VERİMLİLİK DERGİSİ
JOURNAL OF PRODUCTIVITY

Evaluation of Factors Affecting Innovation Productivity by Pythagorean Fuzzy AHP Method

Miraç Tuba Çelik[1], Aytaç Yıldız[1]

ABSTRACT
Purpose: In this study, it is aimed to rank the factors affecting the innovation productivity of enterprises.
Methodology: The Pythagorean Fuzzy Analytical Hierarchy Process (AHP) method, which gives successful results in modelling uncertainty and uses Pythagorean fuzzy sets, is used to rank the factors affecting innovation productivity according to their importance.
Findings: In the application part of study firstly, the factors affecting the innovation productivity were determined and as a result of expert evaluations, the steps of the method were applied and the factors were ranked according to their importance. Finally, the most important factors were determined by performing a sensitivity analysis. When the results obtained from the study are examined, it has been determined that the factor of preparing the technology roadmap affects the innovation productivity the most, while the sector and market structure affect the innovation productivity the least among the determined factors.
Originality: It is the first study in the literature in which the factors affecting innovation productivity are determined and ranked according to their importance.
Keywords: Innovation, Productivity, Innovation Productivity, Pythagorean Fuzzy AHP.
JEL Codes: D24, D81, O32, O47.

İnovasyon Üretkenliğine Etki Eden Faktörlerin Pisagor Bulanık AHP Yöntemi İle Değerlendirilmesi

ÖZET
Amaç: Bu çalışmada, işletmelerin inovasyon verimliliğini etkileyen faktörlerin sıralanması amaçlanmaktadır.
Yöntem: Belirsizliğin modellenmesinde başarılı sonuçlar veren ve Pisagor bulanık kümelerini kullanan Pisagor Bulanık Analitik Hiyerarşi Süreci (AHP) yöntemi yenilik üretkenliğini etkileyen faktörlerin önem derecelerine göre sıralanmasında kullanılmıştır.
Bulgular: Çalışmanın uygulama kısmında öncelikle inovasyon verimliliğini etkileyen faktörler belirlenmiş ve uzman değerlendirmeleri sonucunda yöntemin adımları uygulanmış ve faktörler önem sırasına göre sıralanmıştır. Son olarak duyarlılık analizi yapılarak en önemli faktörler belirlenmiştir. Çalışmadan elde edilen sonuçlar incelendiğinde, belirlenen faktörler arasında inovasyon verimliliğini en çok teknoloji yol haritası hazırlama faktörünün etkilediği, en az ise sektör ve pazar yapısının inovasyon verimliliğini etkilediği tespit edilmiştir.
***Özgünlük*:** İnovasyon üretkenliğine etki eden faktörlerin belirlendiği ve önem derecesine göre sıralandığı literatürdeki ilk çalışma özelliği göstermektedir.
Anahtar Kelimeler: İnovasyon, Verimlilik, İnovasyon Verimliliği, Pisagor Bulanık AHP.
***JEL Kodları*:** D24, D81, O32, O47.

[1] Bursa Technical University, Faculty of Engineering and Natural Sciences, Department of Industrial Engineering, Bursa, Türkiye

Corresponding Author: Miraç Tuba Çelik, tuba.celik@btu.edu.tr
DOI: 10.51551/verimlilik.1319522
Research Article | Submitted: 24.06.2023 | Accepted: 20.12.2023
Cite: Çelik, M.T. and Yıldız, A. (2024). "Evaluation of Factors Affecting Innovation Productivity by Pythagorean Fuzzy AHP Method", *Verimlilik Dergisi*, Productivity for Innovation (SI), 89-106.

1. INTRODUCTION

Due to the high competition experienced today, companies want to make a difference in the fierce competition environment by gaining new customers and increasing their market share. The best way to do this is to generate innovative ideas (Sivam et al., 2019). In this context, the concept of innovation emerges. According to the definition in the Oslo Manual published jointly by the European Commission and the OECD, innovation is “a new or significantly improved product (good or service), or process, a new marketing method or a new approach in business practices, workplace organization or external relations. It is defined as the realization of the organizational method” (Oslo Manual, 2005: 46). Innovation is also expressed as a complex system embedded in complex systems (Tainter, 1988). Innovation is often confused with the concepts of R&D and invention. However, invention and R&D can only be considered as an element of innovation. R&D can be defined as creating new approaches through scientific and applied research. The fact that R&D studies take place in most steps of innovation activities shows how important R&D contributes to innovation (Mairesse and Mohnen, 2004; Tiwari, 2007). Innovation is the general name of the transformation of all kinds of transactions into benefits and returns in order to meet the expectations and demands in the production of services and products in the maximum way. In short, anything that benefits and brings success is innovation (Çetin, 2019: 61). Innovation emerges as innovations that benefit companies by playing a key role in achieving long-term plans that companies make in order to gain an advantage over their competitors, and increasing the satisfaction of their customers and employees (Akgemci et al., 2005). Today, since the growth and profitability of businesses depends on innovation, companies need to ensure continuity of innovation to a large extent (Gupta, 2007: 2).

Innovation is an important factor both in the development of the country's economy and in bringing the country to a better position. For this reason, underdeveloped and developing countries should develop their innovation capabilities by creating global policies (Çetin, 2019: 74). However, innovation can be affected by external variables such as the technical capacity of the enterprise, capital infrastructure, and research infrastructure. This shows that innovation deals with applied and fundamental innovation together (Rao et al., 2001: 7).

Innovation is a process that increases the efficiency of an enterprise and develops as a result of important studies in the struggle for survival and long-term profitability. In this respect, innovation has a great importance in the growth of enterprises. If businesses that can effectively carry out the innovation process can achieve commercialization, they can quickly identify and analyse the possibilities in innovation processes, develop innovations in the best way and offer strategic solutions with high efficiency (Aktaş, 2018: 29).

In this study, it is aimed to rank the factors affecting the innovation productivity of enterprises according to the degree of importance. Thus, it is aimed to raise awareness about which factors should be prioritized if businesses want to increase their innovation productivity. In the second part of the study, the relationship between innovation and productivity is explained and the factors affecting innovation productivity are stated, the method used in the study is mentioned in the third part, the findings obtained from the study are included in the fourth part, and the results and evaluation are made in the last part.

2. INNOVATION AND PRODUCTIVITY

Only with sustainable growth can developing countries become more competitive globally and achieve the same level of prosperity as wealthy countries. This growth is made possible by increasing productivity (Doğan, 2017: 1). The concept of productivity is defined in different ways in the literature. The term productivity was coined by Quesnay in the Journal de l'Agriculture over two centuries ago (Asan, 2006: 28). Starr (1978: 43) defines it as the relationship between the amount of goods or services produced and the amount of resources used in the production of goods and services; Mendel (1983) defined productivity as the ratio of outputs to the resources used in the product in general, productivity is a term used to describe the measure of how well inputs are used to create meaningful outputs. The productivity approach and the measurement of productivity are two key concepts for the concept of productivity. The productivity approach is one way of looking at productivity. The productivity measure is the actual count of input and output (Asan, 2006: 28).

The biggest difficulty in measuring productivity is that the inputs and outputs are very diverse and cannot be gathered under a single common measure because of this diversity. To overcome this great difficulty in measuring inputs, the partial productivity measure is used. This measure computes the ratio of the output quantity corresponding to one unit of an input. For example, there are problems when collecting different labor-hour inputs under a single unit, since there is not a single feature when calculating the labor input (Top, 2002). When measuring productivity, no single measurement technique is used. As institutions and sectors change, the measurement technique is determined according to the target of the study and the characteristics of the organization. Productivity measures are used to monitor the performance of businesses over time, to evaluate the performance of an industry or the productivity of a country (Asan, 2006: 33).

It is seen that economic competitiveness increases in societies with a high standard of living, and innovation productivity increases with this increasing competitiveness. Innovation is the key to increasing productivity in countries (Elçi, 2007: 32). It is seen that economic competitiveness increases in societies with a high standard of living, and productivity in production also increases with this increasing competitiveness. Innovation, which is an important key to increasing productivity in countries, is considered as the main element of competitiveness spread over a wide area as organizational structures, processes, products and services in a business. Entrepreneur uses technology as a competitive tool through innovation, and technological competition also manifests itself as the driving force of growth. Innovation is considered as one of the basic elements of growth strategies in order to enter new markets, increase the existing market share and provide a competitive advantage to the business. Therefore, innovation is an indispensable element of corporate strategies for various purposes such as implementing more efficient production processes and performing better. Innovation serves as a strategic guide for businesses as they try to achieve a sustainable competitive advantage to overcome the problems they face (Fagerberg, 2003: 16).

In addition to increasing productivity, innovation is the key factor in increasing production volume, employment and quality of life. As countries invest in innovation, products and services obtained from scarce resources turn into added value and provide social benefits (Elçi, 2007: 48).

It can be said that innovation increases productivity performance and leads to higher income per employee. Different types of innovation, such as product, process, organizational and marketing, can contribute to improving productivity performance. Product innovations can lead to revenue increases with the introduction of new and improved products. Process innovations can reduce costs and increase productivity by increasing the efficiency of production processes. Organizational innovations can make business processes more effective through the improvement of ways and structures of doing business. Marketing innovations, on the other hand, can increase revenues by improving the marketing strategies of products and services (Hall, 2011: 7).

In the literature, the link between innovation and productivity is specifically explored. The bond between the two is as complex as it is strong and clear (Rao et al., 2001: 7). In the relationship between innovation and productivity, economic conditions such as the size of the financial structure, financing risk and demand are taken into account. In the researches, it has been concluded that economic conditions affect innovation and productivity. Innovation productivity affects the business decisions, investment decisions, strategic plans of enterprises, and the supply and demand in the market in which they operate, thus also affecting the competitiveness of enterprises. It is known that increasing innovation productivity increases national competitiveness. Since every place is a market for every business in today's global competition, innovation productivity plays a determining role in the overall performance of companies (Ciocanel and Pavelescu, 2015).

