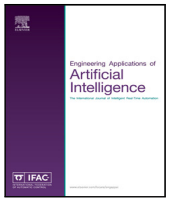
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Investigation of the pharmaceutical warehouse locations under COVID-19—A case study for Duzce, Turkey



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ABSTRACT

Pharmaceutical warehouses are among the centers that play a critical role in the delivery of medicines from the producers to the consumers. Especially with the new drugs and vaccines added during the pandemic period to the supply chain, the importance of the regions they are located in has increased critically. Since the selection of pharmaceutical warehouse location is a strategic decision, it should be handled in detail and a comprehensive analysis should be made for the location selection process. Considering all these, in this study, a real-case application by taking the problem of selecting the best location for a pharmaceutical warehouse is carried out for a city that can be seen as critical in drug distribution in Turkey. For this aim, two effective multi-criteria decision-making (MCDM) methodologies, namely Analytic Hierarchy Process (AHP) and Evaluation based on Distance from Average Solution (EDAS), are integrated under spherical fuzzy environment to reflect fuzziness and indeterminacy better in the decision-making process and the pharmaceutical warehouse location selection problem is discussed by the proposed fuzzy integrated methodology for the first time. Finally, the best region is found for the pharmaceutical warehouse and the results are discussed under the determined criteria. A detailed robustness analysis is also conducted to measure the validity, sensibility and effectiveness of the proposed methodology. With this study, it can be claimed that literature has initiated to be revealed for the pharmaceutical warehouse location problem and a guide has been put forward for those who are willing to study this area.

1. Introduction and related studies

The warehouse location selection problem emerges as an area that has gained more importance for the medical sector during the pandemic period. In the pharmaceutical industry, drugs are handled differently from other physical goods supply chains because of the details in their storage, transportation and regulation (Kumar et al., 2018). It is crucial for pharmaceutical companies to decide on the storage area in order to regulate the costs during the pandemic period and to ensure that drugs and vaccines reach the citizens as soon as possible (Yaman and Akkartal, 2020). While the pharmaceutical market is already being heavily run in many countries due to the unique nature of demand and supply, it has become even more complex with the added uncertainty of the pandemic (Ghatari et al., 2013).

The facility location selection problem has a prevalent implementation in the healthcare industry, from hospitals to clinics, blood banks to pharmaceutical warehouses, and medical facilities. The first goal of the pharmaceutical industry is to make a profit, but the stakeholders of this industry must provide the necessary support for the health systems by providing the drugs at the right time and in the right place (Kumar et al., 2018). For this reason, it is critical that facilities in the pharmaceutical industry are located in the right place.

Pharmaceutical warehouses in many countries such as Turkey are one of the health stakeholders that provide the purchase, sale and distribution of pharmaceutical products within the scope of current legal circumstances (Arslan, 2020; Tengilimoğlu et al., 0000). When the studies on pharmaceutical warehouses are examined in the literature, it has been observed that there are generally studies aimed at establishing an effective supply chain (Abideen and Mohamad, 2021, 2020; Abideen and Binti Mohamad, 2019; Jiang et al., 2019; Özkan, 2017; Qashlim and Basri, 2019; Tat et al., 2020). However, the threat posed by the COVID-19 pandemic to the whole world has caused an emergency in the world (Barshooi and Amirkhani, 2022) and it has become necessary to put forward studies with a new perspective in order to ensure full and timely access to the drugs of those infected with the Coronavirus Disease 2019 (COVID-19) virus and to provide a full-time supply of drugs of COVID-19.

The choice of warehouse location is a long-term decision and is influenced by many different criteria that can be measured both quantitatively and qualitatively (Demirel et al., 2010). Warehouse location

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selection requires simultaneous consideration of many different factors, such as investment cost, human resources, availability, traffic conditions, appropriate policy laws and regulations, zone functionality, effective accessibility, and lower rental costs (Li et al., 2020). In order to address this problem and find the most appropriate solutions, all these conflicting criteria must be evaluated simultaneously. One of the most effective approaches that can be applied to this problem is the MCDM methodology. Such real-life problems are often complex or inherently uncertain, resulting in the fact that the criterion weights and criterion scores of the alternatives are not determined exactly. In this case, criteria weights and criteria-alternative evaluations are determined using linguistic variables. At this point, the evaluations obtained should be converted to numerical values in order to use them in analytical methods. The fuzzy logic approach, which follows a similar path to human reasoning and imitates decision-making, can be used to obtain the numerical values of the evaluations in this step (Amirkhani et al., 2020b; Amirkhani and Barshooi, 2021; Shukla et al., 2017).

Spherical fuzzy sets, proposed by Gündoğdu and Kahraman (Kutlu Gündoğdu and Kahraman, 2019a) as an extension of intuitionistic fuzzy sets, allow decision-makers to define a membership function on a spherical surface and can assign the parameters of this membership function to a wider area independently (Ayyildiz and Taskin Gumus, 2020; Erdoğan, 2022; Kutlu Gündoğdu and Kahraman, 2019a). It is frequently used especially in decision-making problems which is analyzed using linguistic variables and where uncertainty exists (Ayyildiz and Taskin Gumus, 2020; Erdoğan, 2022; Erdoğan et al., 2021; Gul and Ak, 2021; Menekse and Camgoz-Akdag, 2022). Spherical fuzzy numbers satisfy the condition that the sum of the square of the degree of membership, degree of non-membership, and degree of hesitation is less than or equal to one (Erdoğan, 2022; Kutlu Gündoğdu and Kahraman, 2019b).

The AHP approach is an MCDM method that can be applied to rank more than one alternative, considering qualitative and quantitative criteria (Mathew et al., 2020; Saaty, 2008, 1990). In this method, a hierarchical structure is created among the decision elements and rankings of the alternatives are obtained by using the evaluations of the decision-makers (Kutlu Gündoğdu and Kahraman, 2020). Fuzzy set theory is usually integrated to reflect the uncertainty and vagueness in the decision-making problems using MCDM methods (Amirkhani et al., 2020a). In special, extended approaches of the ordinary fuzzy sets are frequently applied to deal with the uncertainty better. An extended fuzzy approach is used to reflect the ambiguity in the most possible way and to digitize the linguistic variables in the best way. Although spherical fuzzy sets are relatively newly developed compared to other fuzzy set extensions, they are frequently used in MCDM problems lately (Buyuk and Temur, 2021; Erdoğan, 2022; Hamal and Senvar, 2021; Kahraman et al., 2021; Omerali and Kaya, 2022; Sarucan et al., 2021; Toker and Görener, 2022; Unal and Temur, 2022). In this study, spherical fuzzy AHP (SF-AHP) is used to determine criteria weight.

EDAS, which is one of the widely used MCDM methods in recent years, is a method based on evaluating alternatives according to their mean solution distances (Ghorabaee et al., 2015). The evaluation of alternatives is carried out according to the higher values of the positive distance matrix from the mean and the lower values of the negative distance matrix from the mean (Stanujkic et al., 2017). Ghorabaee et al. firstly developed the fuzzy EDAS method for the supplier selection problem (Ghorabaee et al., 2016). In this study, the EDAS method has been expanded by using spherical fuzzy sets and the spherical fuzzy EDAS (SF-EDAS) method has been introduced to the literature as a group decision-making method based on uncertainty.

In recent years, artificial intelligence methods have been widely used in scientific research and businesses to minimize errors based on the decision-making mechanism. But sometimes, due to the nature of information, there are uncertain, complex and hesitant situations. With artificial intelligence applications that provide access to real-time information, the decision-maker can make quick and intuitive decisions when it comes to uncertainty, which is characterized as a lack of information about all alternatives or results. In the near future, rapid and effective solutions to problems can be obtained by using artificial intelligence applications with the proposed methodology in this study and similar methods. The proposed integrated fuzzy-based methodology can be applied to numerous problems in artificial intelligence, expert systems and more in today and the near future.

The problem of pharmaceutical warehouse location selection addressed in this paper is focused to ensure the most effective flow of the healthcare supply chain under the ongoing pandemic conditions. To cope with the increase in demand for drugs after the incremental coronavirus cases and to ensure that the vaccine supply chain operates systematically and effectively, the most suitable place for the pharmaceutical warehouse is determined among the alternative areas in a certain region determined for a city in the Black Sea Region of Turkey.

Apart from the locations selection papers using MCDM approach, an analytical and systematic way has been needed to determine the studies in which we can emphasize the differences and which will form the basis of this study. For this purpose, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach is used while researching the relevant literature. PRISMA approach is adopted as Systematic Literature Review Method (SLR) to minimize bias in the reviews and realize the reviews more systematic (Satria et al., 2017). PRISMA is a systematic approach developed by David Moher to review the literature (Moher et al., 2009). The PRISMA approach has five steps in literature search: defining criteria, identifying sources, selecting literature, collecting data, and selecting data items (Santi and Putra, 2018).

Studies using the decision-making approaches for the warehouse location selection of pharmacies are investigated via PRISMA. Besides, the use of fuzzy logic with the adopted approach in decision-making studies is analyzed and examined in detail. Through studies that adopt the addressed approach in determining the location selection of pharmaceutical warehouses, criteria that can be used as evaluation criteria within the scope of this study have been revealed under pandemic conditions. The literature search was performed from 16th November 2021 to 25th December 2021 with the keywords used presented in Table 1.

A total of 96 papers are investigated as a result of the search in the Scopus database with the keywords shown in Table 1. By specifying both inclusion and exclusion criteria after the search, papers directly related to the study are presented. It is planned to reach similar studies that can form a background for the study and compare the inferences. Table 2 shows the inclusion and exclusion criteria for the papers encountered.

When the studies found as a result of the literature search are filtered with the criteria in Table 2, it can be observed that 19 studies could form the basis of this paper. To present the differences between these studies with our paper and to emphasize their contribution to the literature, Table 3 has been presented.

When the relevant literature is examined, the study of Arslan (Arslan, 2020) is found similar to this paper. In this study, a prioritization study is carried out for 3 different pharmaceutical warehouse locations in the Eastern and Southeastern Anatolia Region in Turkey. For this purpose, the AHP method, which is one of the most used MCDM approaches, is adopted. As the limitations of the study, it can be mentioned that implementation is conducted for a very large area, ignoring the uncertainties, using a relatively simple hierarchical structure, and presenting a superficial examination of the problem. In our study, the problem addressed is analyzed primarily by considering the pandemic conditions, a hierarchy of evaluation criteria is created for this special purpose, and a comparison of alternatives is carried out for a more specific area with handling the uncertainties.

The aforementioned literature review to solve different pharmaceutical warehouse location selection problems and its extensions reveal

Table 1
Studies found in the literature review.

Database	Details of the search	Number of studies
SCOPUS	(TITLE-ABS-KEY (Pharmacy) AND TITLE-ABS-KEY (“Location selection”))	2
	(TITLE-ABS-KEY (Pharmacy) AND TITLE-ABS-KEY (“Site selection”))	18
	(TITLE-ABS-KEY (“Pharmacy warehouse”))	24
	(TITLE-ABS-KEY (“Drug distribution”) AND TITLE-ABS-KEY (“Location selection”))	1
	(TITLE-ABS-KEY (“Pharmaceutical warehouse”))	39
	(TITLE-ABS-KEY (“Medical warehouse”))	12

Table 2
Inclusion and exclusion criteria in the literature review.

