Evaluation of the pharmaceutical distribution and warehousing companies through an integrated Fermatean fuzzy entropy-WASPAS approach

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Abstract

Purpose – Pharmaceutical supply chains (PSCs) need a well-operating and faultless logistics system to successfully store and distribute their medicines. Hospitals, health institutes, and pharmacies must maintain extra stock to respond requirements of the patients. Nevertheless, there is an inverse correlation between the level of medicine stock and logistics service level. The high stock level held by health institutions indicates that we have not sufficiently excellent logistics systems presently. As such, selecting appropriate logistics service providers (drug distributors) is crucial and strategic for PSCs. However, this is difficult for decision-makers, as highly complex situations and conflicting criteria influence such evaluation processes. So, a robust, applicable, and strong methodological frame is required to solve these decision-making problems.

Design/methodology/approach – To achieve this challenging issue, the authors develop and apply an integrated entropy-WASPAS methodology with Fermatean fuzzy sets for the first time in the literature. The evaluation process takes place in two stages, as in traditional multi-criteria problems. In the first stage, the importance levels of the criteria are determined by the FF-entropy method. Afterwards, the FF-WASPAS approach ranks the alternatives.

Findings – The feasibility of the proposed model is also supported by a case study where six companies are evaluated comprehensively regarding ten criteria. Herewith, total warehouse capacity, number of refrigerated vehicles, and personnel are the top three criteria that significantly influence the evaluation of pharmaceutical

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distribution and warehousing companies. Further, a comprehensive sensitivity analysis proves the robustness and effectiveness of the proposed approach.

Practical implications – The proposed multi-attribute decision model quantitatively aids managers in selecting logistics service providers considering imprecisions in the multi-criteria decision-making process.

Originality/value – A new model has been developed to present a sound mathematical model for selecting logistics service providers consisting of Fermatean fuzzy entropy and WASPAS methods. The paper's main contribution is presenting a comprehensive and more robust model for the *ex ante* evaluation and ranking of providers.

Keywords Pharmaceutical distribution and warehousing, Pharmaceutical supply chains, Supply chain management, Fermatean fuzzy sets, Fermatean entropy, Fermatean WASPAS

Paper type Research paper

1. Introduction

A pharmaceutical supply chain (PSC) is a highly complex system that supplies raw materials from suppliers, manufactures prescription drugs, and delivers them from drugmakers to patients, hospitals, and pharmacies. Because drugs are related to illness, stable and continuous demands for these pharmaceutical products are out of the question in the health industry. Varying and irregular demands are one reason for the complexity of the PSCs; also, requirements such as transporting and warehousing these products in temperature-controlled systems called the cold chain cause more increase in the pharmaceutical industry supply complexities chains. Besides, since many drugs are perishable, logistics operations have a high risk. Minor mistakes may be tolerable in different supply chains, such as textile and supply chains for electronic products and automotive chains, but they may cause irreparable results in the PSCs that directly affect human health. Misdeliveries or drug spoilage resulting from the logistics operations, which do not manage well, may affect patients' satisfaction waiting for the right and proper health services and health professionals; it may also cause a loss of prestige for drugmakers. More importantly, it may disrupt the recovery process of patients and may cause severe results such as death, becoming permanently disabled, and bedbound for patients.

Drug distributing and warehousing companies are the PSC's most crucial and determinative actors. Thus, World Health Organization (WHO) identified some rules for pharmaceutical distribution companies' responsibilities as: "According to the international body on health, drug distributors have to provide excellent logistics services such as collecting, distributing, storing, and dispatch medicines in optimal conditions to the patients, pharmacies, hospitals, and other health institutions" (WHO, 2010). Drug distributors have many strategic roles and functions, such as collecting too many drugs from drug makers, storing these products in proper conditions, complying with requirements, and dispatching these pharmaceutical products as single or consolidated quickly to the patients, hospitals, and pharmacies. Hence, they can carry out these complicated logistics operations, which one or more drug makers cannot conduct with lower logistics costs and higher efficiency and performance levels. Drug distribution companies can collect and distribute over 100 million different pharmaceutical products only in the USA. The cost advantage of this industry to the health industry is between 33 and 58 billion dollars annually (IFPMA, 2021). In contrast, drug distributors delivered pills and medicine by 2,210,257,978 boxes last year to Turkish patients, hospitals, and pharmacies (Bağcı and Atasever, 2020).

Besides, the global pandemic, COVID-19, caused severe changes and transformations in our daily lives and has more clearly indicated the strategic roles these companies played in the PSCs and their significance. Especially, requirements for susceptible and fragile cold chains, which have to be managed at a low-temperature level for vaccines produced by some drugmakers, have shown that the drug distributors are the essential actors of the supply chains once more. Especially, vaccines need different storage temperatures of 2–8 °C for freeze-sensitive vaccines and −25 to −15 °C for heat-sensitive vaccines (Ecer, 2022). A minor mistake may cause spoilage of the vaccines and become unusable (Sudarmin and Ardi, 2020). Hence, drug distributors should manage a complicated cold chain with different good practices identified for each medicine. Handling this kind of logistics system is complex. The strategic contributions of drug distributing and warehousing companies to the PSCs depend on a well-designed logistics system that is well-operated at an excellent level. Thus, these companies need a well-operated logistics system using advanced and high technology to provide a high-quality service to all health industry stakeholders. Mainly, storage of millions of medicines in the most appropriate conditions, making order picking and dispatching these drugs quickly in a time of need without spoilage depends on well-operating the logistics system at an excellent level.

Consequently, selecting drug distributors with advanced logistics capabilities can reduce logistics costs on a vast scale and help create and manage agile, flexible, and efficient supply chains. Hence, drug distribution and warehousing company selection is a strategic decision for the PSCs. On the other hand, when searching the literature on the PSCs, we noticed surprising and severe gaps in the existing literature. Firstly, the number of previous papers focusing on the PSCs is scarce, and most of them dealt with the risks in the supply chains (El Mokrini *et al.*, 2018; Enyinda *et al.*, 2009, 2010; Nelson *et al.*, 2006; MacInnis, 2006; Jamet, 2004; Thampi *et al.*, 2016; Sudarmin and Ardi, 2020; Ali *et al.*, 2021; Stojanović and Puška, 2021). Moreover, they did not focus on physical risks relating to the transportation and warehousing of the medicines. Additionally, some examined the drug supply chains from a general viewpoint. In this manner, selecting proper drug distributors may contribute to constructing a well-operated, flexible, agile, and efficient supply chain and reduce operational risks on a vast scale.

Considering the above, this paper focuses on selecting and evaluating pharmaceutical distribution companies, a sensitive and crucial issue, by considering the literature's existing research and methodological gaps. In this perspective, ten selection criteria highlighted by WHO are preferred for the analysis. Applying the multi-criteria model combined with Entropy and WASPAS (Weighted Aggregated Sum Product Assessment) under the Fermatean fuzzy sets (FFSs), six drug distributing and warehousing companies in Turkey have been evaluated concerning these criteria in the current paper. The contributions and managerial implications of the current paper to the literature can be summarized as follows.

- The current paper examines drug distribution processes having crucial impacts on the stakeholders of PSCs, such as drugmakers, suppliers, retailers, health institutions, and societies. Further, it proposes a powerful, robust, consistent model for evaluating drug distribution companies.
- In the present study, the selection of proper pharmaceutical distribution companies has been examined as a strategic and long-term decision for drug supply chains since they have strategic importance and play critical roles in the supply chains. Thus, the selection process for these companies has been handled as an extraordinary assessment process. Considering the WHO's criteria, the factors concerning drug distributing companies' performance and logistics abilities have been picked out and used.
- This paper indicates pharmaceutical product distributors' strategic roles and importance and highlights the contribution to the performance of the PSCs.
- We focused on the contributions and strategic impacts of drug distributors on the performance of the supply chains, and we avoided a general assessment for the entire PSC to obtain more reasonable and realistic results.
- The research process carried out with the professionals shows a strong motivation in the industry for using a robust, practical, and helpful decision-making tool that can overcome complex ambiguities to solve this decision-making problem. Keeping in mind these requirements, we propose an effective and stable multi-criteria decision-making (MCDM) framework based on FFSs in the current paper.