Harris' (1999) review of the literature highlights three key productivity factors in an overarching framework where innovation generates development prospects: investment in machinery and equipment, human capital, and trade openness for an investment. Hall (2011: 16) argues that the effort for innovation will turn into productivity gains in favor of companies, and thus, companies will improve and their productivity will increase, and thus, production costs will decrease due to increased demand. Innovation has a long-term and lasting impact on productivity. This suggests innovation as a “growth engine” (Rao et al., 2001: 7). Academics, industry representatives and policy makers are paying close attention to innovation and productivity development as they are considered to be particularly important factors in economic growth. These people work hard to create policies that will promote innovation performance and productivity (Saunila et al., 2020). Innovation and R&D are an important driving force in the development of countries and in ensuring economic growth (Bourgeois and Leblanc, 2002: 46). It is important to include these factors in the production processes so that R&D investments and knowledge sharing can contribute to innovation and productivity. R&D investments facilitate knowledge exchange and affect labor productivity, both directly and indirectly, by collaborating with external partners and investing in the knowledge of other firms in the industry. Additionally, the potential impact of R&D investments on innovation is also important. The complementarity between R&D capital and knowledge spillover explains the potential to increase labor productivity. These factors can also encourage different innovation channels and strategies by increasing the possibilities and quality of inter-firm and sectoral cooperation. As a result, various innovation approaches and strategies may emerge, such as the co-development of new products with external partners (Audretsch and Belitski, 2020).

Thanks to R&D studies, new technologies are developed, the market share, profitability and growth power of the enterprises increase according to their current level and thus contribute to the increase in productivity

(Bourgeois and Leblanc, 2002: 42). In short, besides the innovation activities, R&D studies are also important in increasing both economic growth and productivity. Another important indicator for innovation performance is patents. Because the number of patents shows both the R&D and innovation capacity of a country and the output obtained as a result of innovation activities. Patents support further innovation activities and have a positive impact on economic performance. These effects increase productivity (Doğan, 2017: 16).

When the literature is examined, the concepts of innovation and productivity are discussed separately. Only the effects of innovation on business performance and firm productivity were examined. In this context, a concept called Innovation productivity has not been found. However, in today's world, it has become very important not only to examine how innovations affect performance, but also how productive innovation should be done, that is, in what ways the productivity of innovation should be increased. Because innovations that take a lot of time and cost are not desired. Therefore, this study will focus on determining the factors affecting the productivity of innovations and ranking them according to their importance. However, since the factors affecting innovation productivity are not clearly determined in the literature, in our study, the factors affecting innovation performance obtained from the literature and discussed within the scope of the INOSUIT program organized by TİM (Turkish Exporters Assembly) and aiming to establish corporate innovation systems for companies, were taken into account. It is also seen in the evaluation reports published by TIM that the factors taken from the TIM INOSUIT program increase the productivity of innovation studies in companies (TIM Inosuit, 2019-2022: 7). These factors are discussed in detail below.

- *Innovation strategies:* Innovation strategies are directly related to the performance of the firm. It is the most important part of the overall strategy of the company (Aksoy and Demir, 2019). Thanks to the determined rules, it ensures that the best alternative is selected in the innovation decision-making phase and that the company's goals are realized in the best way. From this point of view, it provides the emergence of more innovation products as it creates a roadmap for the innovations targeted by the enterprise (Yılmaz, 2016: 52).
- *Corporate memory:* Corporate Memory is the storage of data and information that an institution has from the past to the present and its reuse when necessary (Megill, 2005: 1). Since the information accumulated in the corporate memory is reflected in all stages, it is of great importance for the continuity of innovation and therefore the continuity of the competitive power of the company. Experiences and experience gained in the innovation process enable a much more successful and faster process to be realized in the development and implementation of new innovation ideas (Gandon et al., 2002).
- *Idea suggestion/Reward system:* Businesses need to develop new ideas in order to grow in the long run and reach their goals (Dahl, 2011). One of the ways to do this is to discover and encourage innovative individuals, which is the first stage of innovation. The main thing here is to encourage new ideas to transform existing ones into innovative processes. In order to do this, an idea suggestion and reward system is used by the institutions both to encourage the employees to develop new ideas and to increase the motivation and performance of the employees (Güngör, 2011). In this way, an innovative and participatory corporate culture is created, and the probability of the enterprise developing innovative products with more innovative ideas is increased. This contributes to the company's innovation performance in the long run (Aksoy and Demir, 2019).
- *Innovation project teams:* Success in technology and innovation management is achieved not only by making strategic decisions, but also by transforming projects from the idea stage to a commercial product or an efficient new production process. Since this process includes many problem solving activities, it needs to be carried out with a team. Innovation studies carried out with a specific project team result in earlier and more successful results. Korkmaz et al., (2018) also found in their study that there is a positive and strong relationship between the innovation project team and innovation performance.
- *Innovation board:* The innovation board, where innovation activities are centrally monitored, innovative business ideas are evaluated and presented to the management, and different units participate, is a great combination of business-wide managers who manage and oversee the entire innovation journey of companies. This board plays an integral role in the creation and prioritization of an organization's innovation roadmap and makes significant contributions to the emergence of innovative products/services (Aslantaş, 2021).
- *Sector and market structure:* It means that the company offers new products for the market it is in, and that the company's tendency to expand into other markets and its activities are carried out in accordance with the strategic framework. The structure of the sector in which the enterprises are located and the structure of the market affect their innovation status. If the business is in an industry where the needs of customers are constantly changing, the tendency to innovate will increase and they

can develop innovative products and services. Also, when you are in a high-tech industry, this affects further innovation (Muhtar, 2022: 23).

- *Financial support/incentives:* Funds, grants and tax support provided by the state for innovation activities; commercially funded directly from the government for R&D; R&D expenditures at universities and research institutions; represents venture capital investments. Therefore, providing these incentives to businesses will lead these businesses to produce more innovative products/services (Satıcı, 2021; Muhtar, 2022: 21).
- *Human resources:* All human resources management functions, from the selection of the human resources that will demonstrate and implement the innovation to their training and motivation, have also gained importance. Because the realization of innovation is possible with creative and innovative employees with high problem-solving skills who understand the importance of innovation. The correct management of the human resources of the enterprises positively affects the innovation process. When innovative enterprises are examined, it is seen that these enterprises adopt a human resources management approach that chooses their employees well, encourages them, and shares their responsibilities. The adoption of innovation as a corporate culture by businesses and the innovative approach of employees to their work will positively affect their performance (Yılmaz, 2020: 29).
- *R&D investments:* R&D studies are important for innovation and are seen as a prerequisite for innovation. Thanks to the R&D studies, new ideas emerge and these ideas are commercialized and create innovation. The fact that innovation has become more vital for economic growth shows that R&D investments are an important indicator of economic development (Seçilmiş and Konu, 2019). It is necessary for companies to use R&D investments in their efforts to grow and innovate. These R&D investments involve both internalizing information obtained from external sources and exposing their own knowledge and skills. As a result, it can not only increase workforce productivity, but also increase the return from knowledge diffusion by generating a range of new innovations developed internally, created with collaborating partners, or developed by other firms. That is, R&D investments not only increase the company's internal innovation capacity, but also improve its ability to innovate by integrating outside information. This increases the company's growth and competitiveness, while also accelerating the flow of information within the industry and creating a broader innovation ecosystem (Audretsch and Belitski, 2020).
- *Technology roadmap:* The Technology Roadmap is a flexible strategic planning tool that enables companies and industries to link technology and scientific resources with business and business objectives. The purpose of a healthy roadmap is to create innovative products and services that meet customer needs, market demands and company goals in the short and long term. (Ramos et al., 2022). Therefore, it is a fact that the companies that make up the technology roadmap are more motivated to produce promising innovative technological products, thus increasing their innovation performance (Feng et al., 2023).
- *Systematic management of innovation projects:* Successful innovation projects to bring out innovative products and services have complex management processes. Long lead times, variability in the market and business environment (customer expectations, company strategies, environmental factors, technological requirements, etc.) and the change of information as the project progresses have made R&D and innovation projects extra complicated. Therefore, determining the objectives, success criteria and the team that will take part in the project in a systematic way will both accelerate the emergence of innovative products/services and contribute to the increase in the number of these projects (Kurt and Yıldız, 2020).
- *Project portfolio:* It includes the creation of prioritized and focused projects that arise depending on the determination of the critical problem pool and projects that will be based on interdepartmental cooperation by determining the needs/development areas and possible innovation issues in various departments of the enterprise. Thus, regular decisions are made about which innovation projects to invest in under rapidly changing economic conditions. Such decisions contribute to the proliferation of innovative products and services in companies (Kurt and Yıldız, 2020).
- *Open innovation processes and external stakeholder collaborations:* In open innovation, which is a structure created by using both internal and external resources to develop new products and approaches, suppliers, customers, competitors, institutions and organizations, private R&D centers, commercial laboratories, consulting companies, public and private research centers, universities and higher education organizations are included in this cooperation (Güler and Kanber, 2011). As seen in open innovation, many participants come together and create added value by sharing knowledge (Chesbrough and Appleyard, 2007). Projects may arise from internal or external technology sources and new technology may be added to the project at various stages. Therefore, with open innovation,

the innovation of companies is enriched (Chesbrough, 2006) and innovation performance is significantly affected (Muhtar, 2022).

- *Innovation training:* In the enterprises, the trainings, in which general information about the concept of innovation is given first, contribute to the formation of an innovation culture in the enterprise by creating a common language and perception. Innovative product development and problem-solving trainings given to certain employees later on trigger the emergence of more innovative products and services. When considered as a whole, it is thought that the trainings provided to the employees enable businesses to produce more innovative products/services (TİM Inosuit, 2019-2022).

3. METHODOLOGY

3.1. Identification of Factors Affecting Innovation Productivity

Innovation is a vital element for organizations looking to gain and maintain a competitive advantage. In this context, the factors affecting innovation productivity are critical factors that determine the innovation capacity and success of an organization or a country. These factors may differ between organizations and countries, but it is important to consider and manage these factors in order to increase innovation productivity. However, which factor should be given more importance or the transfer of financial resources is also very important. Because transferring these resources to a factor that is not important for the organization will negatively affect the success of the organization. Therefore, knowing which are the most important factors can create an effective innovation strategy, provide a competitive advantage and support sustainable growth.