Inclusion criteria	Exclusion criteria
The studies include warehouse location selection implementation in **MCDM** analysis	Studies whose full text could not be reached
The studies include warehouse location selection in considering health centers	Studies that do not explicitly mention the method used and the results
The studies include warehouse site selection in MCDM analysis	Studies that are written in languages other than English
The studies include medical warehouse site selection implementations for healthcare supply chain	

that only a few studies focus to solve the problem under uncertain and fuzzy environments. Neither of these studies presents comprehensive and detailed criteria hierarchy to model the problem in a more realistic way. Therefore, this study proposes to construct a two-level criteria hierarchy that consists of thirty-three sub-criteria. With this hierarchy, a pharmaceutical warehouse location is modeled and solved under a fuzzy environment. The proposed hybrid decision-making model is applied to a real-world problem in Duzce for the post-COVID-19 era. Robustness analysis that includes sensitivity analysis and comparative analyses are also presented to show the applicability and validity of the model. In addition to all these, it is aimed to contribute to the literature by applying the AHP-EDAS MCDM combination under the extension of spherical fuzzy sets newly presented hybrid approach to the literature. The contribution of this research is to propose a spherical fuzzy-based MCDM model for the most appropriate pharmacy warehouse location for the most effective distribution of drugs and vaccines during the pandemic period. The flowchart of the proposed methodology is presented in Fig. 1.

In this study, a hybrid MCDM approach is used to evaluate all qualitative and quantitative criteria at the same time, and this hybrid approach is developed in a fuzzy framework in order to obtain the closest results to reality and best reflect the uncertainty. Eventually, a hybrid fuzzy decision-making methodology has been proposed for the evaluation of the alternative locations for a pharmaceutical warehouse under pandemic conditions. In light of this aim, the main contribution of this paper can be listed as follows:

i Considering the pandemic conditions, it will be the first study to determine the location of a pharmaceutical warehouse.
ii The pharmaceutical warehouse location problem will be analyzed for the first time with a fuzzy hybrid MCDM approach.
iii Methodologically, the AHP-EDAS hybrid approach has been adopted as a recent approach by extending with SF sets.

The rest of the paper is organized as follows: Section 2 contains the adopted methodology along with the paper. Section 3 shows the real case analysis and Section 4 presents the robustness analysis. Finally, Section 5 gives the conclusion and future directions.

2. Spherical fuzzy based decision-making methodology

The proposed AHP integrated EDAS-based decision-making methodology under the spherical fuzzy environment includes two main stages. In the first stage, SF-AHP is used to determine the weight of each criterion in the hierarchical structure. Then, the proposed SF-EDAS methodology is employed to evaluate alternatives. The following sub-sections give information about the adopted methods in detail.

2.1. Preliminaries of spherical fuzzy sets

Kutlu Gundogdu and Kahraman introduced to the literature spherical fuzzy sets (Kutlu Gündoğdu and Kahraman, 2019b). Spherical fuzzy sets are developed on the basics pythagorean fuzzy (PF) sets and neutrosophic fuzzy sets (Dogan, 2021). Functions are identified on a spherical surface and parameters of the function are defined independently in a larger domain (Erdoğan et al., 2021). Three parameters are used to define spherical fuzzy numbers as the intuitionistic, pythagorean, and neutrosophic fuzzy sets (Ayyildiz and Taskin Gumus, 2020). The parameters are assigned on a spherical surface to generalize fuzzy sets. In this way, more freedom is provided to decision-makers to model ambiguity in information. The representation of the spherical and other extended fuzzy sets is shown in Fig. 1 (Kutlu Gündoğdu and Kahraman, 2020)

The definitions of the spherical fuzzy sets are also explained in the following paragraphs.

Definition 1. Let X be a fixed set. A spherical fuzzy number $\tilde{S}$ can be presented:

$$\tilde{S} \cong \left\{x, \tilde{S}(\mu_{\tilde{s}}(x), \upsilon_{\tilde{s}}(x), \pi_{\tilde{s}}(x)); x \in X\right\} \quad (1)$$

$\mu_{\tilde{s}}(x) : X \mapsto [0,1]$, $\upsilon_{\tilde{s}}(x) : X \mapsto [0,1]$ and $\pi_{\tilde{s}}(x) : X \mapsto [0,1]$ define the membership, non-membership, and hesitancy function of the element $x \in X$ to $\tilde{S}$.

Table 3
Literature results.

#	Authors	Aim	Method	Published in	Year
1	Yaman and Akkartal (2020)	Assessing the factors that influence the location of a warehouse for medical supplies and services	Pythagorean fuzzy set-based DEMATEL	Fourth World Conference on Smart Trends in Systems, Security and Sustainability	2020
2	Zhang et al. (2019)	Employing an optimization method to allocate a certain amount of antiviral drug to selected distribution points	Willingness-to-travel model	Journal of Ambient Intelligence and Humanized Computing	2019
3	Arslan (2020)	Choosing the most suitable warehouse location for a pharmaceutical warehouse	AHP	J. Fac. Pharm. Ankara	2020
4	Ceselli et al. (2014)	Presenting a model for the optimization of logistics operations in emergency health care systems.	Dynamic programming	Discrete Applied Mathematics	2014
5	Chen et al. (2019)	Proposing a generalized multi-level optimization method for designing a common unit dose drug delivery network	Particle swarm optimization	Health Care Management Science	2019
6	Rovers and Mages (2017)	Establishing a model for a drug supply, storage and distribution system in a remote area of Australia	Event Structure Analysis	BMC Health Services Research	2017
7	Dodi et al. (2016)	Investigating the characteristics of direct distribution points of drugs and determining potentially error-prone aspects of the delivery process	Organizational ethnography methodology	Recenti Prog Med	2016
8	Maheswari et al. (2021)	Developing a user-friendly smart MeDrone capable of delivering medication to and from the patient(s) location	Design study	Journal of Physics: Conference Series	2021
9	Risanger et al. (2021)	To determine the geographic coverage that can be achieved through a pharmacy-based testing program in terms of the proportion of individuals willing to travel to the nearest pharmacy testing site to obtain a COVID-19 test	Facility location optimization model	Health Care Management Science	2021
10	Volmer et al. (2015)	Assessing the current situation regarding medical technology in Estonian community pharmacies.	Descriptive cross-sectional questionnaire	Expert Review of Medical Devices	2015
11	Alshehri and Alshammari (2016)	Determining the causes of drug supply shortage in KKESH pharmacy and seeking solutions to avoid this problem.	Descriptive questionnaire	International Business Management	2016
12	Nakiboglu and Gunes (2019)	Identifying the distribution route from the main warehouse to the pharmacies with minimum cost by minimizing the total travel distance and the number of vehicles	Genetic Algorithms	2018 International Conference on Artificial Intelligence and Data Processing (IDAP)	2018
13	Özkan et al. (2017)	Minimizing risk factors in a pharmaceutical supply chain	Fuzzy-based goal programming	Journal of Multiple-Valued Logic and Soft Computing	2017
14	Papageorgiou et al. (2001)	Developing a mathematical model for pharmaceutical companies to develop their storage and distribution strategies	Mixed-integer linear programming	Industrial & Engineering Chemistry Research	2001
15	Yu et al. (2010)	Examining the pharmaceutical products supply chain in China to identify its performance and weaknesses	Literature review	Health Policy	2010
16	Nematollahi et al. (2017)	Presenting two-stage pharmaceutical product supply chains to maximize the occupancy rate in the supply chain	Mathematical modeling	Journal of Cleaner Production	2017
17	Haial et al. (2020)	Identifying the most appropriate network structure in the pharmaceutical products supply chain	Multi-criteria decision-making methods	International Journal of Logistics Systems and Management	2020
18	Ji (2019)	Modeling the problem of drug delivery from hospitals and pharmacies to patients as a vehicle routing problem with a time window	Mixed-integer programming	ACM International Conference Proceeding Series	2019
19	Abideen and Mohamad (2021)	Improving the performance of the Malaysian pharmaceutical warehouse supply chain	Value stream mapping	Journal of Modeling in Management	2021

The main distinction between spherical fuzzy sets and other fuzzy sets is based on hesitancy. In spherical fuzzy sets, the hesitancy degree can be at most 1. Furthermore, the squared sum of three functions takes a value between 0 and 1, and all of the functions are defined independently in [0,1] as aforementioned. Spherical fuzzy sets are defined via three parameters (Kieu et al., 2021):

$$0 \leq \mu_{\tilde{s}}(x)^2 + v_{\tilde{s}}(x)^2 + \pi_{\tilde{s}}(x)^2 \leq 1; x \in U \quad (2)$$

Definition 2. $\tilde{\alpha} = S\left(\mu_{\tilde{\alpha}}, v_{\tilde{\alpha}}, \pi_{\tilde{\alpha}}\right)$ and $\tilde{\beta} = S\left(\mu_{\tilde{\beta}}, v_{\tilde{\beta}}, \pi_{\tilde{\beta}}\right)$ are two spherical numbers. Then the basic operations of them are given (Ali, 2021; Kutlu Gündoğdu and Kahraman, 2020):

$$\tilde{\alpha} \oplus \tilde{\beta} = \tilde{S}\left(\sqrt{\mu_{\tilde{\alpha}}^2 + \mu_{\tilde{\beta}}^2 - \mu_{\tilde{\alpha}}^2\mu_{\tilde{\beta}}^2},\ v_{\tilde{\alpha}}v_{\tilde{\beta}}\sqrt{\left(1-\mu_{\tilde{\alpha}}^2\right)\pi_{\tilde{\beta}}^2 + \left(1-\mu_{\tilde{\beta}}^2\right)\pi_{\tilde{\alpha}}^2 - \pi_{\tilde{\alpha}}^2\pi_{\tilde{\beta}}^2}\right) \quad (3)$$

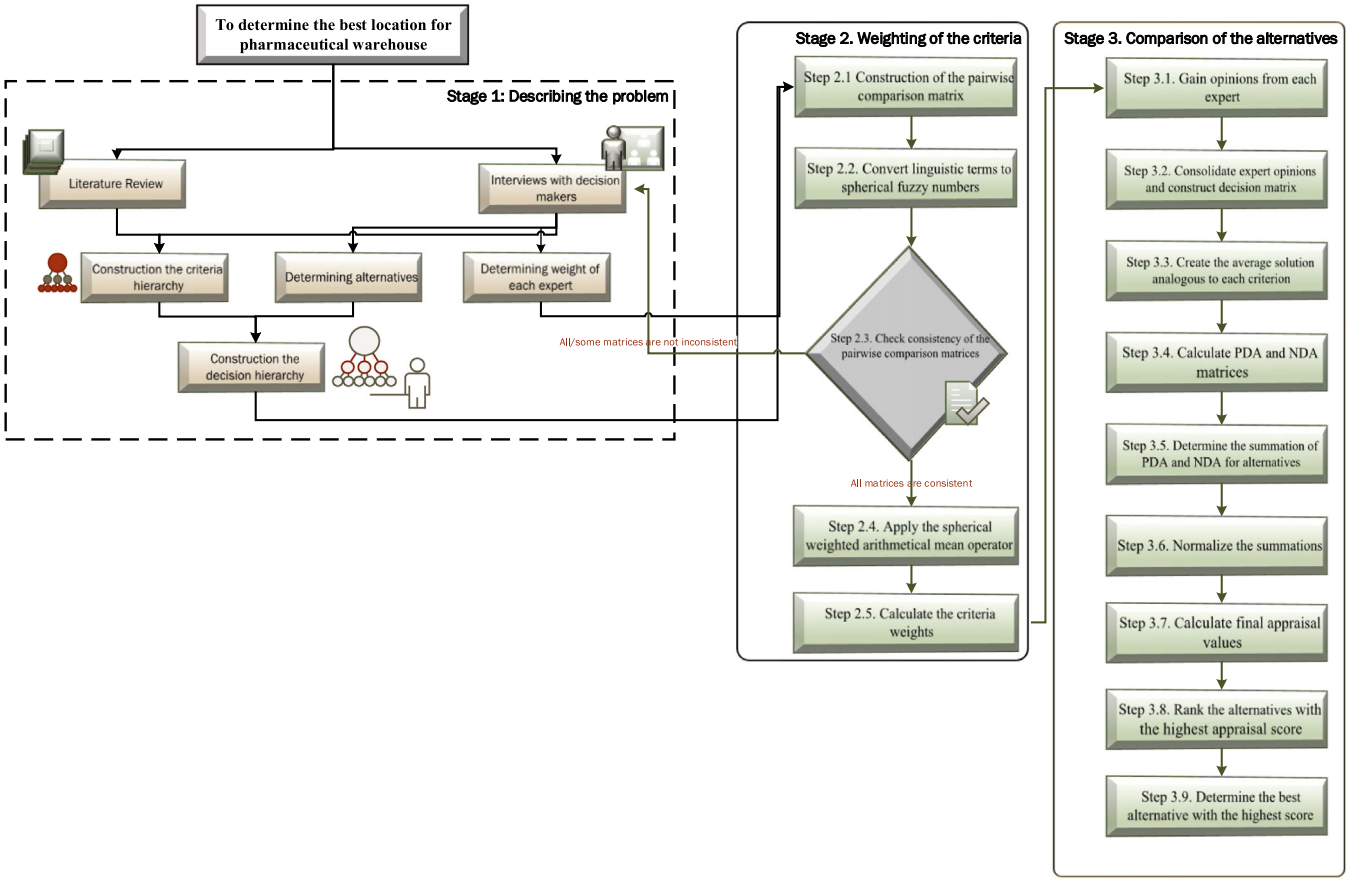


Fig. 1. Flowchart for the proposed method.