Finally, the current paper has many valuable theoretical contributions to the existing literature and managerial implications. These theoretical contributions of the proposed model are: (1) the proposed MCDM framework is based on the FFS and can capture and process uncertainties better than the traditional techniques. Whereas it eliminates many deficiencies of the Intuitionistic and the Pythagorean fuzzy sets, it also combines the advantages of these sets (Senapati and Yager, 2020; Mukhametzyanov, 2021), (2) the other membership grades in the aggregated value affect the other grades even if the belongingness degree (BD) of any alternative is zero; also, there is a relationship between the BD and the non-belongingness degree (NBD) of an alternative (Shahzadi *et al.*, 2021; Kushwaha *et al.*, 2020), and (3) the proposed model extended with the help of the FFSs can help to eliminate excessive and undesirable evaluations performed by decision-makers. Thus, it provides a more flexible and stable evaluation environment. Consequently, this advantage makes it more powerful and reliable for practitioners and decision-makers.

Depending on these advantages, the proposed Entropy and WASPAS combinations based on FFSs can capture and process many complex uncertainties in an evaluation process for selecting a pharmaceutical service provider by practitioners and decision-makers. The following section presents a literature review on pharmaceutical distribution and warehousing companies and drug supply chains. In Section 3, the proposed FF-MCDM framework and its basic algorithm are presented comprehensively. In Section 4, based on the conducted research, the proposed MCDM model is implemented for evaluating the selection of pharmaceutical product distributors in the field of the health industry to demonstrate its applicability. Moreover, the validation of the results is tested with the help of a sensitivity analysis. Section 5 summarizes and discusses the obtained findings. The study is concluded, and the limitations are identified in the penultimate section. Last but not least, Section 7 concludes the work, and recommendations for authors who carry out research on this issue in the future are indicated there.

2. Literature review

Sbai *et al.* (2021) asserted that drug supply chains should have a well-structured inventory management system to develop their strategic abilities. They examined inventory systems with the help of the Analytic Hierarchy Process (AHP) technique. An inventory management system is a crucial and indispensable part of the logistics system, but it is not a single factor in improving operational performance. Also, the drug distributors are logistics service suppliers for the PSCs (Ganguly *et al.*, 2019). However, the selection of pharmaceutical distribution and warehousing companies cannot be accepted as an ordinary business when the vital importance and impacts of the drug distributors are considered. In that sense, drug distribution companies are deserving of particular concern and detailed evaluation. More importantly, some papers (Yazdi *et al.*, 2021) identified a set of criteria to measure the performance of the drug makers. However, the performance of PSCs depends on the logistics abilities and performance of the drug distribution companies than other supply chain actors.

Similarly, Kumar *et al.* (2015) focused on the performance of the drug supply chains with a general viewpoint without considering the strategic importance of the drug distribution firms. Also, some studies dealt with medical device selection and highlighted the significance of selecting appropriate devices to provide high efficiency for health institutes (Emec *et al.*, 2019). Although this paper is exciting, it is not related to the subject of the current paper. Vishwakarma (2018) determined a set of factors for product and service quality provided by drug makers. This study did not consider the drug distribution companies' particular importance, and the paper's main focal point is the quality of pharmaceutical products. Unlike other previous papers existing in the literature, Tavana *et al.* (2015) examined the financial performance of the drug makers and did not consider the operational and logistics performance of the companies.

Furthermore, some papers discussed whether the selection of drug distributors could be evaluated as outsourcing (El Mokrini *et al.*, 2018); they also evaluated the pharmaceutical distribution companies as the selection of logistics service providers. The answer to this question is quite simple: it is not easy to organize and carry out these complicated logistics operations, such as collecting millions of medicines from thousands of manufacturers and distributing them to hundreds of thousands of points for drugmakers. In addition, each type of medicine needs a different cold temperature condition during logistics operations, and drug distributors must provide these conditions for each drug unit. It is impossible to construct a comprehensive and specific logistics system by pharmacies (Yadav *et al.*, 2015) as they have no sufficient financial power and operational abilities. Hence, they cannot organize these operations by constructing advanced logistics systems.

A study carried out by Nag and Helal (2016) is the closest to the current paper regarding the aims of both studies. However, this paper evaluated the selection of drug distributors as ordinary logistic service providers and did not consider these actors' particular and strategic importance in the supply chains. Also, the proposed MCDM framework has some structural problems, limitations, and drawbacks. For example, the suggested technique suffers from the rank reversal problem. Moreover, any change (i.e., adding or removing a criterion or decision alternative, changing the values in the indexes) may cause changes in the ranking results dramatically. Because of that, the reliability of the technique is weak, and decision-makers cannot ensure the accuracy and reasonability of the results.

Studies related to pharmaceutical distribution and warehousing companies and drug supply chains are presented in Table 1.

We noticed surprising and severe gaps in the existing literature when we reviewed the literature in detail. These gaps are sourced from some reasons as follows. First, strategic impacts and contributions of the drug distribution and warehousing companies on the performance and effectiveness of the PSCs have not been examined sufficiently by previous works in the literature. Moreover, these companies are the most crucial and determinative actors of the supply chains, but the selection of these companies was evaluated as the selection of ordinary logistics service providers by previous studies. Consequently, these studies did not consider the extraordinary impacts of these drug distributing companies on the supply chains. Second, however, the WHO has identified a set of criteria that is quite definite and clear for evaluating the performance of drug distribution and warehousing companies. However, only some of these criteria identified by this international body were considered in the previous studies. The third gap is related to the techniques proposed by previous studies in the literature. These papers generally proposed AHP, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations), ARAS (Additive Ratio Assessment), fuzzy AHP, fuzzy TOPSIS, DEA (Data Envelopment Analysis), DEMATEL (Decision Making Trial and Evaluation Laboratory), and VIKOR (Višekriterijumsko Kompromisno Rangiranje) (Kastratović *et al.*, 2017). Although these MCDM frameworks are popular MCDM techniques, they have many limitations and drawbacks.

AHP and TOPSIS approaches suffer from rank reversal problems (García-Cascales and Lamata, 2012; Olson, 1988; Wang and Luo, 2009; Bozanic *et al.*, 2021; Pamucar *et al.*, 2021b). Overall ranking results may dramatically change if an alternative is added or eliminated. Thus, these techniques may not provide a reliable, robust, and effective decision-making environment, as the accuracy of the results is not definite. Besides, AHP requires a consistency check to compute the consistency ratio and many comparisons and computations to reach the ranking results. In addition, DEA can be applied to measure the efficiency of an option, and it provides results such as efficient or inefficient for an option (Jordá *et al.*, 2012; Ali and Lerme, 1997). Hence, it cannot allow for comparison among alternatives because it does not present intermediate values. Also, the VIKOR technique

Table 1.
Outline the relevant research on pharmaceutical warehouses and drug supply chains