Therefore, in this study, it is aimed to rank the factors that affect the productivity of innovation activities of companies according to their importance. In this context, first of all, the factors affecting innovation productivity were determined based on a common perspective by a technology and innovation expert, an academician with approximately four years of mentoring experience assigned by TIM for establishing corporate innovation systems in firms, and an employee who has been working at a company for 23 years, holding the position of R&D Center Manager for the last 12 years, and recently also taking on the role of Innovation Director and are given in Table 1.

Table 1. Factors affecting innovation productivity determined within the scope of the study

Factor Number	*Factors*	*References*
IP-1	Innovation strategies	Yılmaz (2016: 52)
IP-2	Corporate memory	Megill (2005: 1), Gandon et al. (2002)
IP-3	Idea suggestion/Reward system	Dahl (2011), Güngör, (2011), Aksoy and Demir, (2019)
IP-4	Innovation project teams	Korkmaz et al. (2018)
IP-5	Innovation board	Aslantaş (2021)
IP-6	Sector and market structure	Muhtar (2022: 23)
IP-7	Financial support/incentives	Satıcı (2021), Muhtar (2022: 21)
IP-8	Human resources	Yılmaz (2020: 29)
IP-9	R&D investments	Seçilmiş and Konu (2019), Audretsch and Belitski, 2020
IP-10	Technology roadmap	Ramos et al. (2022), Feng et al. (2023)
IP-11	Systematic management of innovation projects	Kurt and Yıldız, 2020
IP-12	Project portfolio	Kurt and Yıldız (2020)
IP-13	Open innovation processes and external stakeholder collaborations	Chesbrough (2006), Chesbrough and Appleyard (2007), Güler and Kanber (2011), Muhtar (2022: 12)
IP-14	Innovation training	TİM İnosuit (2019-2022)

3.1. Pythagorean Fuzzy AHP

Considering the criteria given in Table 1, it is inevitable with classical methods that the evaluations to be made to determine which factor affects innovation productivity more are subjective. Because, it is not possible to make an assessment with precise numbers for each factor, like impacting (1) or not impacting (0). Therefore, instead of classical methods, it is very useful to use methods that use fuzzy sets that take into account other values in the range (very little effect-very high effect), contrary to the 1-0 logic, in the evaluation phase. One of these methods, the Pythagorean fuzzy AHP method, is briefly explained below.

Fuzzy sets are a mathematical framework developed by Zadeh (1965) as an extension of classical set theory. While classical sets are based on clear, well-defined boundaries within which an element does or does not belong to a set, fuzzy sets introduce the concept of partial membership and allow elements to have different degrees of membership in a set. In a fuzzy set, each element is assigned a membership value between 0 and 1, which indicates the degree of belonging of that element to the set. A membership value of 1 represents full membership, while a value of 0 indicates no membership. Values between 0 and 1 represent partial membership degrees (Zimmermann, 2010; Yıldız, 2016). Fuzzy sets are particularly useful for modeling and dealing with imprecise and ambiguous information. They provide a flexible and intuitive way to represent and reason about vague concepts and fuzzy boundaries commonly encountered in many real-world scenarios (De et al., 2022; Özbek and Yildiz, 2020). In other words, the application of mathematics to the real world can be defined for fuzzy logic. An important difference of fuzzy logic from other logic systems is that it allows the use of verbal variables (Şengül et al., 2012; Yıldız and Demir, 2019). Verbal variables provide approximate characterization of concepts that cannot be expressed clearly. Thus, verbal variables become a tool that requires the use of fuzzy sets to express verbal expressions mathematically. In a sense, fuzzy set theory, which is a multi-valued set theory, is a formulation of uncertainty. His approach is not to abandon the concept of membership used in classical set theories and replace it with a completely new one, but to generalize the bivalent membership by carrying it to polyvalent (Şengül et al., 2012).

Later, Atanassov (1986) extended the fuzzy set theory to present an intuitive fuzzy set theory in order to provide an easier approach to expressing uncertainty. Unlike fuzzy sets, it defines the membership degree of the element X as well as the non-membership degree. In heuristic fuzzy set theory, membership and non-membership degrees take values in the range of [0,1]. He also defined a degree of hesitation parameter apart from these two parameters.

Developed by Yager (2013), Pythagorean fuzzy numbers were developed as a generalization to heuristic fuzzy sets, which in some cases cannot cope with uncertainty. Pythagorean fuzzy sets are an extension of traditional fuzzy sets. These clusters provide a more flexible and meaningful way to handle uncertainty in decision making and modeling complex systems. In Pythagorean fuzzy sets, each element is associated with a triple value: degree of membership, degree of non-membership, and degree of indeterminacy. Compared to traditional fuzzy sets, Pythagorean fuzzy sets offer additional information through the degree of indeterminacy. This allows decision makers to express their hesitations more clearly, which is especially useful when dealing with subjective or imprecise information (Lin et al., 2021). Among the fuzzy theories, the Pythagorean fuzzy set (PFS) has been applied to various fields as it is more prominent in expressing and handling uncertainty in uncertain environments (Xiao and Ding, 2019). In these sets, the sum of membership and non-membership degrees may be greater than 1, but the sum of their squares cannot exceed 1. As a result, PFS has better application in multi-criteria decision making (MCDM) problems due to its capacity to avoid uncertainty in decision making (Ejegwa, 2021). Some important definitions of Pythagorean fuzzy sets are given below.

Definition 1: A Pythagorean fuzzy set P is an object expressed as in Equation 1 (Zhang and Xu, 2014).

$$\tilde{P} = \left\{\langle x, \tilde{P}\left(\mu_{\tilde{P}}(x), v_P(x)\right);\ \rangle x \in X\right\} \quad (1)$$

where the membership degree $\mu_p(x)$:x ↦ $[0,1]$ and non-membership degree $v_p(x)$:x ↦ [0,1] of element $x \in X$ to *P*. For every $x \in X$, the following holds (Equation 2):

$$0 \le \mu_p^2(x) + v_p^2(x) \le 1 \quad (2)$$

The degree of indeterminacy is calculated using Equation 3.

$$\mu_{\tilde{P}}(x) = \sqrt{1 - \mu_p^2(x) - v_p^2(x)} \quad (3)$$

The basic operations on Pythagorean fuzzy sets are listed below.

Definition 2: The operations are as in Equations 4-7, where β_1 = $P(\mu_{\beta_1}, v_{\beta_1,})$ *and* β_2 = $P(\mu_{\beta_2}, v_{\beta_2,})$ are two Pythagorean fuzzy numbers.

$$\beta_1 \oplus \beta_2 = P\left(\sqrt{\mu_{\beta_1}^2 + \mu_{\beta_2}^2 - \mu_{\beta_1}^2\mu_{\beta_2}^2}, v_{\beta_1,} v_{\beta_2}\right) \quad (4)$$

$$\beta_1 \otimes \beta_2 = P\left(u_{\beta_1,} u v_{\beta_2}\sqrt{v_{\beta_1}^2 + v_{\beta_2}^2 - v_{\beta_1}^2 v_{\beta_2}^2}\right) \quad (5)$$

$$\lambda\beta_1 = P\left(\sqrt{1 - \left(1 - \mu_{\beta_1}^2\right)^{\lambda}}, v_{\beta_1}^{\lambda}\right) \quad (6)$$

$$\beta_1{}^{\lambda} = P\left(\mu_{\beta_1}^{\lambda}, \sqrt{1-\left(1-v_{\beta_1}^2\right)^{\lambda}}\right) \quad (7)$$

Definition 3: The distance between two PFS is defined by Equation 8.

$$d(\beta_1,\beta_2) = \frac{1}{2}\left(\left|\mu_{\beta_1}^2 - \mu_{\beta_2}^2\right| + \left|v_{\beta_1}^2 - v_{\beta_2}^2\right| + \left|\pi_{\beta_1}^2 - \pi_{\beta_2}^2\right|\right) \quad (8)$$

Definition 4: If more than one decision maker (DM) evaluates the criteria, the interval-valued Pythagorean Fuzzy (PF) numbers are aggregated using the interval-valued PF weighted geometric operator $\beta_i = ([\mu_i^L,\mu_i^U],[v_i^L,v_i^U])$ is a PF number. Where n is the number of DM, and $w_j = (w_1,w_2,w_3,\dots,w_n)^T$ be the weight vector of $\beta_i(i=1,2,3,\dots,n)$ with $\sum_{i=1}^{n} w_i = 1$, then an Interval-Valued Pythagorean Fuzzy Weighted Geometric (IVPFWG) operator is shown as in Equation 9 (Peng and Yang, 2016).

$$IVPFWG(\beta_1,\beta_2,\beta_3,\dots,\beta_n) = \left(\left[\prod_{j=1}^{n}(\mu_{\alpha_J}^L)^{w_j}, \prod_{j=1}^{n}(\mu_{\alpha_J}^U)^{w_j}\right], \left[\prod_{j=1}^{n}(v_{\alpha_J}^L)^{w_j}, \prod_{j=1}^{n}(v_{\alpha_J}^U)^{w_j}\right]\right) \quad (9)$$

In Pythagorean fuzzy sets, the sum of the membership and non-membership degrees can be greater than 1, but not the sum of their squares. This means that for every point (x, y) with heuristic membership degree as well as Pythagorean membership degree, the heuristic membership degrees are all points below the line x + y ≤ 1, while the Pythagorean membership degrees are all points with $x^2 + y^2 \leq 1$. Therefore, the set of Pythagorean membership degrees is larger than the heuristic set of membership degrees. Thus, Pythagorean fuzzy sets give decision makers more freedom to express their views on the uncertainty of the problem (Karasan et al., 2019).

The Pythagorean Fuzzy Analytical Hierarchy Process (AHP), using these sets, is an extension of the traditional AHP method that includes the concept of Pythagorean fuzzy sets (Ayyildiz and Taskin Gumus, 2021). Decision making in the AHP method involves creating a hierarchical structure of criteria and alternatives and then evaluating pairwise comparisons between them to determine their relative importance. Pythagorean fuzzy AHP takes into account uncertainty in these pairwise comparisons by using Pythagorean fuzzy numbers instead of exact numbers (Celik and Yildiz, 2022). Pythagorean fuzzy AHP allows decision makers to express their preferences in a more flexible and realistic way by considering multiple criteria and alternatives at the same time when there is uncertainty in the evaluation process. It enables decision makers to express and handle uncertainties more effectively through Pythagorean fuzzy numbers, resulting in more realistic and nuanced decision results (Yucesan ve Kahraman, 2019).