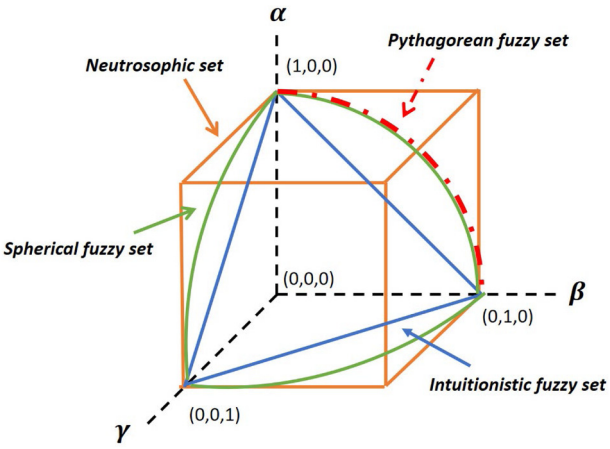


Fig. 2. Geometric representations of the extended fuzzy sets (Kutlu Gündoğdu and Kahraman, 2020).

$$\tilde{\alpha} \otimes \tilde{\beta} = \tilde{\mathrm{S}}\left(\mu_{\tilde{\alpha}}\mu_{\tilde{\beta}}, \sqrt{\mathrm{v}_{\tilde{\alpha}}^2 + \mathrm{v}_{\tilde{\beta}}^2 - \mathrm{v}_{\tilde{\alpha}}^2\mathrm{v}_{\tilde{\beta}}^2}, \sqrt{\left(1-\mathrm{v}_{\tilde{\alpha}}^2\right)\pi_{\tilde{\beta}}^2 + \left(1-\mathrm{v}_{\tilde{\beta}}^2\right)\pi_{\tilde{\alpha}}^2 - \pi_{\tilde{\alpha}}^2\pi_{\tilde{\beta}}^2}\right) \tag{4}$$

$$\tilde{\alpha} \ominus \tilde{\beta} = \begin{cases} \left\langle \left(\dfrac{\mu_{\tilde{\alpha}}^2 - \mu_{\tilde{\beta}}^2}{1-\mu_{\tilde{\beta}}^2}\right)^{\frac{1}{2}}, \dfrac{\mathrm{v}_\alpha}{\mathrm{v}_\beta}, \dfrac{\pi_\alpha}{\pi_\beta} \right\rangle, \text{ if } 0 \le \dfrac{\pi_\alpha}{\pi_\beta}, \dfrac{\mathrm{v}_\alpha}{\mathrm{v}_\beta} \le \dfrac{\left(1-\mu_{\tilde{\alpha}}^2\right)^{\frac{1}{2}}}{\left(1-\mu_{\tilde{\beta}}^2\right)^{\frac{1}{2}}} \le 1 \\ (0,1,0), \text{ Otherwise,} \end{cases} \tag{5}$$

$$\tilde{\alpha} \oslash \tilde{\beta} = \begin{cases} \left\langle \dfrac{\mu_\alpha}{\mu_\beta}, \left(\dfrac{\mathrm{v}_{\tilde{\alpha}}^2 - \mathrm{v}_{\tilde{\beta}}^2}{1-\mathrm{v}_{\tilde{\beta}}^2}\right)^{\frac{1}{2}}, \dfrac{\mathrm{v}_\alpha}{\mathrm{v}_\beta} \right\rangle, \text{ if } 0 \le \dfrac{\mu_\alpha}{\mu_\beta}, \dfrac{\pi_\alpha}{\pi_\beta} \le \dfrac{\left(1-\mathrm{v}_{\tilde{\alpha}}^2\right)^{\frac{1}{2}}}{\left(1-\mathrm{v}_{\tilde{\beta}}^2\right)^{\frac{1}{2}}} \le 1 \\ (0,1,0), \text{ Otherwise,} \end{cases} \tag{6}$$

Definition 3. Spherical fuzzy number $\tilde{\alpha} = S\left(\mu_{\tilde{\alpha}}, \upsilon_{\tilde{\alpha}}, \pi_{\tilde{\alpha}}\right)$ is multiplied by a positive scalar ($\lambda > 0$) (Ali, 2021):

$$\lambda\tilde{\alpha} = \tilde{\mathrm{S}}\left(\sqrt{1-(1-\mu_{\tilde{\alpha}}^2)^\lambda}, \mathrm{v}_{\tilde{\alpha}}^\lambda, \sqrt{(1-\mu_{\tilde{\alpha}}^2)^\lambda - (1-\mu_{\tilde{\alpha}}^2-\pi_{\tilde{\alpha}}^2)^\lambda}\right) \tag{7}$$

Definition 4. The positive power ($\lambda > 0$) of spherical fuzzy number $\tilde{\alpha} = \mathrm{S}\left(\mu_{\tilde{\alpha}}, \mathrm{v}_{\tilde{\alpha}}, \pi_{\tilde{\alpha}}\right)$ is calculated:

$$\tilde{\alpha}^\lambda = \tilde{\mathrm{S}}\left(\mu_{\tilde{\alpha}}^\lambda, \sqrt{1-(1-\mathrm{v}_{\tilde{\alpha}}^2)^\lambda}, \sqrt{(1-\mathrm{v}_{\tilde{\alpha}}^2)^\lambda - (1-\mathrm{v}_{\tilde{\alpha}}^2-\pi_{\tilde{\alpha}}^2)^\lambda}\right) \tag{8}$$

Definition 5. Score function of spherical fuzzy number $\tilde{\alpha} = \mathrm{S}\left(\mu_{\tilde{\alpha}}, \mathrm{v}_{\tilde{\alpha}}, \pi_{\tilde{\alpha}}\right)$ is given.

$$\mathrm{S}^*\left(\tilde{\alpha}_{\mathrm{ij}}\right) = \left(2\mu_{\tilde{\alpha}} - \pi_{\tilde{\alpha}}\right)^2 - \left(\upsilon_{\tilde{\alpha}} - \pi_{\tilde{\alpha}}\right)^2 \tag{9}$$

Definition 6. Spherical fuzzy number $\tilde{\alpha} = \mathrm{S}\left(\mu_{\tilde{\alpha}}, \mathrm{v}_{\tilde{\alpha}}, \pi_{\tilde{\alpha}}\right)$ is defuzzified via Eq. (10).

$$D\left(\tilde{\alpha}\right) = \sqrt{\left|100 * \left[\left(3\mu_{\tilde{\alpha}} - \frac{\pi_{\tilde{\alpha}}}{2}\right)^2 - \left(\frac{\upsilon_{\tilde{\alpha}}}{2} - \pi_{\tilde{\alpha}}\right)^2\right]\right|} \tag{10}$$

Definition 7. Euclidean distance between two spherical fuzzy numbers $\tilde{\alpha} = \mathrm{S}\left(\mu_{\tilde{\alpha}}, \mathrm{v}_{\tilde{\alpha}}, \pi_{\tilde{\alpha}}\right)$ and $\tilde{\beta} = S\left(\mu_{\tilde{\beta}}, \upsilon_{\tilde{\beta}}, \pi_{\tilde{\beta}}\right)$ is calculated:

$$\mathcal{D}(\tilde{\alpha}, \tilde{\beta}) = \sqrt{\left(\left(\mu_{\tilde{\alpha}} - \mu_{\tilde{\beta}}\right)^2 + \left(\upsilon_{\tilde{\alpha}} - \upsilon_{\tilde{\beta}}\right)^2 + \left(\pi_{\tilde{\alpha}} - \pi_{\tilde{\beta}}\right)^2\right)} \tag{11}$$

Table 4
Linguistic terms and spherical fuzzy scales of linguistic terms for criteria evaluation.

Linguistic terms	Spherical fuzzy numbers			Score Index (*SI*)
	μ	υ	π	
Absolutely low important - ALI	0.1	0.9	0	1/9
Very low important - VLI	0.2	0.8	0.1	1/7
Low important - LI	0.3	0.7	0.2	1/5
Slightly low important - SLI	0.4	0.6	0.3	1/3
Equal important - EI	0.5	0.5	0.4	1
Slightly high important - SHI	0.6	0.4	0.3	3
High important - HI	0.7	0.3	0.2	5
Very high important - VHI	0.8	0.2	0.1	7
Absolutely more important - AMI	0.9	0.1	0	9

Definition 8. Spherical Weighted Arithmetic Mean (SWAM) operator is defined with respect to $w = (w_1, w_2, \ldots, w_n)\,; w_i \in [0,1]; \sum_{i=1}^{n} w_i = 1$ as below:

$$\begin{aligned}\mathrm{SWAM}_w\left(\tilde{A}_{s_1}, \tilde{A}_{s_2}, \ldots, \tilde{A}_{s_n}\right) &= w_1\tilde{A}_{s_1} + w_2\tilde{A}_{s_2} + \cdots .. + w_n\tilde{A}_{s_n} \\ &= \left\{\left[1 - \prod_{i=1}^{n}\left(1-\mu_{\tilde{A}_S}^2\right)^{w_i}\right]^{1/2}, \right. \\ &\quad \prod_{i=1}^{n} v_{\tilde{A}_s}^{w_i}, \left[\prod_{i=1}^{n}\left(1-\mu_{\tilde{A}_S}^2\right)^{w_i}\right. \\ &\quad \left.\left. - \prod_{i=1}^{n}\left(1-\mu_{\tilde{A}_s}^2-\pi_{\tilde{A}_s}^2\right)^{w_i}\right]^{1/2}\right\}\end{aligned} \tag{12}$$

2.2. Spherical fuzzy AHP

AHP is used to determine the weight of importance of the criteria (Saaty, 2000). It enables complex decision-making problems to be solved in a simple hierarchical structure (Ayyildiz and Taskin Gumus, 2021). Both qualitative and quantitative criteria can be evaluated together in the AHP approach. The method allows the decision-maker to make a more consistent evaluation procedure. For these reasons, in this study, AHP is utilized to determine the weights of criteria under a spherical fuzzy environment. The steps of SF-AHP are given below (Ayyildiz and Taskin Gumus, 2020):

Step 1. The pairwise comparison matrix is constructed via linguistic terms given in Table 4 (Kutlu Gündoğdu and Kahraman, 2019b).

Step 2. The spherical fuzzy pairwise comparison matrix is constructed by converting linguistic terms to spherical fuzzy numbers.

$$M = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} \tag{13}$$

Let $\tilde{a}_{ij}$ be the pairwise comparison value between criterion i and criterion j.

Step 3. The consistency of the matrix is analyzed. For this purpose, first, the consistency ratio (CR) proposed by Saaty (1977) is calculated using *SI*. Then, the consistency index (*CI*) of the matrix is calculated.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{14}$$

$$CR = \frac{CI}{RI} \tag{15}$$

λ_{max} is the largest eigenvalue of the pairwise comparison matrix. Random index (*RI*) depends on matrix order (n). *RI* is determined via the constant table suggested by Saaty (1977). The *CR* should be less than *0.1*.