Author(s)	Benchmark	Application(s)
Goodarzian *et al.* (2020)	Novel robust fuzzy programming method, multi-objective metaheuristic algorithms	Presenting multi-objective PSCs network
Martins *et al.* (2017)	Mixed-integer linear programming, discrete event simulation model	Addressing the pharmaceutical wholesalers' network redesign problem
Jacobo-Cabrera *et al.* (2018)	Integrating capacitated vehicle routing problem model and the economic order quantity model	Proposing a decision model that integrates distribution within the supply and storage aspects of the insulin supply chain
Elazeem *et al.* (2019)	Autoregressive moving average model time series, neural networks	Proposing data warehouse framework for distribution system in pharmaceutical sector
Irwanto and Hasibuan (2018)	Center of gravity method	Determining the distribution center location for the pharmaceutical industry
Bruque-Camara *et al.* (2004)	Cluster analysis, ANOVA	Proposing organizational factors that explain the differences in terms of IT adoption for the pharmaceutical distribution sector
Izadi and Kimiagari (2014)	Genetic algorithm, Monte Carlo simulation	Distribution network design for pharmaceutical industry in Iran
Abbasi *et al.* (2021)	Credibility-based possibilistic programming	Designing a reliable supply chain network for third-party logistics providers in the pharmaceutical distribution industry
Campelo *et al.* (2019)	Instance size reduction algorithm, the mathematical programming-based decomposition approach	Analyzing consistent vehicle routing problems by considering service level agreements for the pharmaceutical distribution sector
Delfani *et al.* (2020)	Robust fuzzy optimization approach, red deer evolutionary algorithm	Analyzing multi-objective PSC network design problem
Zandieh *et al.* (2018)	Non-dominated sorting genetic algorithm	Designing a sustainable distribution network for the PSC in Iran
Abideen and Mohamad (2021)	Value stream mapping, discrete event simulation technique	Enable dynamic quantification and visualization of future state of pharmaceutical warehouse supply chain in Malaysia
El Mokrini *et al.* (2018)	AHP	Elaborating general approach to distribution network redesign for PSC in Morocco
Çelik Teker (2017)	AHP	Evaluating the selection process of third-party logistics service providers in the pharmaceutical industry

requires a compromise between the worst and best solutions. It is the main drawback of the technique (Kastratović *et al.*, 2017). It may also cause changes in the ranking results, indicating that this approach is not sufficiently resistant to the rank reversal problems. On the other hand, the WASPAS approach has higher reliability (Hashemkhani Zolfani *et al.*, 2013), as it is firmly against the rank reversal problem (Chakraborty and Zavadskas, 2014). In addition, it provides more reliable, robust, and accurate results with fewer computations than other frames. Hence, the WASPAS provides a more reliable, robust, and practical decision-making frame and can be applied to solve highly complicated decision-making problems.

Some authors preferred to use the fuzzy versions of the AHP and TOPSIS approaches. However, the classical version of fuzzy sets focuses only on membership function, and an element can be a member of a set or not. Many fuzzy numbers, such as interval type-2 fuzzy numbers, intuitionistic fuzzy numbers, neutrosophic fuzzy numbers, and Pythagorean fuzzy numbers, have been developed to better express uncertainty (Pamucar *et al.*, 2021a; Xing *et al.*, 2022; Ecer, 2020; Zavadskas *et al.*, 2020; Usama Baig *et al.*, 2022). However, many fuzzy sets cannot capture and process complicated uncertainties, as they overlook unpredictable and complex ambiguities. For example, difficulties with the sum and/or sum of the quadratic function degrees observed in applications involving the aforementioned fuzzy numbers motivated the researcher to conduct further research. FFS, developed by Senapati and Yager (2019a), currently provides significant advantages to researchers. In FFS, the sum of functions and the quadratic sum have no upper limit. For dealing with uncertainty in imprecise information, the FF set theory has proven to be one of the most potent fuzzy sets (Ayyildiz, 2022). Unlike most other fuzzy set approaches, FFS allows for independent determination of the degree of uncertainty. FFS gives decision-makers more flexibility by assigning parameters from a broader range. As a result, decision-makers can express their opinions on membership and non-membership depending on the facts. Because of their relaxed and modified conditions, FF numbers can be used to represent vague, reliable, and inaccurate assessment information.

Furthermore, the total of FFS membership and non-membership cannot exceed one. With this advantage, FFS gives decision-makers more freedom. Linguistic terms used by decision-makers for evaluation can be converted into mathematical expressions using FFS (Liu *et al.*, 2019a, 2019b, Garg *et al.*, 2020; Gül, 2021; Mishra *et al.*, 2021; Shahzadi *et al.*, 2021; Simic *et al.*, 2021a; Ayyildiz, 2022). Because of its advantages, FFS was selected for this study. On the other hand, Entropy was used to weight the criteria in the study, and WASPAS was used to rank the alternatives. Entropy was chosen because it reflects the irregularities and conflicts between the criteria. WASPAS provides more reliable, robust, and accurate results with fewer computations than other frames (Hashemkhani Zolfani *et al.*, 2013; Chakraborty and Zavadskas, 2014). Therefore, this paper combines the advantages of the FFS, Entropy, and WASPAS.

Thus, there are severe gaps in identifying the measures to improve drug distribution companies' abilities and performance to create a flexible, agile, and efficient PSC. Additionally, the previous studies did not sufficiently clear select suitable drug distributors. As a result, this paper can successfully cover the gaps highlighted.

3. Research methodology

This section demonstrates the proposed model and its basic algorithm consisting of five stages and nine implementation steps. The proposed FF model was applied to solve the highly critical decision-making problem in the health industry. Within this perspective, pharmaceutical distribution and warehousing companies will be evaluated using FF-Entropy and FF-WASPAS methods. FFSs should be described before moving on to the explanatory information about the methods. The proposed FF model and its basic algorithm are presented in Figure 1.

3.1 Preliminaries

Senapati and Yager (2019a) proposed the FFS as an extension of intuitionistic fuzzy sets (IFSs) and Pythagorean fuzzy sets (PFSs), providing a more general and flexible representation of uncertainty than these two sets. The $\alpha^3 + \beta^3 \leq 1$ equation cannot be fully met with IFS and PFS. FFSs, like IFSs and PFSs, include three critical components in their definitions. Degree of membership (α), degree of non-membership (β), and degree of uncertainty (π) are the three components. Some basic definitions could be given before getting into detail into FFS (Garg *et al.*, 2020; Keshavarz-Ghorabaee *et al.*, 2020; Senapati and Yager, 2019a, 2019b, 2020).

Definition 3.1. An FF set $\widetilde{\mathcal{R}}$ can be defined as Eq. (1), assuming X is a universe of discourse:

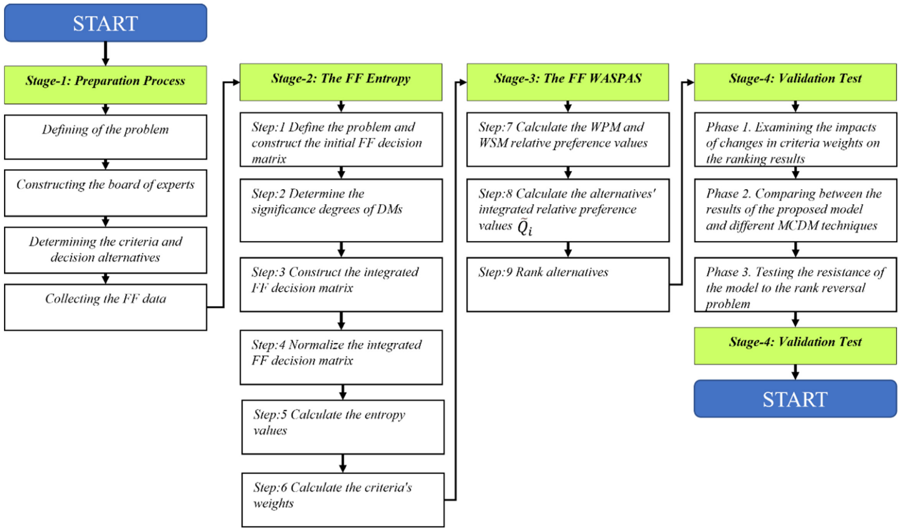
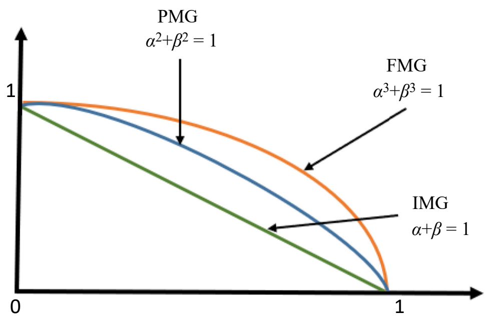