When the literature is reviewed, recent studies using the Pythagorean fuzzy AHP method include Yucesan and Kahraman (2019) for risk assessment in hydroelectric power plants, Ayyildiz and Taskin Gumus (2021) for risk assessment in hazardous materials transportation, Karasan et al. (2019) for solving the storage area selection problem for Istanbul city in Türkiye, Başaran et al. (2023) for measuring and evaluating supplier performance, Shahzad et al. (2022) for analyzing entrepreneurial barriers related to renewable energy promotion in Pakistan, Shahzad et al. (2023) for addressing the obstacles to biomass energy production in Pakistan, Farooq and Moslem (2022) for evaluating and prioritizing critical driver behavior criteria, Deshpande et al. (2023) for ranking enablers in healthcare businesses, and Çelik and Yıldız (2022) for prioritizing green innovation criteria. Moreover, Ayyildiz et al. (2023) integrated Quality Function Deployment (QFD) with Pythagorean fuzzy AHP to investigate the impact of customer expectations and cultivation processes on the hazelnut industry in Türkiye. Lahane and Kant (2021) employed Pythagorean fuzzy AHP and Pythagorean fuzzy DEMATEL approaches to determine the relationships among obstacles in the circular supply chain and analyze their effects. Zhou and Chen (2023) utilized a hybrid approach combining Pythagorean fuzzy AHP, Pythagorean fuzzy TOPSIS, and Linear Assignment Method (LAM) for supplier evaluation. Bulut and Özcan (2023) applied Pythagorean fuzzy AHP-TOPSIS methods to evaluate performance criteria in social media campaigns. Yucesan and Gul (2020) developed a model based on TOPSIS and Pythagorean fuzzy AHP methods to assess hospital service quality. Sarkar and Biswas (2021) integrated the Pythagorean fuzzy AHP-TOPSIS approach for selecting the best transportation company. Çalık (2021) used Pythagorean fuzzy AHP and Pythagorean fuzzy TOPSIS methods to select the best green supplier. Yazıcı et al. (2023) employed Pythagorean fuzzy AHP-Pythagorean fuzzy TOPSIS methods for prioritizing industries in creating a sustainable industrial symbiosis network.

When we look at the studies examined, it has been determined that the Pythagorean fuzzy AHP method is generally used in the solution of the ranking problem in the studied problems. However, it has been observed that it is not used in solving any problem involving innovation issues. Because of these features, the Pythagorean fuzzy AHP method was used in this study. The steps of the Pythagorean Fuzzy AHP method are as follows (Karasan et al., 2019).

Step 1: According to the scale given in Table 2, the decision makers compare the criteria or alternatives in pairs and accordingly create the pairwise comparison matrix.

Table 2. Linguistic variables and pythagorean fuzzy numbers

	Pythagorean Fuzzy Numbers			
Linguistic Variables	*The lower value of the membership degree* (μ_L)	*The upper value of the membership degree* (μ_U)	*The lower value of the non-membership degree* (v_L)	*The upper value of the non-membership degree* (v_U)
Certainly Low Importance (CLI)	0	0	0.9	1
Very Low Importance (VLI)	0.1	0.2	0.8	0.9
Low Importance (LI)	0.2	0.35	0.65	0.8
Below Average Importance (BAI)	0.35	0.45	0.55	0.65
Average Importance (AI)	0.45	0.55	0.45	0.55
Above Average Importance (AAI)	0.55	0.65	0.35	0.45
High Importance (HI)	0.65	0.8	0.2	0.35
Very High Importance (VHI)	0.8	0.9	0.1	0.2
Certainly High Importance (CHI)	0.9	1	0	0
Exactly Equal (EE)	0.1965	0.1965	0.1965	0.1965

Step 2: Calculation of the difference matrix $D=(d_{ik})_{mxm}$ between the lower and upper points of the membership and non-membership functions with the help of Equations 10 and 11.

$$d_{ik_l} = \mu^2_{ik_l} - v^2_{ik_u} \quad (10)$$

$$d_{ik_u} = \mu^2_{ik_u} - v^2_{ik_l} \quad (11)$$

Step 3: Calculation of the multiplicative matrix $S=(s_{ik})_{mxm}$ using Equations 12 and 13.

$$s_{ik_l} = \sqrt{1000^{d_{ik_l}}} \quad (12)$$

$$s_{ik_u} = \sqrt{1000^{d_{ik_u}}} \quad (13)$$

Step 4: Calculation the degrees of determinacy for each criterion with the help of Equation 14.

$$\tau_{ik} = 1 - (\mu^2_{ik_l}) - (v^2_{ik_u} - v^2_{ik_l}) \quad (14)$$

Step 5: Determining the weights before normalization using both the degrees of determinacy and the multiplication matrix with the help of Equation 15.

$$t_{ik} = \left(\frac{s_{ik_l} + s_{ik_u}}{2}\right) \tau_{ik} \quad (15)$$

Step 6: Calculation of weights of importance (w_i) is as in Eqaution 16.

$$w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m}\sum_{k=1}^{m} t_{ik}} \quad (16)$$

4. EMPIRICAL RESULTS

According to the steps described above, the factors affecting innovation productivity were prioritized.

Step 1: The factors given in Table 1 have been collectively assessed based on a common perspective by a previously identified academic and an innovation director. These assessments have been conducted using the scale provided in Table 2, and the results have been obtained through the pairwise comparison matrix given in Table 3.

Table 3. Pairwise comparison matrix of factors affecting innovation productivity

	IP-1	*IP-2*	*IP-3*	*IP-4*	*IP-5*	*IP-6*	*IP-7*	*IP-8*	*IP-9*	*IP-10*	*IP-11*	*IP-12*	*IP-13*	*IP-14*
IP-1	EE	HI	AAI	AAI	HI	VHI	AAI	VHI	AAI	EE	AAI	AAI	AI	HI
IP-2	LI	EE	LI	BAI	AI	AI	BAI	BAI	LI	VLI	BAI	BAI	VLI	LI
IP-3	BAI	HI	EE	AAI	AAI	HI	AAI	HI	BAI	VLI	BAI	AI	BAI	HI
IP-4	BAI	AAI	BAI	EE	BAI	AAI	AAI	HI	BAI	LI	EE	AAI	BAI	AAI
IP-5	LI	AI	BAI	AAI	EE	AAI	BAI	AAI	BAI	LI	EE	AAI	LI	HI
IP-6	VLI	AI	LI	BAI	BAI	EE	VLI	BAI	VLI	VLI	BAI	LI	BAI	LI
IP-7	BAI	AAI	BAI	BAI	AAI	VHI	EE	HI	EE	LI	EE	AAI	AI	HI
IP-8	VLI	AAI	LI	LI	BAI	AAI	LI	EE	VLI	VLI	LI	LI	BAI	BAI
IP-9	BAI	HI	AAI	AAI	AAI	VHI	EE	VHI	EE	BAI	AAI	AAI	AAI	HI
IP-10	EE	VHI	VHI	HI	HI	VHI	HI	VHI	AAI	EE	HI	AAI	HI	VHI
IP-11	BAI	AAI	AAI	EE	EE	AAI	EE	HI	BAI	LI	EE	AAI	AI	HI
IP-12	BAI	AAI	AI	BAI	BAI	HI	BAI	HI	BAI	BAI	BAI	EE	LI	AAI
IP-13	AI	VHI	AAI	AAI	HI	AAI	AI	AAI	BAI	LI	AI	HI	EE	HI
IP-14	LI	HI	LI	BAI	LI	HI	LI	AAI	LI	VLI	LI	BAI	LI	EE

Step 2: The difference matrix between the lower and upper points of the membership and non-membership functions is calculated with the help of Equations 10 and 11 and given in Table 4-5.

Table 4. The difference matrix between lower points of membership and non-membership functions

	IP-1	*IP-2*	*IP-3*	*IP-4*	*IP-5*	*IP-6*	*IP-7*	*IP-8*	*IP-9*	*IP-10*	*IP-11*	*IP-12*	*IP-13*	*IP-14*
IP-1	0.00	0.30	0.10	0.10	0.30	0.60	0.10	0.60	0.10	0.00	0.10	0.10	-0.10	0.30
IP-2	-0.60	0.00	-0.60	-0.30	-0.10	-0.10	-0.30	-0.30	-0.60	-0.80	-0.30	-0.30	-0.80	-0.60
IP-3	-0.30	0.30	0.00	0.10	0.10	0.30	0.10	0.30	-0.30	-0.80	-0.30	-0.10	-0.30	0.30
IP-4	-0.30	0.10	-0.30	0.00	-0.30	0.10	0.10	0.10	-0.30	-0.60	0.00	0.10	-0.30	0.10
IP-5	-0.60	-0.10	-0.30	0.10	0.00	0.10	-0.30	0.10	-0.30	-0.60	0.00	0.10	-0.60	0.10
IP-6	-0.80	-0.10	-0.60	-0.30	-0.30	0.00	-0.80	-0.30	-0.80	-0.80	-0.30	-0.60	-0.30	-0.60
IP-7	-0.30	0.10	-0.30	-0.30	0.10	0.60	0.00	0.10	0.00	-0.60	0.00	0.10	-0.10	0.10
IP-8	-0.80	0.10	-0.60	-0.60	-0.30	0.10	-0.60	0.00	-0.80	-0.80	-0.60	-0.60	-0.30	-0.30
IP-9	-0.30	0.10	0.10	0.10	0.10	0.60	-0.60	0.60	0.00	-0.30	0.10	0.10	0.10	0.10
IP-10	0.00	0.60	0.60	0.10	0.10	0.60	0.10	0.60	0.10	0.00	0.10	0.10	0.10	0.60
IP-11	-0.30	0.10	0.10	0.00	0.00	0.10	0.00	0.10	-0.30	-0.60	0.00	0.10	-0.10	0.10
IP-12	-0.30	0.10	-0.10	-0.30	-0.30	0.10	-0.30	0.10	-0.30	-0.30	-0.30	0.00	-0.60	0.10
IP-13	-0.10	0.60	0.10	0.10	0.10	0.10	-0.10	0.10	-0.30	-0.60	-0.10	0.10	0.00	0.10
IP-14	-0.60	0.10	-0.60	-0.30	-0.60	0.10	-0.60	0.10	-0.60	-0.80	-0.60	-0.30	0.12	0.00