Table 5
Linguistic terms and spherical fuzzy scales of linguistic terms for alternative evaluation.

Linguistic terms	Spherical fuzzy numbers		
	μ	v	π
Extremely Low - EL	0.3	0.7	0.3
Very Low — VL	0.4	0.6	0.4
Low — L	0.5	0.5	0.5
Fair — F	0.6	0.4	0.4
High — H	0.7	0.3	0.3
Very High — VH	0.8	0.2	0.2
Extremely High — EH	0.9	0.1	0.1

Step 4. Spherical weighted arithmetical mean (WM) operator is utilized to calculate the fuzzy weights of criteria.

$$\widetilde{\mathrm{WM}}_j = \tilde{S}\left(\sqrt{1-\prod_{j=1}^{n}(1-\mu_{\tilde{a}_{ij}}^2)^{1/n}}, \prod_{j=1}^{n} v_{\tilde{a}_{ij}}^{1/n}, \sqrt{\prod_{j=1}^{n}(1-\mu_{\tilde{a}_{ij}}^2)^{1/n} - \prod_{j=1}^{n}(1-\mu_{\tilde{a}_{ij}}^2-\pi_{\tilde{a}_{ij}}^2)^{1/n}}\right) \tag{16}$$

Let n be the number of criteria.

Step 5. Calculated weights of criteria in Step 4 are defuzzified via Eq. (10).

Step 6. The weights of the criteria are normalized.

$$w_j = \frac{S_j}{\sum_{j=1}^{n} S_j} \tag{17}$$

2.3. Spherical fuzzy EDAS

EDAS (Evaluation based on Distance from Average Solution) method, which was introduced to the literature by Ghorabaee et al. (2015) is a method that is evaluated by calculations according to the average solution distance in the process of determining the best among the decision alternatives. The underlying logic of the method is similar to the logic of the TOPSIS method. However, there is a fundamental difference, which distinguishes the EDAS method from the frequently used MCDM methods such as TOPSIS and VIKOR, which deal with the closeness of the optimal solution to the positive ideal and negative ideal solution. Accordingly, the evaluation process in the EDAS method is not done over the ideal solution set, but over the positive and negative distances to the mean solution. Therefore, it is rejected the idea of the distance from the ideal and negative ideal solution and considers the distance from the mean solution in the EDAS method. The desirability of alternatives depends on two different indicators and they guide the implementation in EDAS which are the positive distance to the mean solution and the negative distance to the mean solution. In the evaluation, it is required that the positive distance is the highest and the negative distance is the lowest for the optimal solution.

After determining criteria weights, spherical fuzzy EDAS (SF-EDAS) is operated to evaluate alternative locations. The steps of SF-EDAS are given below:

Step 1. The decision matrix is established to evaluate alternatives according to criteria using linguistic terms using Table 5 (Sharaf and Khalil, 2020). Then linguistic terms are converted to spherical fuzzy numbers.

Where $\tilde{X}_{ij}$ be the spherical fuzzy evaluation value of alternative i with respect to criterion j.

Step 2. The average solution analogous to each criterion is created.

$$\tilde{A}_j = \frac{1}{m}\bigoplus_{i=1}^{m} \tilde{X}_{ij}, \forall i, j \tag{18}$$

Remember m is the number of alternatives.

Step 3. To determine the positive distance (PDA) and the negative distance (NDA) matrices from the average solutions, the score value of each average solution ($\tilde{A}_j$) is determined via Eq. (9). For each criterion, PDA and NDA matrices from the mean are determined. Each element of these matrices is calculated differently depending on the type of criterion.

$$PDA = \left[\alpha_{ij}\right]_{m\times n} \text{ and } NDA = \left[\beta_{ij}\right]_{m\times n} \tag{19}$$

where α_{ij} and b_{ij} are the PDA and NDA of alternative i.

The comparison function is defined to compare the difference with 0 and determine the maximum value, as below:

$$Z_{ij} = \begin{cases} S^*(\tilde{X}_{ij}) & \text{if } S^*(\tilde{X}_{ij}) > 0 \\ 0 & \text{if } S^*(\tilde{X}_{ij}) \leqslant 0 \end{cases} \tag{20}$$

For benefit criteria:

$$\alpha_{ij} = \frac{max\left(0, \left(Z_{ij} - S^*(\tilde{A}_j)\right)\right)}{S^*(\tilde{A}_j)} \tag{21}$$

$$b_{ij} = \frac{max\left(0, \left(S^*(\tilde{A}_j) - Z_{ij}\right)\right)}{S^*(\tilde{A}_j)} \tag{22}$$

For cost criteria:

$$\alpha_{ij} = \frac{max\left(0, \left(S^*(\tilde{A}_j) - Z_{ij}\right)\right)}{S^*(\tilde{A}_j)} \tag{23}$$

$$b_{ij} = \frac{max\left(0, \left(Z_{ij} - S^*(\tilde{A}_j)\right)\right)}{S^*(\tilde{A}_j)} \tag{24}$$

Step 4. The weighted summation of PDA and NDA for alternatives is determined.

$$P_i^{(+)} = \sum_{j=1} w_j \alpha_{ij} \tag{25}$$

$$N_i^{(-)} = \sum_{j=1} w_j b_{ij} \tag{26}$$

Step 5. The normalized values of $P_i^{(+)}$ and $N_i^{(-)}$ are calculated.

$$nP_i^{(+)} = \frac{P_i^{(+)}}{max_i\left(P_i^{(+)}\right)} \tag{27}$$

$$nN_i^{(-)} = 1 - \frac{N_i^{(-)}}{max_i\left(N_i^{(-)}\right)} \tag{28}$$

Step 6. The appraisal value of each alternative is computed.

$$\varphi_i = \frac{nP_i^{(+)} + nN_i^{(-)}}{2} \tag{29}$$

Step 7. Alternatives are ranked according to decreasing values of score values of appraisal scores and the alternative with the highest appraisal score is determined as the best choice among the alternatives.

3. Real case study

This section presents the real case analysis of the location selection problem for pharmaceutical warehouses. For this aim, data are collected for the city of Düzce, where there is a lack in the number of pharmaceutical warehouses during the pandemic period and case analysis is carried out for this pilot city before. Six different regions are identified as potential alternatives by searching for suitable places for the new pharmaceutical warehouse planned to be opened. After the determination of the alternatives, the criteria to be used in evaluating and ranking these alternatives are investigated. As a result of the detailed literature research, the following criteria are revealed as given in Table 6 by examining the warehouse location problems and the location selection studies for health centers.

After the criteria hierarchy is clarified, the proposed fuzzy hybrid methodology is conducted to find the best location. Firstly, the criteria weights and criteria alternative scores are obtained. For this aim, three experts are consulted as decision-makers. The first expert is the pharmacist who is serving in the pilot region that we consider for 10 years. The second expert is the academician who is a researcher and studied location selection problems. The last expert is also the academician who is a researcher in the FacultyofPharmaceuticalSciences. As a result of the surveys conducted by meeting with the experts, the weights of the criteria and the criteria-alternative scores are determined.

To calculate the weights, firstly, the evaluations of experts are taken to assess the main and sub-criteria. For this purpose, linguistic terms given in Table 4 are used to compare the determined criteria. Therefore, pairwise comparison matrices are structured for both main and sub-criteria by each expert. As an example, the pairwise comparison matrix for the main criteria by Expert-1 is presented in Table 7. The pairwise comparison matrix for the sub-criteria of C1. Economic main criterion is constructed according to the opinions from Expert-2 is presented in Table 8. In Table 9, the pairwise comparison matrix for the sub-criteria of the C6. Resilience main criterion for Expert-3 is presented.

Then, all matrices are investigated to whether they are consistent or not. For this purpose, CR is calculated for each matrix. Table 10 presents the ratios for the main criteria and sub-criteria pairwise comparison matrices, constructed based on opinions from each expert.

After all the matrices are determined as consistent, the weight calculation process is initiated. Primarily, the weights of the main criteria are calculated by applying steps of SF-AHP and given in Table 11 for each expert.

According to the main criteria weights given in Table 11, C1. Economic main criterion is the most important main criterion to select the best location for a pharmaceutical warehouse according to Expert-1 and Expert-2. Expert-3 thinks C4. Infrastructure is the most important main criterion. C3. Opportunities criterion is determined as one of the two least important criteria for all experts.

After determining the main criteria weights, the same steps are repeated for sub-criteria and sub-criteria weights are determined for each expert as given in Table 12. The global weight of each sub-criterion is determined by multiplying the sub-criterion weight with the weight of the related main criterion for each expert. Then, the sub-criteria weights are aggregated considering the reputations (weights) of experts. During the interviews with the experts, their weights were determined by considering the years of work, experience, or level of expertise related to the subject. The weight of the first expert is determined as 0.45, the weight of the second expert is 0.20 and the weight of the third expert is 0.35. Table 12 also presents the final criteria weights.

When the results obtained for the criterion weights are examined, the most important criterion is determined as “energy” with an importance degree of 0.090. The following criterion is found as “investment cost” with an importance degree of 0.077. The cost of transportation appears as a criterion whose importance is calculated at higher ranks with an importance degree of 0.071. As can be seen, even during the

Table 6
Evaluation criteria for pharmaceutical warehouses.

C1. Economic	
C11. Investment cost	Demircan and Özcan (2021), Ehsanifar et al. (2021), He et al. (2017)
C12. Operating cost	Demirel et al. (2010), Kuo (2011), Ulutaş et al. (2021)
C13. Maintenance/ insurance cost	García et al. (2014)
C14. Storage cost	Demircan and Özcan (2021), Emeç and Akkaya (2018)
C15. Financial incentives	Demirel et al. (2010)
C16. Labor cost	Demircan and Özcan (2021), Demirel et al. (2010), Ehsanifar et al. (2021), Emeç and Akkaya (2018), García et al. (2014)
C17. Transportation cost	Demircan and Özcan (2021), Demirel et al. (2010), Ehsanifar et al. (2021), Emeç and Akkaya (2018), García et al. (2014), Kuo (2011), Ocampo et al. (2020), Ulutaş et al. (2021)
C2. Social	
C21. Available workforce	Demircan and Özcan (2021), Demirel et al. (2010), García et al. (2014)
C22. Local government support	Demircan and Özcan (2021), Demirel et al. (2010), García et al. (2014), He et al. (2017), Ocampo et al. (2020)
C23. Environmental impact	Agrebi and Abed (2021), Awasthi et al. (2011), He et al. (2017), Ocampo et al. (2020)
C24. Impact on traffic congestion	He et al. (2017)
C25. Conformance to freight regulations	Agrebi and Abed (2021), Awasthi et al. (2011), Demirel et al. (2010)
C26. Security	Agrebi and Abed (2021), Awasthi et al. (2011), García et al. (2014), Ocampo et al. (2020)
C27. Community acceptance	García et al. (2014), He et al. (2017)
C3. Opportunities	
C31. Development rate	Emeç and Akkaya (2018)
C32. Number of competitors in radius	Arslan (2020), Kuo (2011)
C33. Parking area	Demircan and Özcan (2021), Kuo (2011)
C34. Future expansion	Agrebi and Abed (2021), Awasthi et al. (2011), Ehsanifar et al. (2021), He et al. (2017)
C4. Infrastructure	
C41. Climate conditions	Demircan and Özcan (2021), Emeç and Akkaya (2018), Ulutaş et al. (2021)
C42. Energy	García et al. (2014)
C43. Telecommunication systems	Demirel et al. (2010), Emeç and Akkaya (2018), Ocampo et al. (2020)
C44. Topographical features	Maharjan and Hanaoka (2017)
C5. Accessibility	
C51. Proximity to main roads	Arslan (2020), García et al. (2014), Ocampo et al. (2020)
C52. Proximity to producers	Demircan and Özcan (2021), Demirel et al. (2010), Ehsanifar et al. (2021), Emeç and Akkaya (2018), Ulutaş et al. (2021)
C53. Proximity to multimodal transport	Agrebi and Abed (2021), Awasthi et al. (2011), Demircan and Özcan (2021), Demirel et al. (2010), García et al. (2014), Ocampo et al. (2020), Ulutaş et al. (2021)
C54. Proximity to potential markets	Agrebi and Abed (2021), Awasthi et al. (2011), Demircan and Özcan (2021), Demirel et al. (2010), Dey et al. (2017), Emeç and Akkaya (2018), García et al. (2014), Ocampo et al. (2020), Özcan et al. (2011), Ulutaş et al. (2021)
C55. Proximity to suppliers	Awasthi et al. (2011), Demirel et al. (2010), Emeç and Akkaya (2018), Ocampo et al. (2020), Özcan et al. (2011), Ulutaş et al. (2021)
C56. Proximity to opponents	Emeç and Akkaya (2018), Ulutaş et al. (2021)
C6. Resilience	
C61. Location resistance	Kuo (2011)
C62. Disaster free location	Emeç and Akkaya (2018), Yılmaz and Kabak (2020)
C63. Stock holding capacity	Demircan and Özcan (2021), Dey et al. (2017), Emeç and Akkaya (2018), Kuo (2011), Ocampo et al. (2020), Özcan et al. (2011), Ulutaş et al. (2021)
C64. Resource availability	Agrebi and Abed (2021), Awasthi et al. (2011), He et al. (2017)
C65. Movement flexibility	Özcan et al. (2011)

Table 7
Pairwise comparison matrix for main criteria constructed by Expert-1.

