region.

The best-performing incubation firms generally operate in software, energy, and information technology sectors. In the software and information technology sectors, firms are driving technological innovation and providing solutions that cater to user needs, enhancing their competitive advantage. The energy sector, especially in renewable sources and efficiency, is rapidly growing, with successful companies developing innovative approaches to sustainable energy production and management. These firms are adopting dynamic strategies to meet market demands and strengthen their competitiveness in these crucial areas.

This study also places significant emphasis on the intermediary role of for-profit and non-profit institutions and organizations in supporting entrepreneurship. A strategic roadmap should be developed and actively implemented to support both entrepreneurs and SMEs in critical areas identified as important in the study, such as R&D, commercialization, and technology. For developing countries, it is crucial for intermediary institutions or organizations to encourage innovative researchers and entrepreneurs, facilitate their expansion into national or international markets, and allocate resources to enable them to produce technology-focused products and services, using instruments such as universities, technology development zones, incubators, technology transfer offices, angel investors, government support mechanisms, and incentive programs. Supporting small businesses and entrepreneurs that produce innovative outputs and playing a positive role in their transformation into unicorns or global brands also has a positive and accelerating impact on the national economy and development.

For future work, this study can be expanded by conducting clustering analyses based on the detailed survey data. Additionally, common competency factors can be explored across variables such as firm age, region, and sector, while discussing their statistical significance. Examining the influence of diversity within teams, sector-specific challenges, and the adoption of emerging technologies could enhance understanding of performance dynamics. From the perspective of MCDM, alternative methodologies (e.g., ELECTRE, PROMETHEE, TOPSIS and DEMATEL) can be applied to compare the outcomes and validate the results.

Acknowledgment

This study was funded by The Scientific and Technological Research Council of Türkiye (TÜBİTAK) (Grant Number 122G192).

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