Table 5. The difference matrix between upper points of membership and non-membership functions

	IP-1	*IP-2*	*IP-3*	*IP-4*	*IP-5*	*IP-6*	*IP-7*	*IP-8*	*IP-9*	*IP-10*	*IP-11*	*IP-12*	*IP-13*	*IP-14*
IP-1	0.00	0.60	0.30	0.30	0.60	0.80	0.30	0.80	0.30	0.00	0.30	0.30	0.10	0.60
IP-2	-0.30	0.00	-0.30	-0.10	0.10	0.10	-0.10	-0.10	-0.30	-0.60	-0.10	-0.10	-0.60	-0.30
IP-3	-0.10	0.60	0.00	0.30	0.30	0.60	0.30	0.60	-0.10	-0.60	-0.10	0.10	-0.10	0.60
IP-4	-0.10	0.30	-0.10	0.00	-0.10	0.30	0.30	0.30	-0.10	-0.30	0.00	0.30	-0.10	0.30
IP-5	-0.30	0.10	-0.10	0.30	0.00	0.30	-0.10	0.30	-0.10	-0.30	0.00	0.30	-0.30	0.30
IP-6	-0.60	0.10	-0.30	-0.10	-0.10	0.00	-0.60	-0.10	-0.60	-0.60	-0.10	-0.30	-0.10	-0.30
IP-7	-0.10	0.30	-0.10	-0.10	0.30	0.80	0.00	0.30	0.00	-0.30	0.00	0.30	0.10	0.30
IP-8	-0.60	0.30	-0.30	-0.30	-0.10	0.30	-0.30	0.00	-0.60	-0.60	-0.30	-0.30	-0.10	-0.10
IP-9	-0.10	0.30	0.30	0.30	0.30	0.80	-0.30	0.80	0.00	-0.10	0.30	0.30	0.30	0.30
IP-10	0.00	0.80	0.80	0.30	0.30	0.80	0.30	0.80	0.30	0.00	0.30	0.30	0.30	0.80
IP-11	-0.10	0.30	0.30	0.00	0.00	0.30	0.00	0.30	-0.10	-0.30	0.00	0.30	0.10	0.30
IP-12	-0.10	0.30	0.10	-0.10	-0.10	0.30	-0.10	0.30	-0.10	-0.10	-0.10	0.00	-0.30	0.30
IP-13	0.10	0.80	0.30	0.30	0.30	0.30	0.10	0.30	-0.10	-0.30	0.10	0.30	0.00	0.30
IP-14	-0.30	0.30	-0.30	-0.10	-0.30	0.30	-0.30	0.30	-0.30	-0.60	-0.30	-0.10	-0.22	0.00

Step 3: The multiplicative matrix was calculated using Equations 12 and 13 and given in Table 6-7.

Table 6. The multiplicative matrix of the lower points

	IP-1	*IP-2*	*IP-3*	*IP-4*	*IP-5*	*IP-6*	*IP-7*	*IP-8*	*IP-9*	*IP-10*	*IP-11*	*IP-12*	*IP-13*	*IP-14*
IP-1	1.00	2.82	1.41	1.41	2.82	7.94	1.41	7.94	1.41	1.00	1.41	1.41	0.71	2.82
IP-2	0.13	1.00	0.13	0.35	0.71	0.71	0.35	0.35	0.13	0.06	0.35	0.35	0.06	0.13
IP-3	0.35	2.82	1.00	1.41	1.41	2.82	1.41	2.82	0.35	0.06	0.35	0.71	0.35	2.82
IP-4	0.35	1.41	0.35	1.00	0.35	1.41	1.41	1.41	0.35	0.13	1.00	1.41	0.35	1.41
IP-5	0.13	0.71	0.35	1.41	1.00	1.41	0.35	1.41	0.35	0.13	1.00	1.41	0.13	1.41
IP-6	0.06	0.71	0.13	0.35	0.35	1.00	0.06	0.35	0.06	0.06	0.35	0.13	0.35	0.13
IP-7	0.35	1.41	0.35	0.35	1.41	7.94	1.00	1.41	1.00	0.13	1.00	1.41	0.71	1.41
IP-8	0.06	1.41	0.13	0.13	0.35	1.41	0.13	1.00	0.06	0.06	0.13	0.13	0.35	0.35
IP-9	0.35	1.41	1.41	1.41	1.41	7.94	0.13	7.94	1.00	0.35	1.41	1.41	1.41	1.41
IP-10	1.00	7.94	7.94	1.41	1.41	7.94	1.41	7.94	1.41	1.00	1.41	1.41	1.41	7.94
IP-11	0.35	1.41	1.41	1.00	1.00	1.41	1.00	1.41	0.35	0.13	1.00	1.41	0.71	1.41
IP-12	0.35	1.41	0.71	0.35	0.35	1.41	0.35	1.41	0.35	0.35	0.35	1.00	0.13	1.41
IP-13	0.71	7.94	1.41	1.41	1.41	1.41	0.71	1.41	0.35	0.13	0.71	1.41	1.00	1.41
IP-14	0.13	1.41	0.13	0.35	0.13	1.41	0.13	1.41	0.13	0.06	0.13	0.35	1.53	1.00

Table 7. The multiplicative matrix of upper points

	IP-1	*IP-2*	*IP-3*	*IP-4*	*IP-5*	*IP-6*	*IP-7*	*IP-8*	*IP-9*	*IP-10*	*IP-11*	*IP-12*	*IP-13*	*IP-14*
IP-1	1.00	7.94	2.82	2.82	7.94	15.85	2.82	15.85	2.82	1.00	2.82	2.82	1.41	7.94
IP-2	0.35	1.00	0.35	0.71	1.41	1.41	0.71	0.71	0.35	0.13	0.71	0.71	0.13	0.35
IP-3	0.71	7.94	1.00	2.82	2.82	7.94	2.82	7.94	0.71	0.13	0.71	1.41	0.71	7.94
IP-4	0.71	2.82	0.71	1.00	0.71	2.82	2.82	2.82	0.71	0.35	1.00	2.82	0.71	2.82
IP-5	0.35	1.41	0.71	2.82	1.00	2.82	0.71	2.82	0.71	0.35	1.00	2.82	0.35	2.82
IP-6	0.13	1.41	0.35	0.71	0.71	1.00	0.13	0.71	0.13	0.13	0.71	0.35	0.71	0.35
IP-7	0.71	2.82	0.71	0.71	2.82	15.85	1.00	2.82	1.00	0.35	1.00	2.82	1.41	2.82
IP-8	0.13	2.82	0.35	0.35	0.71	2.82	0.35	1.00	0.13	0.13	0.35	0.35	0.71	0.71
IP-9	0.71	2.82	2.82	2.82	2.82	15.85	0.35	15.85	1.00	0.71	2.82	2.82	2.82	2.82
IP-10	1.00	15.85	15.85	2.82	2.82	15.85	2.82	15.85	2.82	1.00	2.82	2.82	2.82	15.85
IP-11	0.71	2.82	2.82	1.00	1.00	2.82	1.00	2.82	0.71	0.35	1.00	2.82	1.41	2.82
IP-12	0.71	2.82	1.41	0.71	0.71	2.82	0.71	2.82	0.71	0.71	0.71	1.00	0.35	2.82
IP-13	1.41	15.85	2.82	2.82	2.82	2.82	1.41	2.82	0.71	0.35	1.41	2.82	1.00	2.82
IP-14	0.35	2.82	0.35	0.71	0.35	2.82	0.35	2.82	0.35	0.13	0.35	0.71	0.47	1.00

Step 4: In Table 8, the degrees of uncertainty are given for each factor calculated with the help of Equation 14.

Table 8. Determinacy degrees of the factors

	IP-1	*IP-2*	*IP-3*	*IP-4*	*IP-5*	*IP-6*	*IP-7*	*IP-8*	*IP-9*	*IP-10*	*IP-11*	*IP-12*	*IP-13*	*IP-14*
IP-1	1.00	0.70	0.80	0.80	0.70	0.80	0.80	0.80	0.80	1.00	0.80	0.80	0.80	0.70
IP-2	0.70	1.00	0.70	0.80	0.80	0.80	0.80	0.80	0.70	0.80	0.80	0.80	0.80	0.70
IP-3	0.80	0.70	1.00	0.80	0.80	0.70	0.80	0.70	0.80	0.80	0.80	0.80	0.80	0.70
IP-4	0.80	0.80	0.80	1.00	0.80	0.80	0.80	0.80	0.80	0.70	1.00	0.80	0.80	0.80
IP-5	0.70	0.80	0.80	0.80	1.00	0.80	0.80	0.80	0.80	0.70	1.00	0.80	0.70	0.80
IP-6	0.80	0.80	0.70	0.80	0.80	1.00	0.80	0.80	0.80	0.80	0.80	0.70	0.80	0.70
IP-7	0.80	0.80	0.80	0.80	0.80	0.80	1.00	0.80	1.00	0.70	1.00	0.80	0.80	0.80
IP-8	0.80	0.80	0.70	0.70	0.80	0.80	0.70	1.00	0.80	0.80	0.70	0.70	0.80	0.80
IP-9	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.80	1.00	0.80	0.80	0.80	0.80	0.80
IP-10	1.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	1.00	0.80	0.80	0.80	0.80
IP-11	0.80	0.80	0.80	1.00	1.00	0.80	1.00	0.80	0.80	0.70	1.00	0.80	0.80	0.80
IP-12	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	1.00	0.70	0.80
IP-13	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.80	0.80	1.00	0.80
IP-14	0.70	0.80	0.70	0.80	0.70	0.80	0.70	0.80	0.70	0.80	0.70	0.80	1.34	1.00

Step 5: Pre-normalized weights are calculated with the help of Equation 15 and given in Table 9.