Figure 1.
The proposed integrated FF-MCDM framework and its basic algorithm

$$\widetilde{R} = \{\langle x, \alpha_{\mathcal{R}}(x), \beta_{\mathcal{R}}(x)\rangle : x \in X\} \tag{1}$$

For ease of representation, FFS will be called $\widetilde{R} = (\alpha_{\mathcal{R}}, \beta_{\mathcal{R}})$ in Eq. (1). The linguistic assessments in the FFS correspond to the membership and non-membership support values shown in $\alpha_{\mathcal{R}}$ and $\beta_{\mathcal{R}}$, respectively. Also, in Eq. (1) $\alpha_{\mathcal{R}}(x) : X \rightarrow [0,1]$, $\beta_{\mathcal{R}}(x) : X \rightarrow [0,1]$ and $0 \leq (\alpha_{\mathcal{R}}(x))^3 + (\beta_{\mathcal{R}}(x))^3 \leq 1$. The degree of uncertainty is expressed as $\pi_{\mathcal{R}}(x) = \sqrt[3]{1 - (\alpha_{\mathcal{R}}(x))^3 - (\beta_{\mathcal{R}}(x))^3}$. Figure 2 shows a visual comparison of IFS membership grades (IMGs), PFS membership grades (PMGs), and FFS membership grades (FMGs).

IMGs are in or below the curves of $\alpha + \beta \leq 1$, PMGs of $\alpha^2 + \beta^2 \leq 1$, and FMGs of $\alpha^3 + \beta^3 \leq 1$, as shown in Figure 2. Besides, as seen in Figure 2, FMGs provide a greater width



Note(s): Keshavarz-Ghorabaee *et al.*, 2020; Senapati & Yager, 2020

Figure 2.
Comparison of IMGs, PMGs, and FMGs spaces

definition than the other two fuzzy membership grades (Keshavarz-Ghorabaee *et al.*, 2020; Senapati and Yager, 2019a, 2020).

Definition 3.2. Eqs. (2)–(5) define operators in FFSs, where $\widetilde{R} = (\alpha_{\mathcal{R}}, \beta_{\mathcal{R}})$ and $\widetilde{\mathcal{S}} = (\alpha_S, \beta_S)$ are two FFS, and λ is a positive real number (Keshavarz-Ghorabaee *et al.*, 2020; Senapati and Yager, 2019a, 2020):

$$\widetilde{\mathcal{R}} \oplus \widetilde{\mathcal{S}} = \left(\sqrt[3]{\alpha_{\mathcal{R}}^3 + \alpha_S^3 - \alpha_{\mathcal{R}}^3 \alpha_S^3},\ \beta_{\mathcal{R}} \beta_S \right) \tag{2}$$

$$\widetilde{\mathcal{R}} \otimes \widetilde{\mathcal{S}} = \left(\alpha_{\mathcal{R}} \alpha_S,\ \sqrt[3]{\beta_{\mathcal{R}}^3 + \beta_S^3 - \beta_{\mathcal{R}}^3 \beta_S^3} \right) \tag{3}$$

$$\lambda.\widetilde{\mathcal{R}} = \left(\sqrt[3]{1 - \left(1 - \alpha_{\mathcal{R}}^3\right)^{\lambda}},\ \beta_{\widetilde{\mathcal{R}}}^{\lambda} \right) \tag{4}$$

$$\widetilde{\mathcal{R}}^{\lambda} = \left(\alpha_{\widetilde{\mathcal{R}}}^{\lambda},\ \sqrt[3]{1 - \left(1 - \beta_{\mathcal{R}}^3\right)^{\lambda}} \right) \tag{5}$$

Definition 3.3. The score function $\mathcal{T}$ is defined by Eq. (6), and the accuracy function $\mathcal{A}$ is defined by Eq. (7), where $\widetilde{R} = (\alpha_{\mathcal{R}}, \beta_{\mathcal{R}})$ (Keshavarz-Ghorabaee *et al.*, 2020; Senapati and Yager, 2019a, 2020).

$$\mathcal{T} = \alpha_{\mathcal{R}}^3 - \beta_{\mathcal{R}}^3 \tag{6}$$

$$\mathcal{A} = \alpha_{\mathcal{R}}^3 + \beta_{\mathcal{R}}^3 \tag{7}$$

To compare two FFS, such as $\widetilde{R}$ and $\widetilde{\mathcal{S}}$, the score and accuracy functions are used. The following scenarios are addressed in these comparisons (Keshavarz-Ghorabaee *et al.*, 2020; Senapati and Yager, 2019a, 2019b, 2020):

(1) If $\mathcal{T}(\widetilde{R}) < \mathcal{T}(\widetilde{\mathcal{S}})$, then $\widetilde{R} < \widetilde{\mathcal{S}}$

(2) If $\mathcal{T}(\widetilde{R}) > \mathcal{T}(\widetilde{\mathcal{S}})$, then $\widetilde{R} > \widetilde{\mathcal{S}}$

(3) If $\mathcal{T}(\widetilde{R}) = \mathcal{T}(\widetilde{\mathcal{S}})$, then

- If $\mathcal{A}(\widetilde{R}) < \mathcal{A}(\widetilde{\mathcal{S}})$, then $\widetilde{R} < \widetilde{\mathcal{S}}$
- If $\mathcal{A}(\widetilde{R}) > \mathcal{A}(\widetilde{\mathcal{S}})$, then $\widetilde{R} > \widetilde{\mathcal{S}}$
- If $\mathcal{A}(\widetilde{R}) = \mathcal{A}(\widetilde{\mathcal{S}})$, then $\widetilde{R} = \widetilde{\mathcal{S}}$

Definition 3.4. Eq. (8) gives the complement of $\widetilde{R} = (\alpha_{\mathcal{R}}, \beta_{\mathcal{R}})$, which is an FFS (Keshavarz-Ghorabaee *et al.*, 2020; Senapati and Yager, 2019a, 2020).

$$Com(\widetilde{R}) = (\beta_{\mathcal{R}}, \alpha_{\mathcal{R}}) \tag{8}$$

Definition 3.5. Eq. (9) defines FF Weighted Average (FFWA) operator. In Eq. (9), $w = (w_1, \ldots,\ w_n)^T$ is the weight vector, where $\widetilde{R}_i = (\alpha_{\mathcal{R}_i}, \beta_{\mathcal{R}_i})$, $(i = 1, 2, \ldots, n)$.

$$\text{FFWA}\,(\widetilde{R}_1, \widetilde{R}_2, \ldots, \widetilde{R}_n) = \left(\sum_{i=1}^{n} w_i \alpha_{\mathcal{R}_i}, \sum_{i=1}^{n} w_i \beta_{\mathcal{R}_i} \right) \tag{9}$$

Definition 3.6. $\widetilde{R} = (\alpha_{\mathcal{R}}, \beta_{\mathcal{R}})$ and $\widetilde{\mathcal{S}} = (\alpha_S, \beta_S)$ as two FFS, the Hamming distance between $\widetilde{R}$ and $\widetilde{\mathcal{S}}$ is defined by Eq. (10), and the Euclidean distance is defined by Eq. (11) (Li *et al.*, 2019; Senapati and Yager, 2020).