Main criteria	C1	C2	C3	C4	C5	C6
C1. Economic	E	VH	H	SH	E	SH
C2. Social	L	E	SH	VL	L	SL
C3. Opportunities	L	SL	E	SL	L	E
C4. Infrastructure	SL	VH	SH	E	SL	SH
C5. Accessibility	E	H	H	SH	E	SH
C6. Resilience	SL	SH	E	SL	SL	E

Table 8
Pairwise comparison matrix for sub-criteria of Economic constructed by Expert-2.

Economic	C11	C12	C13	C14	C15	C16	C17
C11. Investment cost	E	SL	SH	H	H	H	H
C12. Operating cost	SH	E	SH	H	H	VH	H
C13. Maintenance cost	SL	SL	E	SH	SH	SH	SH
C14. Storage cost	L	L	SL	E	SH	E	SL
C15. Financial incentives	L	L	SL	SL	E	E	SL
C16. Labor cost	L	VL	SL	E	E	E	E
C17. Transportation cost	L	L	SL	SH	SH	E	E

pandemic period, cost-based criteria have emerged as more important factors in the selection of pharmaceutical warehouse best location with the total weight percent as %28,2. The criteria under the "Social" class are calculated as the group of criteria with the least importance with the total weight percent as % 9,6. At this point, it can be interpreted that critical effects will not be encountered in the decision process regarding finding employees for the pharmaceutical warehouse to be established, the acceptance of this facility by the society, its environmental effects and its effects on traffic, and that there will be no issue

Table 9
Pairwise comparison matrix for sub-criteria of Resilience constructed by Expert-3.

Resilience	C61	C62	C63	C64	C65
C61. Location resistance	E	SL	SH	SL	SH
C62. Disaster free location	SH	E	H	E	H
C63. Stock holding capacity	SL	L	E	L	E
C64. Resource availability	SH	E	H	E	H
C65. Movement flexibility	SL	L	E	L	E

Table 10
Consistency ratios of pairwise comparison matrices.

	Expert-1	Expert-2	Expert-3
Main criteria	0.093	0.061	0.071
Sub criteria of Economic	0.095	0.06	0.043
Sub criteria of Social	0.098	0.082	0.06
Sub criteria of Opportunities	0.087	0.097	0.075
Sub criteria of Infrastructure	0.075	0.016	0.033
Sub criteria of Accessibility	0.095	0.089	0.046
Sub criteria of Resilience	0.074	0.049	0.012

Table 11
Main criteria weights for each expert.

Main criteria	Expert-1	Expert-2	Expert-3
C1. Economic	0.301	0.338	0.223
C2. Social	0.074	0.258	0.032
C3. Opportunities	0.049	0.059	0.071
C4. Infrastructure	0.237	0.137	0.278
C5. Accessibility	0.252	0.067	0.225
C6. Resilience	0.087	0.141	0.171

in this sense for the regions considered as alternatives. Besides, when the four most important criteria are compared with the other criteria, it is seen that they have total importance of 30%. At this point, it can be interpreted that 12% of the criteria are the factors that affect the results the most in this decision-making problem.

After the importance of the criteria for the decision-making process is determined, the six different alternatives located in Duzce, Turkey are evaluated as candidate locations to place a pharmaceutical warehouse. Fig. 3 presents the alternative locations for the pharmaceutical warehouse location selection problem.

Experts' evaluations are taken to assess the alternative locations by linguistic terms given in Table 5 with respect to each sub-criterion. For the criteria-alternative evaluations, consensus from the experts is sought. After experts have agreed on the assessments, evaluations are revealed as seen in Table 13.

Thereafter, evaluations of experts are converted to spherical fuzzy numbers to utilize in the proposed fuzzy decision-making methodology. The average solution analogous to each criterion is calculated by Eq. (18) and given in Table 14. The scores of average solutions are also presented in Table 14.

The positive and negative distance matrices are constructed based on Eqs. (19)–(25) considering the type of each criterion which can be beneficial or cost-oriented. Table 15 shows the PDA and NDA matrices for each criterion.

The weighted summation of *PDA* and *NDA* for alternatives is determined and normalized. By this way, the appraisal value of each alternative is calculated and given in Table 16.

After the application of the SF-EDAS approach, the rankings of the alternatives are obtained. The first-ranked alternative is the A-4 alternative with 0.800 appraisal score value. This alternative is followed by the alternatives of A-3 and A-5 with the appraisal score values of 0.728 and 0.666, respectively.

The A-4 alternative, which is found in the first place, is the closest alternative to the sea route and is also located on the strategic road connecting the Black Sea region, which is the northern region of the country, and the Marmara region, which is the heart of the country.

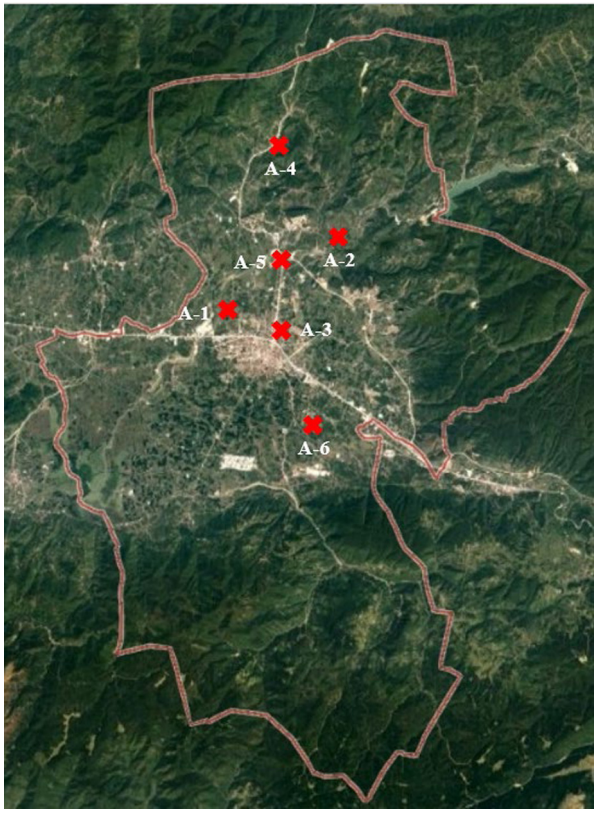


Fig. 3. Alternative locations for pharmaceutical warehouse.

Especially since it is located at the connection point with other regions, that puts it at a critical point as a location and thus ensures lower transportation costs. It also appears as the farthest alternative location from the city center, which also provides comfort in terms of traffic complexity. This location, which is determined in the first place, is the alternative that can provide the lowest cost in terms of initial investment costs due to its distance from the city center. It is quite easy to reach the designated location, there is a two-way road and there is no traffic congestion as mentioned. This alternative is also located close to the villages and surrounding settlements, which has a positive effect in terms of finding workers and supporting employment. In terms of all the criteria considered in this paper, it seems quite reasonable to determine this location alternative in the first place.

4. Robustness analysis

In MCDM problems, various analyses are often used to search for the robustness of the proposed methodology which are sensitivity analysis, validity analysis and comparative analysis (Alkan and Kahraman, 2022; Celik and Gul, 2021; Gul and Ak, 2021; Haktanır and Kahraman, 2022; İlbahar et al., 2022; Karasan et al., 2022; Karaşan et al., 2021). Through these analyses, the results are tried to be verified and the changes in the outputs can be observed. Based on these aims, it is revealed a comprehensive robustness analysis that includes sensitivity analysis and comparative analyses. First, a detailed sensitivity analysis is conducted to verify the stability of the proposed methodology. Secondly, a validation analysis is carried out using the PF environment with the same methods, namely AHP and EDAS. Finally, a comparative analysis is conducted with the same criteria weight set which is determined by SF-AHP but alternatives are evaluated with the SF-VIKOR methodology to compare the results of SF-EDAS. The following sub-sections present the three-phase robustness analysis.

Table 12
Weights of the sub-criteria.

Sub-criteria	Sub-criteria weights for each expert			Final weights of criteria	
	Expert-1	Expert-2	Expert-3	Weight	Ranking
C11. Investment cost	0.236	0.278	0.330	0.077	2
C12. Operating cost	0.112	0.336	0.050	0.042	7
C13. Maintenance/insurance cost	0.023	0.141	0.026	0.015	26
C14. Storage cost	0.141	0.067	0.050	0.028	13
C15. Financial incentives	0.043	0.044	0.213	0.025	16
C16. Labor cost	0.087	0.044	0.117	0.024	17
C17. Transportation cost	0.358	0.091	0.213	0.071	4
C21. Available workforce	0.039	0.220	0.335	0.016	24
C22. Local government support	0.154	0.299	0.191	0.023	19
C23. Environmental impact	0.184	0.247	0.066	0.020	20
C24. Impact on traffic congestion	0.242	0.033	0.018	0.010	31
C25. Conformance to freight regulations	0.106	0.120	0.066	0.010	30
C26. Security	0.207	0.050	0.191	0.012	28
C27. Community acceptance	0.068	0.030	0.134	0.005	32
C31. Development rate	0.351	0.550	0.053	0.016	25
C32. Number of competitors in radius	0.391	0.280	0.274	0.019	22
C33. Parking area	0.089	0.046	0.112	0.005	33
C34. Future expansion	0.168	0.124	0.562	0.019	21
C41. Climate conditions	0.201	0.216	0.033	0.031	12
C42. Energy	0.391	0.437	0.368	0.090	1
C43. Telecommunication systems	0.308	0.130	0.368	0.072	3
C44. Topographical features	0.101	0.216	0.230	0.039	9
C51. Proximity to main roads	0.030	0.066	0.159	0.017	23
C52. Proximity to producers	0.254	0.064	0.055	0.034	11
C53. Proximity to multimodal transport	0.097	0.174	0.159	0.026	14
C54. Proximity to potential markets	0.187	0.389	0.375	0.056	5
C55. Proximity to suppliers	0.304	0.217	0.126	0.047	6
C56. Proximity to opponents	0.129	0.091	0.126	0.026	15
C61. Location resistance	0.057	0.392	0.176	0.024	18
C62. Disaster free location	0.326	0.285	0.342	0.041	8
C63. Stock holding capacity	0.110	0.070	0.071	0.010	29
C64. Resource availability	0.349	0.172	0.342	0.039	10
C65. Movement flexibility	0.157	0.081	0.071	0.013	27

4.1. Sensitivity analysis

A sensitivity analysis is performed to show and discuss the changes in the proposed novel integrated methodology results when some parameters are altered. For this purpose, the weights of experts are changed between two experts while the other ones remain the same. That is, the Expert-1 weight is replaced subsequently with the weights of Expert-2 and Expert-3, while the remaining one is constant. Then, the Expert-2 and Expert-3 weights are changed and go on. In the last scenario, all expert weights are assumed to be equal. Each scenario is detailed in Table 17.