Table 9. Matrix of weights before normalization

	IP-1	*IP-2*	*IP-3*	*IP-4*	*IP-5*	*IP-6*	*IP-7*	*IP-8*	*IP-9*	*IP-10*	*IP-11*	*IP-12*	*IP-13*	*IP-14*
IP-1	1.00	3.77	1.69	1.69	3.77	9.52	1.69	9.52	1.69	1.00	1.69	1.69	0.85	3.77
IP-2	0.17	1.00	0.17	0.43	0.85	0.85	0.43	0.43	0.17	0.08	0.43	0.43	0.08	0.17
IP-3	0.43	3.77	1.00	1.69	1.69	3.77	1.69	3.77	0.43	0.08	0.43	0.85	0.43	3.77
IP-4	0.43	1.69	0.43	1.00	0.43	1.69	1.69	1.69	0.43	0.17	1.00	1.69	0.43	1.69
IP-5	0.17	0.85	0.43	1.69	1.00	1.69	0.43	1.69	0.43	0.17	1.00	1.69	0.17	1.69
IP-6	0.08	0.85	0.17	0.43	0.43	1.00	0.08	0.43	0.08	0.08	0.43	0.17	0.43	0.17
IP-7	0.43	1.69	0.43	0.43	1.69	9.52	1.00	1.69	1.00	0.17	1.00	1.69	0.85	1.69
IP-8	0.08	1.69	0.17	0.17	0.43	1.69	0.17	1.00	0.08	0.08	0.17	0.17	0.43	0.43
IP-9	0.43	1.69	1.69	1.69	1.69	9.52	0.17	9.52	1.00	0.43	1.69	1.69	1.69	1.69
IP-10	1.00	9.52	9.52	1.69	1.69	9.52	1.69	9.52	1.69	1.00	1.69	1.69	1.69	9.52
IP-11	0.43	1.69	1.69	1.00	1.00	1.69	1.00	1.69	0.43	0.17	1.00	1.69	0.85	1.69
IP-12	0.43	1.69	0.85	0.43	0.43	1.69	0.43	1.69	0.43	0.43	0.43	1.00	0.17	1.69
IP-13	0.85	9.52	1.69	1.69	1.69	1.69	0.85	1.69	0.43	0.17	0.85	1.69	1.00	1.69
IP-14	0.17	1.69	0.17	0.43	0.17	1.69	0.17	1.69	0.17	0.08	0.17	0.43	1.34	1.00

Step 6: The importance weights of each factor were calculated using the Equation 16 and are given in Table 10.

Table 10. Importance weight and ranking of criteria

Factors	*Weights before normalization*	*Normalized importance weights*	*Ranking*
Innovation strategies	43.34	0.15	2
Corporate memory	5.65	0.02	13
Idea suggestion/Reward system	23.77	0.08	5
Innovation project teams	14.45	0.05	8
Innovation board	13.09	0.05	9
Sector and market structure	4.78	0.02	14
Financial support/Incentives	23.27	0.08	6
Human resources	6.73	0.02	12
R&D investments	34.59	0.12	3
Technology roadmap	61.43	0.21	1
Systematic management of innovation projects	16.02	0.06	7
Project portfolio	11.76	0.04	10
Open innovation processes and external stakeholder collaborations	25.50	0.09	4
Innovation training	9.35	0.03	11

When Table 10 is examined, it is seen that the "Technology roadmap" factor is the most important factor affecting innovation productivity with its importance weight value of 0.209. "Innovation strategies" emerged as the second and "R&D investments" as the third important criteria. "Sector and market structure" and "Corporate memory" were determined as the last two factors.

Then, sensitivity analysis was performed depending on the scenarios given in Table 11 in order to determine whether the ranking of factors would be different according to different factor weights. Here, it is aimed to evaluate how stable the results and decisions taken from the Pythagorean fuzzy AHP method are. Because changing the weights will show us how reliable the judgments are and how they may change under different conditions. Therefore, it will help us to make our judgments easier, depending on whether the rankings have changed or not. It will ultimately help optimize our decisions by identifying which factor affects innovation productivity the most.

Table 11. Combinations of scenarios with different factor weights

Scenarios	*Combinations*	*Scenarios*	*Combinations*
Scenario 1	Current		
Scenario 2	IP-1 CLI, The Rest current	Scenario 16	IP-1 CHI, The Rest current
Scenario 3	IP-2 CLI, The Rest current	Scenario 17	IP-2 CHI, The Rest current
Scenario 4	IP-3 CLI, The Rest current	Scenario 18	IP-3 CHI, The Rest current
Scenario 5	IP-4 CLI, The Rest current	Scenario 19	IP-4 CHI, The Rest current
Scenario 6	IP-5 CLI, The Rest current	Scenario 20	IP-5 CHI, The Rest current
Scenario 7	IP-6 CLI, The Rest current	Scenario 21	IP-6 CHI, The Rest current
Scenario 8	IP-7 CLI, The Rest current	Scenario 22	IP-7 CHI, The Rest current
Scenario 9	IP-8 CLI, The Rest current	Scenario 23	IP-8 CHI, The Rest current
Scenario 10	IP-9 CLI, The Rest current	Scenario 24	IP-9 CHI, The Rest current
Scenario 11	IP-10 CLI, The Rest current	Scenario 25	IP-10 CHI, The Rest current
Scenario 12	IP-11 CLI, The Rest current	Scenario 26	IP-11 CHI, The Rest current
Scenario 13	IP-12 CLI, The Rest current	Scenario 27	IP-12 CHI, The Rest current
Scenario 14	IP-13 CLI, The Rest current	Scenario 28	IP-13 CHI, The Rest current
Scenario 15	IP-14 CLI, The Rest current	Scenario 29	IP-14 CHI, The Rest current

The results of the sensitivity analysis conducted with a total of 29 scenarios are given in Figure 1.

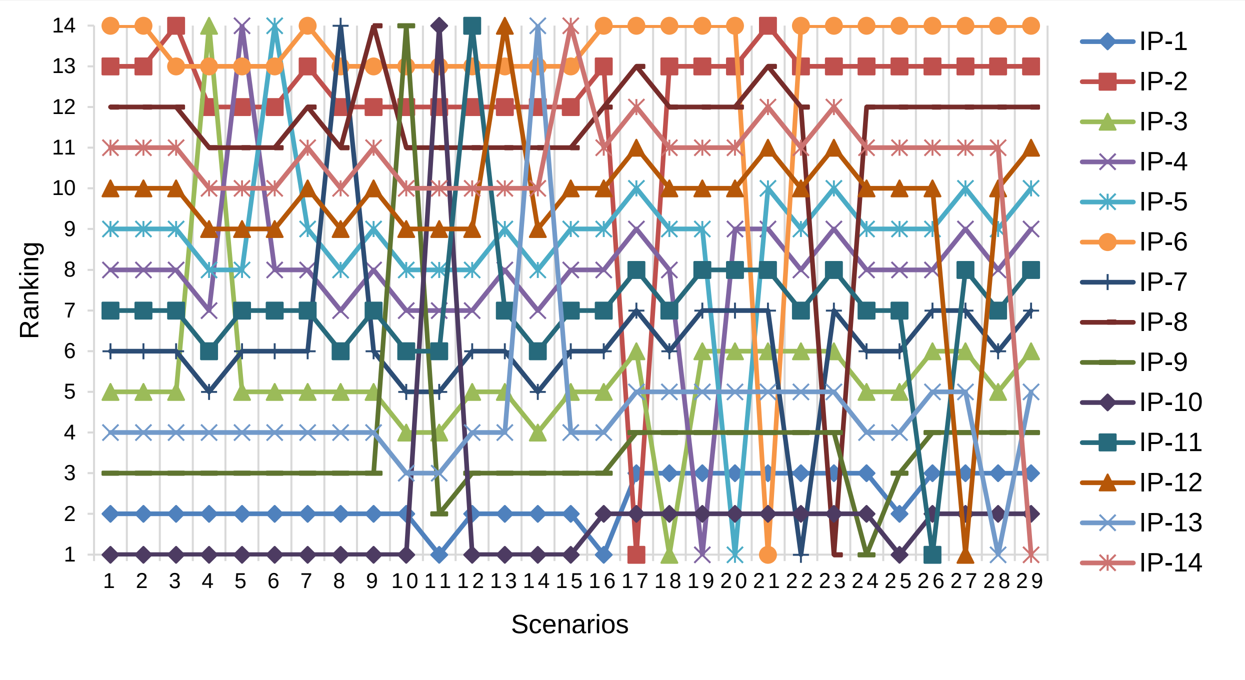

Figure 1. Changes in sensitivity analysis results

In the first stage of the sensitivity analysis, all factors were given CLI importance weights, respectively, while the weights of the other factors were not changed (scenarios 2-15). In these scenarios, except for Scenario 11, the IP-10 (Technology roadmap) factor took the first place. When we give CLI importance weight to the IP-10 (Technology roadmap) factor, this factor is in the last place, while IP-1 (Innovation strategy) is in the first place. This result shows that the Technology roadmap factor is not of low importance, but is certainly of high importance.

In the second stage of the sensitivity analysis (scenarios 16-29), CHI importance weights were given to all factors, respectively, while the weights of other factors were not changed. In these scenarios, each factor given CHI importance was ranked 1st. In this analysis, IP-10 took the 2nd place in all scenarios except the 25th scenario, and the 1st in the 25th scenario. IP-1, on the other hand, took the 3rd place in these scenarios.

Looking at all the scenarios in the analysis in general, IP-10 ranked first, IP-1 ranked second, and IP-9 ranked third in 15 scenarios. When the CLI and CHI importance weights were given to the factors, the rankings of almost all factors changed by 1 place.

When the analysis results are evaluated, it can be said that the IP-10 (Technology roadmap) factor is the most important factor affecting innovation productivity. IP-1 (Innovation strategies) and IP-9 (R&D

investments) factors seem to be important factors after the technology roadmap. IP-6 (Sector and market structure) and IP-2 (Corporate memory) factors were found to be in the last place and as the factors that least affect innovation factors. It can be said that the results of the Pythagorean Fuzzy AHP Method are sensitive and can be used in solving ranking problems as in this study.