$$d_H(\widetilde{R}, \widetilde{\mathcal{S}}) = \frac{1}{2}\left(\left|\alpha_{\mathcal{R}}^3 - \alpha_S^3\right| + \left|\beta_{\mathcal{R}}^3 - \beta_S^3\right| + \left|\pi_{\mathcal{R}}^3 - \pi_S^3\right| \right) \tag{10}$$

$$d_E(\widetilde{R}, \widetilde{\mathcal{S}}) = \sqrt{\frac{1}{2}\left[\left(\alpha_{\mathcal{R}}^3 - \alpha_S^3\right)^2 - \left(\beta_{\mathcal{R}}^3 - \beta_S^3\right)^2 + \left(\pi_{\mathcal{R}}^3 - \pi_S^3\right)^2 \right]} \tag{11}$$

Definition 3.7. $\mathcal{T}(\widetilde{R})$, whose definition is given for FFS before, is a score function that takes values between -1 and $+1$. Keshavarz-Ghorabaee *et al.* (2020) proposed a new definition of the positive scoring function $(\mathcal{T}^P(\widetilde{X}_{ij}))$, which is given in Eq. (12).

$$\mathcal{T}^P(\widetilde{X}_{ij}) = 1 + \mathcal{T}(\widetilde{X}_{ij}) \tag{12}$$

The number of studies involving FFS in the literature is quite limited. Once the limited number of studies are analyzed, it is recognized general characteristics and definitions of FFS (Senapati and Yager, 2019a, 2019b, 2020), as well as novel FF-TODIM and FF-TOPSIS extensions (Senapati and Yager, 2019a, 2019b, 2020; Li *et al.*, 2019). Further, in one of these studies, Keshavarz-Ghorabaee *et al.* (2020) used FF-WASPAS to solve green supplier selection. Some studies include capital budgeting (Sergi and Sari, 2021), new FB-Yager operators, and laboratory selection for COVID-19 testing (Garg *et al.*, 2020), the novel FF-Entropy measure and weighting method extension (Deng and Wang, 2020), FF-CRITIC and FF-EDAS extensions, a sustainable third-party logistics provider selection (Mishra *et al.*, 2021), and definition of new FF operators (Hadi *et al.*, 2021). The studies demonstrate that FF research's theoretical and practical breadth is expanding. However, according to the authors' information, no study was found that performed the FF-Entropy and FF-WASPAS methods together, which points out the paper's main contribution. Thus, the FF-Entropy approach is used to weigh the criteria in this study, whilst the FF-WASPAS framework is employed to rank the alternatives. The following subsections give necessary explanations for FF-Entropy and FF-WASPAS.

3.2 FF-entropy

The FF-Entropy measure, developed by Deng and Wang (2020), shows the degree of dispersion of FFSs. The new FF-Entropy measure $E(F)$ describes the information's uncertainty and imprecision in FFS. Let $Z = \{z_1, \ldots, z_n\}$ be a fixed set, an FFS F in Z is expressed as $F = \{< z_i, \alpha_F(z_i), \beta_F(z_i) >: z_i \epsilon Z\}$, where $\alpha_F(z_i) : Z \to [0,1]$, and $\beta_F(z_i) : Z \to [0,1]$. In this context, the FF-entropy measure defined on FFSs is given in Eq. (13).

$$E(F) = 1 - \frac{\sum_{i=1}^{n} \left[S(F_i)\left(1 - \pi_F^3(z_i)\right) \right]^2}{n} \tag{13}$$

where $S(F_i) = \alpha_F^3(z_i) - \beta_F^3(z_i)$, and $\pi_F^3(z_i) = 1 - \alpha_F^3(z_i) - \beta_F^3(z_i)$. The entropy measure for FFN (Fermatean fuzzy number), according to Eq. (13), is stated as below:

$$E(F_i) = 1 - \sum_{i=1}^{n} \left[S(F_i)\left(1 - \pi_F^3(z_i)\right)\right]^2 \forall z_i \in Z \quad (14)$$

After explaining the FF-Entropy measure, the FF-Entropy weighting method's application steps can be given.

Step 1. Define the problem and construct the initial FF decision matrix. The criteria to be considered in solving the decision problem, the alternatives and the decision-makers or experts who perform the evaluations are all determined. $F_k = (f_{ijk})(i = 1, \ldots, m, j = 1 \ldots, n)$ represents the FF decision matrix reflecting the evaluations of the kth decision-maker, where $(i = 1, \ldots, m, j = 1 \ldots, n)$. In the decision problem, there are n criteria, m alternatives, and r decision-makers, where $\{C_1, C_{2,\ldots,} C_n\}$, $\{A_1, A_{2,\ldots,} A_m\}$, $\{O_1, O_{2,\ldots,} O_r\}$. As a result, the f_{ijk} depicts the evaluation of the kth decision-maker for ith alternatives for criterion j using FFNs. Table 2 shows the fuzzy values that can be utilized in response to nine linguistic assessment terms in FFSs that indicate importance, preference, or judgment (Keshavarz-Ghorabaee *et al.*, 2020; Mishra *et al.*, 2021).

Step 2. Determine the significance degrees of DMs. Considering the disparities in expertise, authority, and responsibility among decision-makers, it may be necessary to give different weights to their assessments of the problems. The weight values of the decision-makers can be calculated similarly to the weighting of the criteria. $W = (\alpha_k, \beta_k)$, the FFS equivalent of the weight assigned to the k-th decision maker's evaluations of the problem, and the k-th decision maker's weight value (ψ_k) is derived using Eq (15), where $\psi_k \geq 0$, $\sum_{k=1}^{r} \psi_k = 1$, and $k = 1, \ldots, r$.

$$\psi_k = \frac{\alpha_k^3\left[1 + (\gamma_1 + \gamma_2)\left(1 - \alpha_k^3 - \beta_k^3\right)\right]}{\sum_{k=1}^{r}\left(\alpha_k^3\left[1 + (\gamma_1 + \gamma_2)\left(1 - \alpha_k^3 - \beta_k^3\right)\right]\right)}, \ \gamma_1 + \gamma_2 = 1, \gamma_1, \gamma_2 > 0 \quad (15)$$

γ_1 and γ_2 in Eq. (15) are the weighted averages of membership and non-membership grades. Mishra *et al.* (2021) examined the effects of different values for γ_1 and γ_2. It was stated that when the value of γ_1 is changed from 0 to 1, and the value of γ_2 is changed from 1 to 0, the

Linguistic terms	$(\alpha; \beta)$
Extremely Low (EL)	(0.1; 0.9)
Very Low (VL)	(0.1; 0.75)
Low (L)	(0.25; 0.6)
Medium Low (ML)	(0.4; 0.5)
Medium (M)	(0.5; 0.4)
Medium High (MH)	(0.6; 0.3)
High (H)	(0.7; 0.2)
Very High (VH)	(0.8; 0.1)
Extremely High (EH)	(0.9; 0.1)

Table 2. The FF linguistic scale

relative score of FF numbers increases. However, Mishra *et al.* (2021) used 0.5 values for γ_1 and γ_2. On the other hand, this study will give equal weight to decision-makers.