The sub-criteria weights are aggregated and recalculated according to adjusted expert weights. Thus, the sensitivity of the proposed methodology against the changes in expert weights is analyzed. In this way, changes in the alternative rankings can be seen, and these results help decision-makers in determining priorities and alternative evaluations by making it easier to analyze the process. The results of sensitivity analysis can be seen in Fig. 4 with the final scores of each alternative.

As can be seen in Fig. 3, the best alternative is the same for all scenarios. So it can be said that A-3 is the best alternative for the evaluated problem for different expert weights and the stability of the proposed methodology is revealed.

4.2. Validation analysis

A validation analysis is performed for the proposed integrated SF sets based MCDM methodology used in the pharmaceutical warehouse location selection problem to evaluate its reliability and validity. The effect of the change for SF sets on the results is investigated in this validation analysis. The results are compared, and the validation of the proposed methodology is discussed. For this purpose, the problem is solved under pythagorean fuzzy (PF) environment with the same methods, namely AHP and EDAS. Firstly, PF-AHP is utilized to determine criteria weights, then alternative locations are evaluated by PF-EDAS. The steps of PF-AHP (Ayyildiz et al., 2021) integrated PF-EDAS (Göçer, 2022) methodology are presented below:

Step 1. The pairwise comparison matrix is constructed via linguistic terms (Ilbahar et al., 2018) given in Table 18.

Step 2. The differences matrix is constructed.

$$d_{ij_L} = {\mu_{ij_L}}^2 - {\upsilon_{ij_L}}^2 \tag{30}$$

$$d_{ij_U} = {\mu_{ij_U}}^2 - {\upsilon_{ij_U}}^2 \tag{31}$$

Step 3. The interval multiplicative matrix is determined.

$$s_{ij_L} = \sqrt{1000^{d_{ij_L}}} \tag{32}$$

$$s_{ij_U} = \sqrt{1000^{d_{ij_U}}} \tag{33}$$

Step 4. The indeterminacy value is calculated.

$$h_{ij} = 1 - \left({\mu_{ij_U}}^2 - {\mu_{ij_L}}^2\right) - \left({\upsilon_{ij_U}}^2 - {\upsilon_{ij_L}}^2\right) \tag{34}$$

Step 5. Unnormalized weights are computed.

$$t_{ij} = \left(\frac{s_{ij_L} + s_{ij_U}}{2}\right) h_{ij} \tag{35}$$

Step 6. The priority weights are determined.

$$w_i = \frac{\sum_{i=1}^{m} t_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{m} t_{ij}} \tag{36}$$

Table 13
Alternative evaluation matrix.

Sub-criteria	Type of criteria	A-1	A-2	A-3	A-4	A-5	A-6
C11. Investment cost	Cost	F	F	L	VL	VL	EH
C12. Operating cost	Cost	H	F	EL	VL	L	EH
C13. Maintenance/insurance cost	Cost	L	F	VL	F	H	VH
C14. Storage cost	Cost	H	VH	VH	L	H	VL
C15. Financial incentives	Benefit	H	F	F	H	F	VH
C16. Labor cost	Cost	L	L	H	L	H	VL
C17. Transportation cost	Cost	H	VH	VL	VH	VL	H
C21. Available workforce	Benefit	L	F	VH	F	VH	F
C22. Local government support	Benefit	VH	H	F	F	F	H
C23. Environmental impact	Cost	L	L	F	L	F	L
C24. Impact on traffic congestion	Cost	VL	VL	H	L	H	L
C25. Conformance to freight regulations	Benefit	F	F	L	F	L	F
C26. Security	Benefit	L	F	H	H	H	H
C27. Community acceptance	Benefit	VH	VH	F	VH	H	VH
C31. Development rate	Benefit	L	L	H	F	H	F
C32. Number of competitors in radius	Cost	VL	EL	H	EL	H	EL
C33. Parking area	Benefit	EH	VH	L	EH	VL	EH
C34. Future expansion	Benefit	VH	H	L	VH	L	VH
C41. Climate conditions	Benefit	H	F	VH	F	VH	F
C42. Energy	Benefit	F	F	H	H	H	VH
C43. Telecommunication systems	Benefit	L	L	H	F	H	F
C44. Topographical features	Benefit	F	L	H	F	H	H
C51. Distance to main roads	Cost	L	H	VL	VL	VL	H
C52. Distance to producers	Cost	H	VL	H	VL	H	F
C53. Distance to multimodal transport	Cost	F	F	F	F	F	F
C54. Distance to potential markets	Cost	F	F	L	F	L	F
C55. Distance to suppliers	Cost	F	VL	L	VL	F	L
C56. Distance to opponents	Benefit	VH	EH	EL	VH	VL	VL
C61. Location resistance	Benefit	L	H	F	H	F	F
C62. Disaster free location	Benefit	L	H	F	H	F	L
C63. Stock holding capacity	Benefit	F	F	EL	VL	L	EH
C64. Resource availability	Benefit	F	L	H	F	H	F
C65. Movement flexibility	Benefit	H	L	VL	H	VL	H

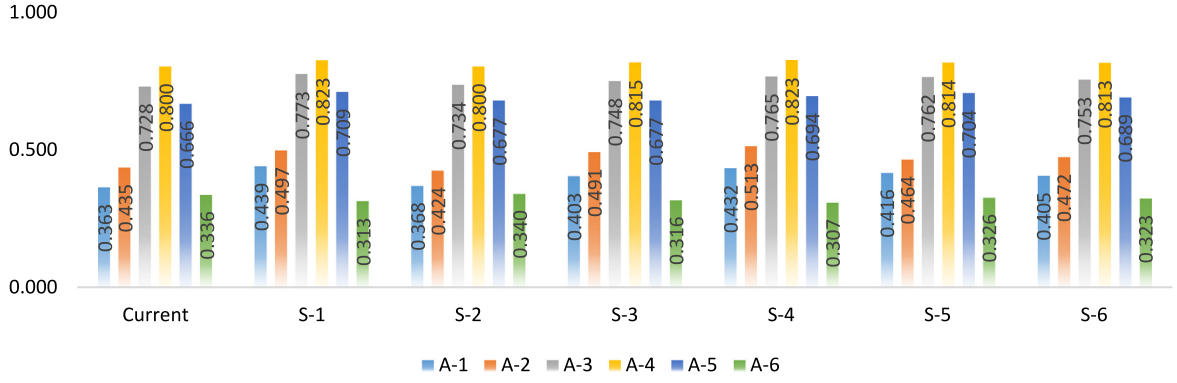


Fig. 4. The results of sensitivity analysis.

Step 7. The alternative evaluation matrix is established to evaluate alternatives according to criteria using linguistic terms using Table 19 (Göçer, 2022).

Step 8. The average solution based on all criteria is calculated.

$$\tilde{A}_j = \frac{1}{m} \oplus \tilde{x}_{ij} = \left(\sqrt{1 - \left(\prod_{i=1}^{m} \left(1 - \mu_{\tilde{x}_{ij}}^2 \right) \right)^{1/m}}, \left(\prod_{i=1}^{m} v_{\tilde{x}_{ij}}^2 \right)^{1/m} \right) \tag{37}$$

Step 9. $PDA = [\alpha_{ij}]_{m\times n}$ and $NDA = [\beta_{ij}]_{m\times n}$ are determined.

$$a_{ij} = \begin{cases} \dfrac{max\left\{1, e^{s(\tilde{x}_{ij}) - s(\tilde{A}_j)}\right\}}{e^{s(\tilde{A}_j)}} & C_j \text{ is benefit type criterion} \\ \dfrac{max\left\{1, e^{s(\tilde{A}_j) - s(\tilde{x}_{ij})}\right\}}{e^{s(\tilde{A}_j)}} & C_j \text{ is cost type criterion} \end{cases} \tag{38}$$

$$b_{ij} = \begin{cases} \dfrac{max\left\{1, e^{s(\tilde{A}_j) - s(\tilde{x}_{ij})}\right\}}{e^{s(\tilde{A}_j)}} & C_j \text{ is benefit type criterion} \\ \dfrac{max\left\{1, e^{s(\tilde{x}_{ij}) - s(\tilde{A}_j)}\right\}}{e^{s(\tilde{A}_j)}} & C_j \text{ is cost type criterion} \end{cases} \tag{39}$$

The score function $s\left(\tilde{P}\right)$ of a PF number is defined (Zhang and Xu, 2014):

$$S\left(\tilde{P}\right) = \left(\mu_{\tilde{P}}\right)^2 - \left(v_{\tilde{P}}\right)^2 \tag{40}$$

The remaining steps are the same as SF-EDAS.

To determine criteria weights, linguistic terms are converted to PF numbers via Table 18. The PF-AHP methodology is applied to consistent pairwise comparison matrices and by this way both main and sub-criteria weights are calculated. Table 20 presents the aggregated sub-criteria weights as the result of PF-AHP. In the aggregation process, the same expert weights are used. The criteria weights determined by

Table 14
Average solutions.

Sub-criteria	μ	v	π	$S^*(\tilde{A}_j)$
C11	0.642	0.508	0.356	0.838
C12	0.653	0.532	0.329	0.913
C13	0.631	0.547	0.365	0.772
C14	0.688	0.345	0.314	1.129
C15	0.679	0.436	0.332	1.042
C16	0.573	0.468	0.419	0.525
C17	0.681	0.355	0.293	1.139
C21	0.676	0.444	0.347	1.003
C22	0.679	0.399	0.332	1.048
C23	0.537	0.497	0.467	0.368
C24	0.561	0.516	0.403	0.505
C25	0.570	0.461	0.434	0.499
C26	0.660	0.455	0.350	0.928
C27	0.762	0.349	0.248	1.615
C31	0.612	0.482	0.400	0.672
C32	0.510	0.514	0.323	0.448
C33	0.812	0.267	0.217	1.977
C34	0.716	0.366	0.314	1.247
C41	0.701	0.408	0.314	1.175
C42	0.693	0.448	0.315	1.131
C43	0.612	0.482	0.400	0.672
C44	0.643	0.477	0.367	0.833
C51	0.550	0.497	0.384	0.498
C52	0.612	0.489	0.348	0.747
C53	0.600	0.458	0.400	0.637
C54	0.570	0.461	0.434	0.499
C55	0.511	0.528	0.439	0.333
C56	0.706	0.277	0.252	1.346
C61	0.625	0.432	0.383	0.749
C62	0.612	0.419	0.400	0.678
C63	0.636	0.558	0.346	0.812
C64	0.625	0.465	0.383	0.745
C65	0.598	0.443	0.367	0.682

SF-AHP are also presented in Table 20 to compare the existing results. In this table, W and R represent the final weight and final ranking, respectively.

As can be seen in Table 20, the most important criterion is determined as "C42. Energy" by both two methods. And the ten most important criteria are determined as the same in two methods with different orders. So, it can be said that the SF-AHP methodology produces robust criteria weights to evaluate alternative pharmaceutical warehouse location.

In the second stage of the validation analysis, PF-EDAS is applied to Table 13 and the most suitable location is analyzed. By applying the aforementioned steps of PF-EDAS, the following results given in Table 21 are obtained.