5. CONCLUSION

In today's conditions, there is a compelling competitive environment for businesses with the effect of globalization. In this competitive environment, businesses are increasing their investments in innovation day by day, as they are aware that they need to turn to innovation, which the whole world has been focusing on and working on recently, in order to continue their existence. Because, from the point of view of countries, the most important reason for this is that it plays an important role in sustainable development, social welfare, increase in employment, providing national competitive advantage and raising the quality of life. When it is considered for companies, it is a very important tool that allows entering new markets, reducing costs, thus increasing efficiency and profitability, increasing product and service quality, and increasing productivity. However, some factors need to be considered in order to make innovations faster and with added value.

Therefore, in this study, it is aimed to rank the factors affecting innovation productivity according to their importance by using the Pythagorean fuzzy AHP method. In this way, it is aimed for enterprises to innovate and increase their productivity by taking into account the most important factors.

According to the results obtained from the study, it has been determined that the preparation of technology roadmaps has the largest impact on innovation productivity. When we look at the purpose of the technology roadmap, it is a tool that visualizes the technologies required to launch new products or services that will meet the needs and requirements of customers, and they are very effective and should be considered especially in the execution of innovation projects. In addition, they act as an important bridge in the management of innovative projects and portfolios that are compatible with the strategies of the enterprises. Therefore, since the technology roadmaps of the enterprises are related to many factors, the preparation of these maps will also increase the innovation productivity. In this context, it is parallel to the aim of ranking this factor in the first place.

When we look at the other results obtained from the study, innovation strategies appear as the second important factor. They will increase their innovation productivity as it will be a guide for businesses to determine innovation strategies that indicate how and with what they will carry out their innovations and guide them. Since R&D investments, which is one of the important factors, are a direct route to innovation, companies need to increase their investments for R&D. When we look at the effect of open innovation and collaborations, it is seen that the learning and knowledge dissemination that occurs thanks to the cooperation and close relations with organizations increases innovation productivity. This result shows parallelism with the study of Güler and Kanber (2011). Therefore, since our country is in a much weaker position in terms of cooperation between the actors in the system compared to other EU countries, all actors of the innovation system such as companies, universities-public research institutions, R&D institutions, governments, support and bridge organizations, financing institutions act together for the success of innovation. Policies should be developed and they should be in long-term relations with each other.

Looking at the situation in general, according to the Global Innovation Index (GII) report, in which the annual performance of 132 countries' economies is evaluated, Türkiye has risen to 37th place in 2022 by rising 4 places, and has managed to enter the top 40 for the first time by rising 14 places in the index in the last two years. However, in order for these rankings to be higher, businesses need to produce innovative products/services that produce more added value. For this, they need to know what to do first.

When the results obtained from the study are examined, it is revealed that enterprises should first draw up their technology roadmaps, determine their strategies accordingly, and increase their innovation productivity by making R&D investments to realize all these. In this respect, the study will provide an important guide to the managers of the enterprises that want to increase the innovation productivity, on which areas to focus on and will help these managers to make the right decisions and provide benefits to the business in terms of both time and cost.

Considering the study, it is the first study in which the factors affecting innovation productivity are examined and ranked according to their importance. Therefore, the factors used in the study will be a ready guide for researchers who want to work on innovation productivity issues and they will be able to use the results obtained from this study in their studies. In the future, a study can be conducted in which more factors are considered and the costs of these factors are taken into account and different methods are compared.

Author Contributions
Miraç Tuba Çelik: Literature review, Methodology, Analysis, Writing-original draft, Modelling, Writing-review and editing *Aytaç Yıldız:* Conceptualization, Methodology, Analysis, Writing-original draft, Modelling, Writing-review and editing

Conflict of Interest
No potential conflict of interest was declared by the author(s).

Funding
Any specific grant has not been received from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with Ethical Standards
It was declared by the author(s) that the tools and methods used in the study do not require the permission of the Ethics Committee.

Ethical Statement
It was declared by the author(s) that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.

REFERENCES

Akgemci, T., Öğüt, A. and Ay Tosun, M. (2005). "Küresel Rekabetin Sunduğu Fırsatlar ve Tehditler Bağlamında Kobi'lerde Stratejik Yenilik Yönetimi: SWOT Analizine Dayalı Kuramsal Bir Değerlendirme", *Sosyal Ekonomik Araştırmalar Dergisi*, 5 (10), 139-156.

Aksoy, E. and Demir, A.O. (2019). "Firmalarin Inovasyon Sürecini Etkileyen Unsurlar", *İstanbul Ticaret Üniversitesi Girişimcilik Dergisi*, 3(5), 61-74.

Aktaş, E. (2018). "İnovasyon Yönetimi Ve Işletmelerde Inovasyon Yönetimine Yönelik Bir Araştırma", Yüksek Lisans Tezi, Okan Üniversitesi Sosyal Bilimler Enstitüsü, İstanbul.

Asan, G. (2006). "Productivity Improvement Application in an Automotive Company", Yüksek Lisans Tezi, Dokuz Eylül Üniversitesi Fen Bilimleri Enstitüsü, İzmir.

Aslantaş, T. (2021). "İnovasyon Kapasitesini Değerlendirmeye Yönelik Bir Uygulama", *Gazi University Journal of Science Part A: Engineering and Innovation*, 8(3), 339-360.

Atanassov, K. (1986). "Intuitionistic Fuzzy Sets", *Fuzzy Sets and Systems*, 20(1986), 87-96.

Audretsch, D.B. and Belitski, M. (2020). "The Role of R&D and Knowledge Spillovers in Innovation and Productivity", *European Economic Review*, 123, 103391.

Ayyildiz, E. and Taskin Gumus, A. (2021). "Pythagorean Fuzzy AHP Based Risk Assessment Methodology for Hazardous Material Transportation: An Application in Istanbul", *Environmental Science and Pollution Research*, 28, 35798-35810.

Ayyildiz, E., Yildiz, A., Taskin, A., and Ozkan, C. (2023). "An Interval Valued Pythagorean Fuzzy AHP Integrated Quality Function Deployment Methodology for Hazelnut Production in Turkey", *Expert Systems with Applications*, 120708.

Başaran, Y., Aladağ, H. and Işık, Z. (2023). "Pythagorean Fuzzy AHP Based Dynamic Subcontractor Management Framework", *Buildings*, 13(5), 1351.

Bourgeois, Y. and LeBlanc, S. (2002). "Innovation in Atlantic Canada", The Canadian Institute for Research on Regional Development", Maritime Series, Canada.

Bulut, M. and Özcan, E. (2023). "Ranking of Advertising Goals on Social Network Sites by Pythagorean Fuzzy Hierarchical Decision Making: Facebook", *Engineering Applications of Artificial Intelligence*, 117, 105542.

Celik, M.T. and Yildiz, A. (2022). "Evaluation of Green Innovation Criteria by Using Pythagorean Fuzzy AHP Method", *Journal of Engineering Research and Applied Science*, 11(2), 2185-2193.

Chesbrough, H. (2006). "Open Innovation: A New Paradigm for Understanding Industrial Innovation", *Open Innovation: Researching A New Paradigm*, 400, 0-19.

Chesbrough, H.W. and Appleyard, M.M. (2007). "Open Innovation and Strategy", *California Management Review*, 50(1), 57-76.

Ciocanel, A.B. and Pavelescu, F.M. (2015). "Innovation and Competitiveness in European Context", *Procedia Economics and Finance*, 32, 728-737.

Çalık, A. (2021). "A Novel Pythagorean fuzzy AHP and Fuzzy TOPSIS Methodology for Green Supplier Selection in the Industry 4.0 Era", *Soft Computing*, 25(3), 2253-2265.

Çetin, T. (2019). "Pazar Rekabeti Kapsamında Yöneticilerin Inovasyon Algısı Ile Seçilen Toplam Kalite Yönetimi Uygulamalarının Ürün Kalitesine Ve Inovasyonuna Etkisi", Doktora Tezi, Kütahya Dumlupınar Üniversitesi Sosyal Bilimler Enstitüsü, Kütahya.

Dahl, A. (2011). "The Idea-Driven Workforce Finding New Ways to Engage Employees in Innovation", *World American Management Association*, 35-37.

De, A.K., Chakraborty, D. and Biswas, A. (2022). "Literature Review on Type-2 Fuzzy Set Theory", *Soft Computing*, 26(18), 9049-9068.

Deshpande, Y., Sayre, T., Deshmukh, A., Shaji, D. and Bhosale, V. (2023). "A Pythagorean Fuzzy AHP Approach to Evaluate the Enablers of Healthcare Operations", *Advanced Engineering Optimization Through Intelligent Techniques: Select Proceedings of AEOTIT 2022,* 347-357.

Doğan, Ö. (2017). "Türkiye İmalat Sanayi Firmalarının Ar-Ge, Yenilik, İhracat ve Üretkenlikleri Arasındaki Dinamik İlişki", Doktora Tezi, Ankara Üniversitesi Sosyal Bilimler Enstitüsü, Ankara.

Ejegwa, P.A. (2021). "Generalized triparametric Correlation Coefficient for Pythagorean Fuzzy Sets with Application to MCDM Problems", *Granular Computing*, 6(3), 557-566.

Elçi, Ş. (2007), "İnovasyon Kalkınmanın ve Rekabetin Anahtarı", Technopolis Group, Ankara

Fagerberg, J. (2003). "The Dynamics of Technology, Growth and Trade: A Schumpeterian Perspective", Centre for Technology, Innovation and Culture, University of Oslo, Working Paper, 25.

Farooq, D. and Moslem, S. (2022). “Estimating Driver Behavior Measures Related to Traffic Safety by Investigating 2-Dimensional Uncertain Linguistic Data-A Pythagorean Fuzzy Analytic Hierarchy Process Approach”, *Sustainability*, 14(3), 1881.

Feng, L., Zhao, W., Wang, J., Feng, J. and Guo, Y. (2023). “Combining Machine Learning with A Pharmaceutical Technology Roadmap to Analyze Technological Innovation Opportunities”, *Computers & Industrial Engineering*, 176, 108974.