Step 3. Construct the integrated FF decision matrix. The decision makers' evaluations are integrated with using the FFWA operator in Eq. (9), and the integrated FF decision matrix $\widetilde{X}$ is constructed. For this purpose, elements of the $\widetilde{X}$ is calculated using Eq. (16), where $\widetilde{X}_{ij} = \alpha_{X_{ijk}}, \beta_{X_{ijk}}$.

$$\widetilde{X}_{ij} = \text{FFWA}\left(\widetilde{F}_{ij1}, \widetilde{F}_{ij2}, \ldots, \widetilde{F}_{ijr}\right) = \left(\sum_{k=1}^{r} \psi_k \alpha_{F_{ijk}}, \sum_{k=1}^{r} \psi_k \beta_{F_{ijk}}\right) \tag{16}$$

α_{F_k} *and* β_{F_k} are degrees of membership and non-membership, expressing the linguistic judgement of the k-th decision-maker, respectively.

Step 4. Normalize the integrated FF decision matrix. The normalization procedure is completed with Eq. (17), which considers the optimization orientation of the criteria.

$$\widetilde{n}_{ij} = \begin{cases} \widetilde{x}_{ij} & , \quad j \in J^{+} \\ Com(\widetilde{x}_{ij}) & , \quad j \in J^{-} \end{cases} \tag{17}$$

where J^{+} stands for benefit-oriented criterion, while J^{-} stands for cost-oriented criteria. As a result, we have the normalized decision matrix $\widetilde{N} = (\widetilde{n}_{ij})$.

Step 5. Calculate the entropy values. The Entropy for each FFN in $\widetilde{N}$ is calculated using Eq (13).

Step 6. Calculate the criteria's weights. The weight values are derived using the entropy measures of the criteria. For this purpose, Eq. (18) is given.

$$\omega_j = \frac{1 - \overline{E}(C_j)}{n - \sum_{j=1}^{n} \overline{E}(C_j)} \tag{18}$$

The $\overline{E}(C_j)$ value in Eq. (18) is obtained using Eq. (19).

$$\overline{E}(C_j) = \frac{1}{n} \sum_{i=1}^{m} E(n_{ij}) \tag{19}$$

The criteria weight values obtained with FF-Entropy are in the range of 0–1.

3.3 FF-WASPAS

The method used to solve multi-criteria decision problems is a crucial factor that directly impacts the result. Zavadskas *et al.* (2012) developed WASPAS, which provides a solution based on the integration of WPM (Weighted Product Model) and WSM (Weighted Sum Model) methods. Compared to WPM and WSM, the WASPAS method aims to produce more consistent results (Zavadskas *et al.*, 2012). The methods developed by considering crisp sets for problems including uncertainty are ineffective. For this reason, extensions of existing methods to fuzzy sets are continuously being developed. By keeping these requirements in mind, the authors decided to apply FF-WASPAS because it has many valuable advantages, which can help overcome many complicated uncertainties. The health industry has a highly dynamic structure, as it tries to develop innovative techniques, newly produced medical stuff and drugs. Furthermore, most institutes and companies in the health industry do not publish their statistical data (i.e., financial and operational) and activity reports. Hence, there are insufficient information and a lack of data about this industry. Therefore, decision-makers may have to decide with insufficient information and a lack of data in many conditions.

In this context, the FFS extension of WASPAS was proposed by Keshavarz-Ghorabaee *et al.* (2020). The FF-Entropy process steps are followed until the criterion weights are determined in implementing FF-WASPAS. The following process is then carried out:

Step 7. Calculate the WPM and WSM relative preference values: Using the sum, product, and other operators defined for FFS, Eq. (20) produces WSM relative preference values, and Eq. (21) gives WPM relative preference values.

$$\widetilde{Q}_i^S = \bigoplus_{j=1}^{n} \left(\omega_j \otimes \widetilde{n}_{ij}\right) \tag{20}$$

$$\widetilde{Q}_i^P = \bigotimes_{j=1}^{n} \left(\widetilde{n}_{ij}^{\omega_j}\right) \tag{21}$$

Step 8: Calculate the alternatives' integrated relative preference values ($\widetilde{Q}_i$)*:* To obtain $\widetilde{Q}_i$ values, the WSM and WPM values calculated with Eq. s (20–21) are combined with Eq. (22).

$$\widetilde{Q}_i = \lambda \widetilde{Q}_i^S \oplus (1-\lambda)\widetilde{Q}_i^P \tag{22}$$

In Eq. (22), the integration parameter λ takes a value between 0 and 1. The WPM score computed with Eq. (20) is obtained as the $\widetilde{Q}_i$ value if $\lambda = 0$ and the WSM score created with Eq. (20) is obtained as the $\widetilde{Q}_i$ value if $\lambda = 1$. In the case of $\lambda = 0.5$, the $\widetilde{Q}_i$ value is computed by applying the arithmetic mean of the WSM and WPM scores.

Step 9. Rank alternatives: The $\widetilde{Q}_i$ values for the alternatives are transformed to a crisp score value, $\mathcal{T}^P(\widetilde{X}_i)$ using Eq. (12). Then, the alternatives are ordered from the largest to the smallest according to $\mathcal{T}^P(\widetilde{X}_i)$ values. Therefore, the solution of the problem is completed.

4. Application of the model to the selection of pharmaceutical supplier

In this section, the proposed FF-MCDM model is implemented for evaluating the pharmaceutical distribution and warehousing companies' selection processes to demonstrate the implementation of the novel proposed approach. By following the phases of the research process, we constructed a board of experts consisting of ten highly experienced professionals having extensive knowledge of the health industry. We decided to construct a board of experts to obtain more rational, reasonable, and logical results because the health industry has a highly dynamic structure, and it is required much detailed information, which has not been done by researchers who are out of this industry. We identified some criteria for candidates to be members of the board of experts. (1) having experience in the industry of at least 14 years as a senior executive or company owner (2) being experienced in the selection of suppliers, logistics service providers, collaborators, and other stakeholders of the health supply chain at least one time. (3) Having graduated from related departments of reputable universities. By considering these criteria, we evaluated 54 candidates and selected ten highly experienced professionals having extensive knowledge of the industry among these candidates. The members of the boards and their details are given in Table 3.

The decision-makers evaluated the criteria by giving a significance score between 1 and 9. Next, crisp values for each alternative concerning this criterion are calculated by applying the geometric mean operation. Researchers performed many face-to-face interviews with these professionals and well-attended round table meetings. Each board member took charge as an advisor in each phase of the research process. Afterwards, the research questions determined by researchers in the current paper were directed to the decision-makers. A set of research questions are presented as follows. (1) Is there any mathematical tool or methodological frame used to solve decision-making problems in the health industry? (2) What are the significant criteria and factors for selecting the appropriate drug distribution companies?

According to the decision-makers' opinion, no mathematical model or decision support system is used to evaluate drug distributors. Moreover, decision-makers consider these selection processes as a particular case that is required special evaluation. Besides, they suggested considering the criteria identified by WHO. However, we did not handle some of these criteria, as making subjective or objective evaluations for those is impossible. There are already binding regulations and standards related to most of these criteria, which did not consider in the current paper. Including them in the scope of evaluation may not benefit from the perspective of the obtained results. The final determining criteria are given in Table 4.

We organized many round-table meetings and face-to-face interviews with the experts to identify the criteria. Although it is not a standard procedure, we prefer to work with the experts to identify up-to-date and proper criteria for real-life decision-making problems. Also, we performed a comprehensive literature review to determine the criteria used in the previous studies. By eliminating the repetitive criteria, we presented the list of those to decision-makers. After they evaluated these criteria, we identified the criteria set by providing a complete consensus of the experts at the end of the long-lasting negotiations.

In real-life conditions, interactions among the criteria are expected situations. However, the interaction between a small number of criteria is accepted as logical and reasonable (Figueira *et al.*, 2009). Therefore, it is required to avoid interaction between many criterion pairs. When the interaction between criterion pairs is evaluated, interactions between the criteria are pretty few in the current paper. For instance, C2 and C3 can influent the C6 criterion. Similarly, C7 can be influenced by the C1, C4, C9, and C10 criteria. However, it is a common situation, as interactions between the criteria affect the decision-making problems in a definite industry.