According to PF-EDAS results, the rankings of the candidate pharmaceutical warehouse locations with respect to the determined criteria are A-4 > A-3 > A-5> A-6 > A-2 > A-1 which agrees with the SF-EDAS for the first three ranks. The rankings of remaining alternatives have changed among themselves. The comparison of the alternative locations ranking according to the integrated AHP-EDAS methodology under PF and SF environments is presented in Fig. 5.

As can be seen in Fig. 5, the results of the integrated methodology for the different fuzzy environments are almost the same, and A-4 is the best candidate location to be a pharmaceutical warehouse with respect to six main and thirty-three sub-criteria. Therefore, the proposed AHP integrated EDAS methodology based on SF sets is determined as valid and effective to solve complex location selection or different MCDM problems.

4.3. Comparative analysis

A comparative analysis is performed to validate the effectiveness and robustness of the proposed hybrid methodology to determine the best location for a pharmaceutical warehouse. The same criteria weight set which is determined by SF-AHP is used and alternatives are evaluated with the SF-VIKOR methodology to compare the results of SF-EDAS. The steps of the SF-VIKOR methodology are explained below (Ayyildiz and Taskin, 2022)

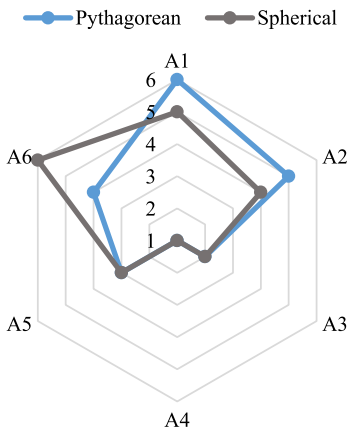


Fig. 5. Results of the validation analysis.

Step 1. The score value of each evaluation is calculated based on Definition 5.

Step 2. The positive ideal solution is determined for each criterion.

$$\tilde{X}^* = \left\{C_i, max_i \ < \text{Score}\left(X_{ij}\right) > | \ i = 1, 2 \dots m\right\} \text{ for the beneficial criterion} \tag{41}$$

$$\tilde{X}^* = \left\{C_i, min_i \ < \text{Score}\left(X_{ij}\right) > | \ i = 1, 2 \dots m\right\} \text{ for the cost criterion} \tag{42}$$

Step 3. The negative ideal solution is determined for each criterion.

$$\tilde{X}^- = \left\{C_i, min_i \ < \text{Score}\left(X_{ij}\right) > | \ i = 1, 2 \dots m\right\} \text{ for the beneficial criterion} \tag{43}$$

$$\tilde{X}^- = \left\{C_i, max_i \ < \text{Score}\left(X_{ij}\right) > | \ i = 1, 2 \dots m\right\} \text{ for the cost criterion} \tag{44}$$

Let m be the number of alternatives.

Step 4. S_i (the weighted total regret) and R_i (the weighted maximum regret) values are calculated.

$$S_i = \sum_{j=1}^{n} w_j \frac{\mathcal{D}\left(\tilde{X}_{ij}, \tilde{X}_j^*\right)}{\mathcal{D}\left(\tilde{X}_j^-, \tilde{X}_j^*\right)} \tag{45}$$

$$R_i = \max_j \left(w_j \frac{\mathcal{D}\left(\tilde{X}_{ij}, \tilde{X}_j^*\right)}{\mathcal{D}\left(\tilde{X}_j^-, \tilde{X}_j^*\right)} \right) \tag{46}$$

Step 5. Q_i values are computed for alternatives:

$$Q_i = v\frac{\left(S_i - S^+\right)}{\left(S^- - S^+\right)} + (1 - v)\frac{\left(R_i - R^+\right)}{\left(R^- - R^+\right)} \tag{47}$$

where $R^+ = \min_i R_i; R^- = \max_i R_i$ and $S^+ = \min_i S_i; S^- = \max_i S_i$. v represents the weight of strategy of maximum group utility and is generally determined as *0.5* (Kutlu Gündoğdu and Kahraman, 2019a).

Step 6. Alternatives are ranked by Q_i in ascending order.

After constructing the evaluation matrix for alternatives with experts, the positive and negative solutions are determined as given in Table 22.

S_i, R_i and Q_i values are calculated with respect to criteria weights and the alternatives are ordered as given in Table 23.

According to the obtained result by SF-VIKOR, A3 has the lowest Q_i score with 0.015 and determined as the best option. It is followed by

Table 15
PDA and NDA matrices.

	Type	PDA						NDA					
		A1	A2	A3	A4	A5	A6	A1	A2	A3	A4	A5	A6
C11	Cost	0.237	0.237	0.702	0.857	0.857	0.000	0.000	0.000	0.000	0.000	0.000	2.447
C12	Cost	0.000	0.299	1.000	0.869	0.726	0.000	0.325	0.000	0.000	0.000	0.000	2.164
C13	Cost	0.676	0.171	0.845	0.171	0.000	0.000	0.000	0.000	0.000	0.000	0.567	1.539
C14	Cost	0.000	0.000	0.000	0.779	0.000	0.894	0.072	0.736	0.736	0.000	0.072	0.000
C15	Benefit	0.161	0.000	0.000	0.161	0.000	0.881	0.000	0.386	0.386	0.000	0.386	0.000
C16	Cost	0.524	0.524	0.000	0.524	0.000	0.771	0.000	0.000	1.304	0.000	1.304	0.000
C17	Cost	0.000	0.000	0.895	0.000	0.895	0.000	0.062	0.721	0.000	0.721	0.000	0.062
C21	Benefit	0.000	0.000	0.955	0.000	0.955	0.000	0.751	0.362	0.000	0.362	0.000	0.362
C22	Benefit	0.869	0.154	0.000	0.000	0.000	0.154	0.000	0.000	0.390	0.390	0.390	0.000
C23	Cost	0.321	0.321	0.000	0.321	0.000	0.321	0.000	0.000	0.739	0.000	0.739	0.000
C24	Cost	0.763	0.763	0.000	0.505	0.000	0.505	0.000	0.000	1.394	0.000	1.394	0.000
C25	Benefit	0.283	0.283	0.000	0.283	0.000	0.283	0.000	0.000	0.499	0.000	0.499	0.000
C26	Benefit	0.000	0.000	0.304	0.304	0.304	0.304	0.731	0.310	0.000	0.000	0.000	0.000
C27	Benefit	0.213	0.213	0.000	0.213	0.000	0.213	0.000	0.000	0.604	0.000	0.251	0.000
C31	Benefit	0.000	0.000	0.802	0.000	0.802	0.000	0.628	0.628	0.000	0.047	0.000	0.047
C32	Cost	0.732	1.000	0.000	1.000	0.000	1.000	0.000	0.000	1.701	0.000	1.701	0.000
C33	Benefit	0.462	0.000	0.000	0.462	0.000	0.462	0.000	0.009	0.874	0.000	0.939	0.000
C34	Benefit	0.572	0.000	0.000	0.572	0.000	0.572	0.000	0.030	0.800	0.000	0.800	0.000
C41	Benefit	0.030	0.000	0.669	0.000	0.669	0.000	0.000	0.455	0.000	0.455	0.000	0.455
C42	Benefit	0.000	0.000	0.070	0.070	0.070	0.733	0.434	0.434	0.000	0.000	0.000	0.000
C43	Benefit	0.000	0.000	0.802	0.000	0.802	0.000	0.628	0.628	0.000	0.047	0.000	0.047
C44	Benefit	0.000	0.000	0.453	0.000	0.453	0.453	0.231	0.700	0.000	0.231	0.000	0.000
C51	Cost	0.498	0.000	0.759	0.759	0.759	0.000	0.000	1.429	0.000	0.000	0.000	1.429
C52	Cost	0.000	0.839	0.000	0.839	0.000	0.143	0.620	0.000	0.620	0.000	0.620	0.000
C53	Cost	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005	0.005	0.005	0.005	0.005
C54	Cost	0.000	0.000	0.499	0.000	0.499	0.000	0.283	0.283	0.000	0.283	0.000	0.283
C55	Cost	0.000	0.639	0.249	0.639	0.000	0.249	0.923	0.000	0.000	0.000	0.923	0.000
C56	Benefit	0.456	1.147	0.000	0.456	0.000	0.000	0.000	0.000	1.000	0.000	0.911	0.911
C61	Benefit	0.000	0.615	0.000	0.615	0.000	0.000	0.666	0.000	0.146	0.000	0.146	0.146
C62	Benefit	0.000	0.785	0.000	0.785	0.000	0.000	0.631	0.000	0.056	0.000	0.056	0.631
C63	Benefit	0.000	0.000	0.000	0.000	0.000	2.560	0.212	0.212	1.000	0.852	0.692	0.000
C64	Benefit	0.000	0.000	0.625	0.000	0.625	0.000	0.141	0.664	0.000	0.141	0.000	0.141
C65	Benefit	0.774	0.000	0.000	0.774	0.000	0.774	0.000	0.633	0.824	0.000	0.824	0.000

Table 16
The results of SF-EDAS application.

	A1	A2	A3	A4	A5	A6
$P_i^{(+)}$	0.140	0.221	0.382	0.340	0.359	0.257
$N_i^{(-)}$	0.274	0.303	0.233	0.124	0.259	0.427
$nP_i^{(+)}$	0.367	0.578	1.000	0.889	0.938	0.671
$nN_i^{(-)}$	0.359	0.291	0.456	0.711	0.393	0.000
Score	0.363	0.435	0.728	0.800	0.666	0.336
Ranking	5	4	2	1	3	6

Table 17
The scenarios for sensitivity analysis.

Scenario	Weights		
	E-1	E-2	E-3
Current	0.45	0.2	0.35
S-1	0.2	0.45	0.35
S-2	0.35	0.2	0.45
S-3	0.45	0.35	0.2
S-4	0.35	0.45	0.2
S-5	0.2	0.35	0.4
S-6	0.33	0.33	0.33

A5 and A4 with scores of 0.038 and 0.220, respectively. These three alternatives are determined as the best three alternatives according to the result of SF-EDAS application in a different ranking. Fig. 6 compares the results of SF-EDAS and SF-VIKOR.

The ranking order of alternatives by SF-VIKOR is similar to the result of the SF-EDAS as can be seen in Fig. 4. The ranking of alternatives is not a considerable change, although the ranking methodology is altered. According to the comparative analysis, the result of the proposed hybrid methodology is consistent with SF-VIKOR which is also one of the most popular MCDM methodologies.

Table 18
Scale for the PF-AHP evaluations.

Linguistic terms	Pythagorean fuzzy numbers			
	μ_L	μ_U	υ_L	υ_u
Certainly Low Importance — CLI	0.00	0.00	0.90	1.00
Very Low Importance — VLI	0.10	0.2	0.8	0.9
Low Importance — LI	0.20	0.35	0.65	0.8
Below Average Importance -BAI	0.35	0.45	0.55	0.65
Equal Importance — EI	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	0.80	0.20	0.35
Very High Importance — VHI	0.80	0.90	0.10	0.20
Certainly High Importance — CHI	0.90	1.00	0.00	0.00

Table 19
Scale for the PF-EDAS evaluations.

Linguistic terms	Pythagorean fuzzy numbers	
	μ	υ
Extremely Low — EL	0.05	0.95
Very Low — VL	0.15	0.85
Low — L	0.25	0.75
Fair — F	0.50	0.50
High — H	0.75	0.25
Very High — VH	0.85	0.15
Extremely High — EH	0.95	0.05

5. Conclusion and future directions

The choice of pharmaceutical warehouse location stands out as one of the issues that should be addressed as a priority. However, in addressing this problem, pandemic conditions should be taken into account, along with the details of the storage, transportation and

Table 20
Sub-criteria weights comparison for PF-AHP and SF-AHP.