Gandon, F., Poggi, A., Rimassa, G. and Turci, P. (2002). “Multi-Agent Corporate Memory Management System”, *Applied Artificial Intelligence*, 16(9-10), 699-720.

Gupta, P. (2007). “Firm Specific Measures of Innovation”, Illinois Institute of Technology, Chicago.

Güler, E.Ö. and Kanber, S. (2011). “İnovasyon Aktivitelerinin İnovasyon Performansi Üzerine Etkileri: İmalat Sanayii Uygulamasi”, *Çukurova Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 20(1), 61-76.

Güngör, P. (2011). “The Relationship between Reward Management System and Employee Performance with the Mediating Role of Motivation: A Quantitative Study on Global Banks”, *Procedia Social and Behavioral Sciences*, 24, 1510-1520.

Hall, B.H. (2011). “Innovation and Productivity (No. W17178)”, National Bureau of Economic Research.

Harris, R.G. (1999). “Determinants of Canadian Productivity Growth: Issues and Prospects.”, *Industry Canada Conference on Canada in the 21st Century: A Time for Vision*. Ottawa.

Karasan, A., Ilbahar, E. and Kahraman, C. (2019). “A Novel Pythagorean Fuzzy AHP and Its Application to Landfill Site Selection Problem”, *Soft Computing*, 23, 10953-10968.

Korkmaz, I.H., Taşkesen, A.C. and Cetinkaya, C. (2018). “İnovasyon Yönetimi Süreçlerini Etkileyen Faktörlerin Kahramanmaraş’ta Faaliyet Gösteren KOBI'ler Üzerinden Incelenmesi”, *R&S-Research Studies Anatolia Journal*, 1(2), 113-125.

Kurt, Z.B. and Yıldız, A. (2020). “Fuzzy TOPSIS Based Decision Model for Evaluating and Prioritizing R&D/Innovation Projects, Ar-Ge/İnovasyon Projelerinin Değerlendirilmesi ve Önceliklendirilmesi İçin Fuzzy TOPSIS Tabanlı Karar Modeli”, *Electronic Letters on Science and Engineering*, 16(2), 93-107.

Lahane, S. and Kant, R. (2021). “Evaluating the Circular Supply Chain Implementation Barriers Using Pythagorean Fuzzy AHP- DEMATEL Approach”, *Cleaner Logistics and Supply Chain*, 2, 100014.

Lin, M., Chen, Y., and Chen, R. (2021). “Bibliometric Analysis on Pythagorean Fuzzy Sets During 2013-2020”, *International Journal of Intelligent Computing and Cybernetics*, 14(2), 104-121.

Mairesse, J. and Mohnen, P. (2004). The importance of R&D for innovation: a reassessment using French survey data. *The Journal of Technology Transfer*, *30*(1-2), 183-197.

Megill, K.A. (2005). “Corporate Memory: Records and Information Management in The Knowledge Age”, KG Saur

Mendel, M.E. (1983).” Improving Productivity and Effectiveness”, United States of America: Prentice Hall, Inc.

Muhtar, A.C. (2022). “İnovasyon Performansına Etki Eden Faktörlerin Bulanık Bilişsel Haritalama Yöntemi ile Önceliklendirilmesi ve Telekomünikasyon Sektöründe Bulanık Çok Kriterli Karar Verme Yöntemleri ile Proje Seçimi”, Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi Lisansüstü Eğitim Enstitüsü, İstanbul.

OECD/EUROSTAT, (2005). “Oslo Manual- Guidelines for Collecting and Interpreting Innovation Data”, OECD Publications, Third edition, Paris.

Oslo Guide (2005). “Principles for Collecting and Interpreting Innovation Data”, 3rd Edition, OECD/Eurostat Joint Publication.

Özbek, A. and Yildiz, A. (2020). “Digital Supplier Selection for a Garment Business Using Interval Type-2 Fuzzy TOPSIS”, *Textile and Apparel*, 30(1), 61-72.

Peng, X., and Yang, Y. (2016). “Fundamental Properties of Interval-Valued Pythagorean Fuzzy Aggregation Operators” *International Journal of Intelligent Systems*, 31(5), 444-487.

Ramos, A.G., Daim, T., Gaats, L., Hutmacher, D.W. and Hackenberger, D. (2022). “Technology Roadmap for the Development of a 3D Cell Culture Workstation for a Biomedical Industry Startup”, *Technological Forecasting and Social Change*, 174, 121213.

Rao, S., Ahmad, A., Horsman, W. and Kaptein-Russell, P. (2001). “The Importance of Innovation for Productivity”, CSLS.

Sarkar, B. and Biswas, A. (2021). “Pythagorean Fuzzy AHP-TOPSIS Integrated Approach for Transportation Management Through a New Distance Measure”, *Soft Computing*, 25(5), 4073-4089.

Satıcı, S. (2021). “Ülkelerin Inovasyon Performansının CRITIC Temelli WASPAS Yöntemiyle Değerlendirilmesi”, *Girişimcilik ve Kalkınma Dergisi*, 16(2), 91-104.

Saunila, M., Ukko, J., Rantala, T., Nasiri, M. and Rantanen, H. (2020). "Preceding Operational Capabilities as Antecedents for Productivity and Innovation Performance", *Journal of Business Economics*, 90(4), 537-561.

Seçilmiş, N. and Konu, A. (2019). "OECD Ülkelerinde Ar-Ge Teşvikleri ve Inovasyon Ilişkisi Üzerine Ampirik Bir Inceleme", *Kahramanmaraş Sütçü İmam Üniversitesi Sosyal Bilimler Dergisi*, 16(2), 686-702.

Shahzad, K., Lu, B. and Abdul, D. (2022). "Entrepreneur Barrier Analysis on Renewable Energy Promotion in the Context of Pakistan Using Pythagorean Fuzzy AHP Method", *Environmental Science and Pollution Research*, 29(36), 54756-54768.

Shahzad, K., Lu, B., Abdul, D., Safi, A., Umar, M. and Afridi, N. K. (2023). "Assessment of Biomass Energy Barriers Towards Sustainable Development: Application of Pythagorean Fuzzy AHP", *Geological Journal*, 58(4), 1607-1622.

Sivam, A., Dieguez, T., Ferreira, L.P. and Silva, F.J.G. (2019). "Key Settings for Successful Open Innovation Arena", *Journal of Computational Design and Engineering*, 6(4), 507-515.

Starr, M.K. (1978). "Operations Management", U.S.A: Prentice-Hall, Inc

Şengül, Ü., Eren, M. and Shiraz, S. E. (2012). "Bulanık AHP İle Belediyelerin Toplu Taşima Araç Seçimi", *Erciyes Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 40, 143-165.

Tainter, J.A. (1988). "The Collapse of Complex Societies", Cambridge University Press, Cambridge.

TİM Inosuit (2019-2022). "Etki Analizi",

https://tim.org.tr/files/downloads/inosuit/TIM_Inosuit_Programi.pdf (Erişim Tarihi: 15.06.2023).

Tiwari, R. (2007). "The Early Phases of Innovation: Opportunities and Challenges in Public-Private Partnership", *Asia Pacific Tech Monitor,* 24 (1), 32-37.

Top, A. (2002). Verimlilik ve Üretkenlik Üzerine Düşünceler, *Öneri Dergisi*, 5 (17), 31-34.

Xiao, F. and Ding, W. (2019). "Divergence Measure of Pythagorean Fuzzy Sets and its Application in Medical Diagnosis", *Applied Soft Computing*, 79, 254-267.

Yager, R.R. (2013). "Pythagorean Membership Grades in Multicriteria Decision Making", *IEEE Transactions on Fuzzy Systems*, 22(4), 958-965.

Yazıcı, E., Alakaş, H.M. and Eren, T. (2023). "Prioritizing of Sectors for Establishing a Sustainable Industrial Symbiosis Network with Pythagorean Fuzzy AHP-Pythagorean Fuzzy TOPSIS Method: A Case of Industrial Park in Ankara", *Environmental Science and Pollution Research*, 30, 77875-77889.

Yildiz, A. (2016). "Interval Type 2-Fuzzy TOPSIS and Fuzzy TOPSIS Method in Supplier Selection in Garment Industry/Metoda Fuzzy TOPSIS Interval Tip 2 Si Metoda Fuzzy TOPSIS În Selectarea Furnizorului Din Industria De Confectii", *Industria Textila*, 67(5), 322.

Yıldız, A. and Demir, Y. (2019). "Bulanik TOPSIS Yöntemiyle Türkiye'nin Yerli Otomobili İçin En Uygun Fabrika Yerinin Seçimi", *Business and Management Studies: An International Journal*, 7(4),1427-1445.

Yılmaz, O. (2020). "İnovasyon Yönetimi", Gazi Kitabevi, Ankara.

Yılmaz, Y.E. (2016). "Pazarlamada Süreç, Inovasyon Stratejileri ve Firma Performansı Ilişkisi", Yüksek Lisans Tezi, Okan Üniversitesi Sosyal Bilimler Enstitüsü, İstanbul.

Yucesan, M. and Gul, M. (2020). "Hospital Service Quality Evaluation: An Integrated Model Based on Pythagorean Fuzzy AHP and Fuzzy TOPSIS", *Soft Computing*, 24(5), 3237-3255.

Yucesan, M. and Kahraman, G. (2019). "Risk Evaluation and Prevention in Hydropower Plant Operations: A Model Based on Pythagorean Fuzzy AHP", *Energy Policy*, 126, 343-351.

Zadeh, L.A. (1965). "Fuzzy sets", *Information and control*, 8(3), 338-353.

Zhang, X. and Xu, Z. (2014). "Extension of TOPSIS to Multiple Criteria Decision Making with Pythagorean Fuzzy Sets", *International Journal of Intelligent Systems*, 29(12), 1061-1078.

Zhou, F. and Chen, T. Y. (2023). "A Hybrid Group Decision-Making Approach Involving Pythagorean Fuzzy Uncertainty for Green Supplier Selection", *International Journal of Production Economics*, 261, 108875.

Zimmermann, H.J. (2010). "Fuzzy Set Theory", *Wiley Interdisciplinary Reviews: Computational Statistics*, 2(3), 317-332.