No	Graduation	Duty	Exp
DM-1	Business	Manager	15
DM-2	Hospital Management	Assistant Director	12
DM-3	Economy	Responsible	16
DM-4	Business	Manager	18
DM-5	Health Management	Responsible	22
DM-6	Public Administration	Manager	27
DM-7	Medical Faculty	Department of pathology	25
DM-8	Medical Faculty	Department of ENT	30
DM-9	Faculty of pharmacy	Manager	21
DM-10	Faculty of pharmacy	Member	14

Table 3.
Details of the members of the board of experts

Codes	Criteria	Explanation	References
C1	Number of vehicles for distribution	It refers to the number of trucks and vans for distribution operations	Alidrisi (2021)
C2	Number of personnel	Professional staff employed for distributing medicals and drugs	Alidrisi (2021), Nguyen *et al.*, (2022), Ho *et al.*, (2010), Han *et al.*, (2020)
C3	Number of warehouses	It refers to the number of cold warehouses operated by the firms	Chauhan *et al.* (2022)
C4	Total warehouse capacity	The total storage capacity of the warehouses	This study
C5	Logistics speed	The time between order and delivery of the medical substances	Alidrisi (2021), Chauhan *et al.*, (2022), Nag and Helal (2016), Govindan and Chaudhuri (2016), Nguyen *et al.*, (2022), Stević *et al.* (2020)
C6	Service cost	The average price for service per product unit	Chauhan *et al.*, (2022), Ho *et al.*, (2010), Alikhani *et al.*, (2019), Kirytopoulos *et al.*, (2008), Nag and Helal (2016), Nguyen *et al.*, (2022), Bamatov *et al.*, (2020), Stević *et al.* (2020), Çelik Teker (2017)
C7	Flexibility	Abilities of the distributors concerning flexibility	Alidrisi (2021), Kirytopoulos *et al.*, (2008), Nag and Helal (2016), Liao *et al.*, (2020), Jamali and Rasti-Barzoki (2019), Khan and Ali (2021), Çelik Teker (2017), Nguyen *et al.*, (2022)
C8	Number of refrigerated vehicles	The number of refrigerated vehicles used for distribution operations	Chauhan *et al.*, (2022), Han *et al.*, (2020)
C9	Number of items in inventory	It refers to the product variety presented by distributors	Alidrisi (2021), Chauhan *et al.*, (2022)
C10	Accuracy in deliveries	It means the number of faultless deliveries per ten delivery operations	Alidrisi (2021), Nguyen *et al.*, (2022)

Table 4. The selection criteria for evaluating the drug distributors and references

Assigning pharmaceutical warehouses into the high, medium, or low-performance classes directly impacts the procurement of drugs and materials in the health sector. Then, we identified alternatives with decision-makers by following a similar way to determine the selection criteria. For this purpose, we asked them what the leading key players in the current industry are. In addition, to collect more information on that, we reviewed the web pages of all stakeholders in the health industry and the chamber of pharmacists. At the end of the process, we identified the decision alternatives given in Table 5.

The identified pharmaceutical warehousing and distributing companies are the key players in the health industry, and all of them give service to all stakeholders of the health industry, such as hospitals, pharmacies, and direct patients. The evaluations of pharmaceutical warehouses and criteria optimization orientations are presented in Appendix.

According to Appendix, equal weights were given to all decision-makers. The decision makers' evaluations were integrated using Eq. (16); thus, the aggregated decision matrix was constructed. Then, the criteria weights were calculated using FF-Entropy were obtained. Table 6 shows the integrated decision matrix.

The FF entropy measures and weights of criteria calculated using the integrated decision matrix are presented in Table 7.

The importance order of the criteria is C4≻C8≻C2≻C1≻C3≻C9≻C6≻C5≻C10, concerning the results in Table 7. In this context, the total warehouse capacity is the influential criterion, whereas delivery accuracy is the least important. Measures for the WSM and WPM methods were obtained using Eqs. (21)-(22). Then, the integrated relative preference values of alternatives in FF-WASPAS were calculated by Eq. (23), where $\lambda = 0.5$. Table 8 shows the result obtained in this context.

Obviously, A5 is the best pharmaceutical supplier. We applied the proposed FF-MCDM framework to solve decision-making problems about selecting suitable drug distribution companies to demonstrate the implementation of the proposed model. Though the obtained results seem reasonable, we performed a comprehensive sensitivity analysis to test the validity of the proposed novel model and its results.

5. The validation test

This section performed a comprehensive sensitivity analysis consisting of two stages to examine the proposed model's robustness, applicability, and stability. In the first stage, the impacts of the criteria weight modifications on the ranking results are analyzed. Examining impacts of the changing the criteria weights in the overall ranking results is one of the significant tests proving the stability and consistency of the proposed decision-making models. In the existing literature, the authors proposed examining the impacts of changing the first influential or three influential criteria weights on the ranking results (Stanković *et al.*, 2020). However, changing the weights of the remaining criteria may influence the overall ranking results. Thus, in the current paper, the authors decided to apply an algorithm proposed by Görçün *et al.* (2021) because this approach examines the impacts of changing all criteria weights respectively, and it can capture all possible conditions concerning changing the ranking results. In addition, the proposed approach tries all possible changes, including which have not probable or have a low likelihood in the real world. As a result, the proposed approach can be accepted as a powerful tool for testing the stability of the proposed decision-making technique due to its advantages.

For this purpose, different 100 scenarios were formed by researchers. The weight of each criterion was gradually changed by 10% in each scenario (i.e., 10%, 20% ,..., 100%) until the criterion weight was equal to zero. Also, the weights of the remaining factors are corrected to meet the condition that the sum of weights should be equal to 1. New weight values of the criteria are determined for each scenario by applying Eqs. (23)-(25), respectively.

$$w_{fv}^{1} = w_{pv}^{1} - \left(w_{pv}^{1}.m_v\right) \tag{23}$$

$$w_{nv}^{2} = \frac{\left(1-w_{pv}^{1}\right)}{n-1} + w_{pv}^{2} \tag{24}$$

Table 5.
The decision alternatives for drug distributors

Codes	Decision alternatives
A1	Eurasia Pharmaceutical Warehouse
A2	Edak Pharmaceutical Warehouse
A3	Hedef Alliance
A4	Istanbul Pharmacists Cooperative
A5	Selcuk Pharmaceutical Warehouse
A6	Vizyon Pharmaceutical Warehouse

Table 6. The integrated decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	(0.12, 0.86)	(0.13, 0.84)	(0.12, 0.84)	(0.10, 0.87)	(0.59, 0.31)	(0.61, 0.29)	(0.60, 0.30)	(0.10, 0.87)	(0.13, 0.83)	(0.60, 0.30)
A2	(0.12, 0.84)	(0.12, 0.75)	(0.10, 0.80)	(0.10, 0.87)	(0.68, 0.22)	(0.77, 0.15)	(0.64, 0.26)	(0.10, 0.84)	(0.18, 0.68)	(0.64, 0.26)
A3	(0.20, 0.67)	(0.12, 0.75)	(0.56, 0.34)	(0.12, 0.84)	(0.68, 0.22)	(0.36, 0.53)	(0.62, 0.28)	(0.16, 0.69)	(0.64, 0.26)	(0.62, 0.28)
A4	(0.12, 0.77)	(0.12, 0.86)	(0.17, 0.70)	(0.12, 0.86)	(0.58, 0.32)	(0.51, 0.39)	(0.77, 0.15)	(0.10, 0.75)	(0.61, 0.29)	(0.55, 0.35)
A5	(0.77, 0.15)	(0.77, 0.15)	(0.77, 0.15)	(0.77, 0.15)	(0.77, 0.15)	(0.12, 0.84)	(0.77, 0.15)	(0.77, 0.15)	(0.77, 0.15)	(0.77, 0.15)
A6	(0.13, 0.83)	(0.13, 0.83)	(0.13, 0.83)	(0.12, 0.86)	(0.58, 0.32)	(0.49, 0.41)	(0.63, 0.27)	(0.12, 0.86)	(0.15, 0.81)	(0.63, 0.27)

$$w_{fv}^{1}+\sum w_{nv}^{2}=1 \tag{25}$$

Here, w_{fv}^{1} denotes the new value of the modified weight of j-th factor, w_{pv}^{1} is the previous values of the criterion, m_v is the modification degree in terms of percentage (i.e., 10%, 20%,...,100%). Also, w_{nv}^{2} symbolizes new values of remaining factors, n is the number of factors, w_{pv}^{2} is the previous values of the remaining criteria.