Sub-criteria	PF-AHP		SF-AHP		Sub-criteria	PF-AHP		SF-AHP	
	W	*R*	*W*	*R*		*W*	*R*	*W*	*R*
C11. Investment cost	0.078	4	0.077	2	C41. Climate conditions	0.030	11	0.031	12
C12. Operating cost	0.041	7	0.042	7	C42. Energy	0.098	1	0.090	1
C13. Maintenance/insurance cost	0.013	26	0.015	26	C43. Telecommunication systems	0.095	2	0.072	3
C14. Storage cost	0.028	12	0.028	13	C44. Topographical features	0.036	9	0.039	9
C15. Financial incentives	0.026	13	0.025	16	C51. Prox. to main roads	0.017	21	0.017	23
C16. Labor cost	0.020	19	0.024	17	C52. Prox. to producers	0.023	17	0.034	11
C17. Transportation cost	0.087	3	0.071	4	C53. Prox. to multimodal transport	0.024	15	0.026	14
C21. Available workforce	0.015	24	0.016	24	C54. Prox. to potential markets	0.062	5	0.056	5
C22. Government support	0.021	18	0.023	19	C55. Proximity to suppliers	0.051	6	0.047	6
C23. Environmental impact	0.015	25	0.020	20	C56. Proximity to opponents	0.025	14	0.026	15
C24. Impact on traffic cong.	0.009	30	0.010	31	C61. Location resistance	0.023	16	0.024	18
C25. Conformance to freight reg.	0.008	31	0.010	30	C62. Disaster free location	0.038	8	0.041	8
C26. Security	0.009	29	0.012	28	C63. Stock holding capacity	0.010	28	0.010	29
C27. Community acceptance	0.004	32	0.005	32	C64. Resource availability	0.030	10	0.039	10
C31. Development rate	0.016	23	0.016	25	C65. Movement flexibility	0.011	27	0.013	27
C32. Number of competitors	0.018	20	0.019	22					
C33. Parking area	0.003	33	0.005	33					
C34. Future expansion	0.016	22	0.019	21					

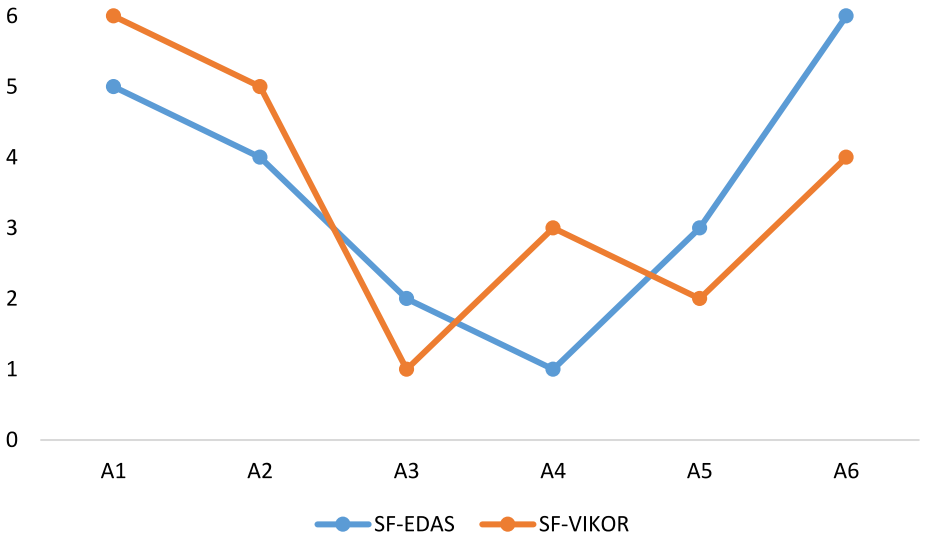


Fig. 6. The rankings of the alternatives for both SF-EDAS and SF-VIKOR.

Table 21
The results of PF-EDAS application.

	A1	A2	A3	A4	A5	A6
$P_i^{(+)}$	0.863	0.957	1.119	1.122	1.068	0.919
$N_i^{(-)}$	0.968	0.983	0.910	0.824	0.894	0.925
$nP_i^{(+)}$	0.769	0.852	0.997	1.000	0.952	0.819
$nN_i^{(-)}$	0.014	0.000	0.074	0.162	0.090	0.059
Score	0.392	0.426	0.535	0.581	0.521	0.439
Ranking	6	5	2	1	3	4

arrangement of drugs. Since the warehouse location problem is a long-term strategic decision, it is a decision-making process that requires careful analysis and incorporation of as many factors as possible into the decision process. At this point, along with the criteria whose numerical values can be obtained for the warehouse location selection problem, it is necessary to take into account the effect of linguistically expressive criteria on the decision process. In addition, the fact that some criteria may be in conflict with each other forces the problem to be analyzed in detail with all the criteria expressed linguistically and numerously. The presence of multiple and conflicting criteria in a decision analysis makes it appropriate to use MCDM methodologies. The complexity of warehouse location selection problems involving real-life analysis is an important factor that should be included in the decision-making process. Uncertainty in the decision process and hesitations in the evaluations cause difficulties in determining the weights of the evaluation criteria and criterion-alternative scores, and it necessitates the use of linguistic variables in the decision-making process. Fuzzy logic enables the linguistically evaluated criteria and alternatives to be converted into numerical values so that they can be used in analytical methods.

Eventually, this study proposes a hybrid fuzzy decision-making methodology for the evaluation of alternative locations of pharmacy warehouses in order to ensure the most effective flow of the health supply chain in pandemic conditions. In this paper, the AHP method, which is one of the most frequently used approaches to determine criteria weights in MCDM problems, is applied under the SF environment to reflect the uncertainty in the best way for selection of appropriate pharmaceutical warehouse location. In order to rank the alternatives, EDAS, which is a method that has been used frequently in the MCDM literature has been applied in the SF framework. When the results obtained for the weights of criteria are examined, the most important criterion is determined as “energy” with an importance degree of 0.090. The following criterion is found as “investment cost” with an importance degree of 0.077. The cost of transportation appears as a criterion whose

Table 22
The positive ideal and negative ideal solutions.

	C11			C12			C13			C14			C15			C16		
$\tilde{X}^*$	0.4	0.6	0.4	0.3	0.7	0.3	0.4	0.6	0.4	0.4	0.6	0.4	0.8	0.2	0.2	0.4	0.6	0.4
$\tilde{X}^-$	0.9	0.1	0.1	0.9	0.1	0.1	0.8	0.2	0.2	0.8	0.2	0.2	0.6	0.4	0.4	0.7	0.3	0.3
	C17			C21			C22			C23			C24			C25		
$\tilde{X}^*$	0.4	0.6	0.4	0.8	0.2	0.2	0.8	0.2	0.2	0.5	0.5	0.5	0.4	0.6	0.4	0.6	0.4	0.4
$\tilde{X}^-$	0.8	0.2	0.2	0.5	0.5	0.5	0.6	0.4	0.4	0.6	0.4	0.4	0.7	0.3	0.3	0.5	0.5	0.5
	C27			C27			C31			C32			C33			C34		
$\tilde{X}^*$	0.7	0.3	0.3	0.8	0.2	0.2	0.7	0.3	0.3	0.3	0.7	0.3	0.9	0.1	0.1	0.8	0.2	0.2
$\tilde{X}^-$	0.5	0.5	0.5	0.6	0.4	0.4	0.5	0.5	0.5	0.7	0.3	0.3	0.4	0.6	0.4	0.5	0.5	0.5
	C41			C42			C43			C44			C51			C52		
$\tilde{X}^*$	0.8	0.2	0.2	0.8	0.2	0.2	0.7	0.3	0.3	0.7	0.3	0.3	0.4	0.6	0.4	0.4	0.6	0.4
$\tilde{X}^-$	0.6	0.4	0.4	0.6	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.7	0.3	0.3	0.7	0.3	0.3
	C53			C54			C55			C56			C61			C62		
$\tilde{X}^*$	0.6	0.4	0.4	0.5	0.5	0.5	0.4	0.6	0.4	0.9	0.1	0.1	0.7	0.3	0.3	0.7	0.3	0.3
$\tilde{X}^-$	0.6	0.4	0.4	0.6	0.4	0.4	0.6	0.4	0.4	0.3	0.7	0.3	0.5	0.5	0.5	0.5	0.5	0.5
	C63			C64			C65											
$\tilde{X}^*$	0.9	0.1	0.1	0.7	0.3	0.3	0.7	0.3	0.3									
$\tilde{X}^-$	0.3	0.7	0.3	0.5	0.5	0.5	0.4	0.6	0.4									

Table 23
The values of S_i, R_i and Q_i rankings.

Alternative	S_i	R_i	Q_i	Rank
A1	0.637	0.091	1.000	6
A2	0.606	0.091	0.940	5
A3	0.389	0.045	0.015	1
A4	0.381	0.065	0.220	3
A5	0.400	0.045	0.038	2
A6	0.500	0.077	0.581	4

importance is calculated at higher ranks with an importance degree of 0.071. As can be seen, even during the pandemic period, cost-based criteria have emerged as more important factors in the selection of pharmaceutical warehouse best location with the total weight percent as %28,2. The criteria under the "Social" class are calculated as the group of criteria with the least importance. At this point, it can be interpreted that critical effects will not be encountered in the decision process regarding finding employees for the pharmaceutical warehouse to be established, the acceptance of this facility by the society, its environmental effects and its effects on traffic, and that there will be no issue in this sense for the regions considered as alternatives. Besides, when the four most important criteria are compared with the other criteria, it is seen that they have total importance of 30%. At this point, it can be interpreted that 12% of the criteria are the factors that affect the results the most in this decision-making problem.

In the fuzzy multi-criteria analysis is carried out for the city of Düzce, which is located in the north of Turkey and is a bridge with other regions and the heart of the country, the Marmara Region, it is seen that the most suitable alternative is the region marked with A-4 on the map in Fig. 2 with 0.800 score value and this alternative is followed by the alternatives of A-3 and A-5 with the score values of 0.728 and 0.666, respectively. When a detailed examination is conducted in terms of the criteria considered and the results are discussed with the experts, it can be interpreted that the use of the first-ranked area as a pharmaceutical warehouse location is a reasonable result, due to its affordable cost, ease of transportation and supporting the region in terms of employment.

Detailed robustness analysis is carried out to verify the stability and applicability of the proposed methodology. Firstly, a sensitivity analysis is also conducted in order to observe the effect of the parameters on the results in the proposed decision process. According to the sensitivity analysis results, it is determined that the best alternative remained the same for all scenarios for different weights of experts. Thus, it can be claimed that the proposed method is stable to changes in decision parameters. A validity analysis is also conducted to compare the results of the proposed methodology. Finally, a comparative analysis is carried out and it is revealed that there is no major change in the results, which indicates that the obtained ranking is consistent.

This paper proposes AHP-EDAS hybrid methodology under SF environment which is proved to be successful in handling fuzziness and indeterminacy in complex decision-making problems. The main contributions of this study to the current literature and application area can be summarized as follows: (1) The key factors to evaluate candidate pharmaceutical warehouse locations for the post-COVID-19 era are determined and classified under main titles; (2) AHP is integrated to EDAS methodology under SF environment to make more detailed and comprehensive multi-criteria analysis considering the indeterminacy and fuzziness in information; (3) The most important criteria are determined with respect to expert opinions via SF-AHP; (4) A real-life case for Duzce, Turkey is performed and the applicability and reliability of the proposed integrated MCDM methodology is shown with three-phase robustness analysis; (5) Six alternatives are analyzed with respect to thirty-three criteria and the most appropriate one is specified via SF-EDAS; (6) The proposed integrated methodology can be used a helpful guide for healthcare organizations to develop and improve their strategies considering the pharmaceutical supply chain.

As future suggestions, different MCDM approaches can be applied to compare the results, or proposed fuzzy-based decision-making methodology can be conducted for different and/or larger regions.

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CRediT authorship contribution statement

Melike Erdogan: Methodology, Supervision, Validation, Writing – review & editing. **Ertugrul Ayyildiz:** Data correction, Writing – original draft, Methodology, Data collection, Application.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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