Then, we identified new criteria weights for all scenarios by applying eqs. (23)–(25), and we determined the recent ranking performances of the alternatives concerning the scenarios. The new ranking results are presented in Figure 3.

Based on Figure 3, there is no change in the ranking performances of all alternatives. All of them have remained in the same ranking position even though we made excessive modifications in the criteria weights by forcing the real-life conditions related to the significance of the factors. It has been observed that differences among the relative significance scores of the alternatives were reduced in some scenarios, but those have not been sufficient to change the ranking results. Significantly, the relative importance scores of the A2, A4, and A6 in scenario 10th are relatively closer than the scores determined in the initial ranking results. Even though these results may have partly been affected by the high differences among the significance score of the alternatives, these differences are not a single determinative factor, as the proposed model can eliminate the excessive evaluations and their impacts on the ranking results. Hence, the remaining alternatives in the same ranking positions for all conditions formed in the scenarios, including extreme modifications of the criteria weights, prove the proposed model's stability and consistency.

In the second validation test phase, we applied four popular MCDM frameworks based on the FFSs such as FFS-SAW, FFS-ARAS, FFS-TOPSIS, and FFS-COPRAS to compare the results of the proposed MCDM framework and implemented MCDM approaches. The ranking results obtained by applying these approaches are presented in Table 9.

As seen in Figure 4, the decision alternatives have remained in the same ranking positions, and the ranking results of the proposed model are entirely the same as the results of the other implemented MCDM frameworks.

Table 7.
The FF entropy measures and weights of criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.8474	0.8766	0.8766	0.8120	0.9983	0.9974	0.9979	0.8120	0.9006	0.9979
A2	0.8766	0.9683	0.9363	0.8120	0.9902	0.9566	0.9953	0.8766	0.9911	0.9953
A3	0.9918	0.9683	0.9991	0.8766	0.9902	0.9996	0.9968	0.9884	0.9953	0.9968
A4	0.9598	0.8474	0.9862	0.8474	0.9986	0.9998	0.9991	0.9683	0.9974	0.9993
A5	0.9566	0.9566	0.9566	0.9566	0.9566	0.8766	0.9566	0.9566	0.9566	0.9566
A6	0.9006	0.9006	0.9006	0.8474	0.9986	0.9999	0.9961	0.8474	0.9202	0.9961
$\overline{E}(C_j)$	0.9221	0.9196	0.9426	0.8586	0.9888	0.9716	0.9903	0.9082	0.9602	0.9903
Weights	0.1422	0.1468	0.1049	0.2581	0.0205	0.0518	0.0177	0.1677	0.0727	0.0176

Table 8.
The results of FF-WASPAS

Alternatives	$\widetilde{Q}_i^S$	$\widetilde{Q}_i^P$	$\widetilde{Q}_i$	$\mathcal{T}^P(\widetilde{X}_i)$	Rank
A1	(0.25, 0.79)	(0.13, 0.94)	(0.21, 0.86)	0.3678	6
A2	(0.27, 0.76)	(0.12, 0.89)	(0.22, 0.82)	0.4556	4
A3	(0.41, 0.58)	(0.21, 0.74)	(0.34, 0.65)	0.7592	2
A4	(0.32, 0.69)	(0.15, 0.83)	(0.27, 0.76)	0.5835	3
A5	(0.84, 0.15)	(0.77, 0.15)	(0.81, 0.15)	1.5309	1
A6	(0.27, 0.77)	(0.14, 0.91)	(0.23, 0.83)	0.4312	5

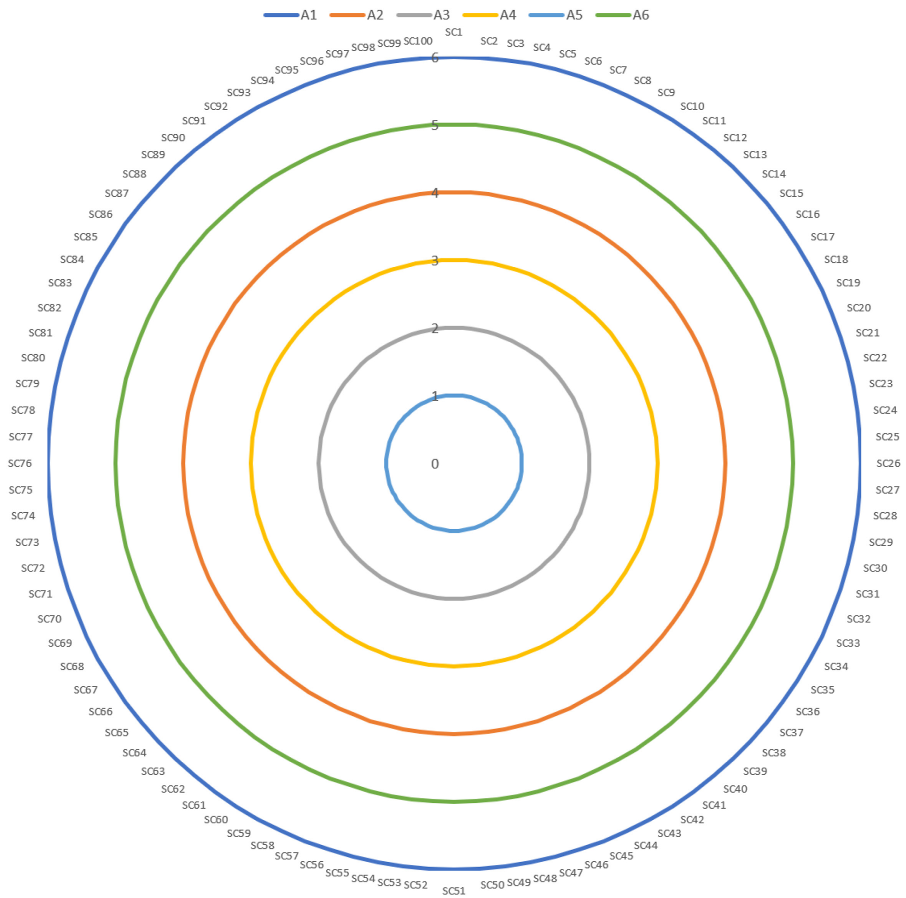


Figure 3.
Impacts of changes of criteria weight on the ranking performance of the alternatives

	FF-WASPAS	FF-SAW	FF-ARAS	FF-TOPSIS	FF-COPRAS
A1	6	6	6	6	6
A2	4	4	4	4	4
A3	2	2	2	2	2
A4	3	3	3	3	3
A5	1	1	1	1	1
A6	5	5	5	5	5

Table 9.
The ranking results of the implemented FF approaches

The results obtained by applying the proposed and popular decision-making models in the current paper are the same, but these models have some structural problems and limitations. First, the simple additive weighting technique (SAW) is one of the most preferred approaches due to its practical algorithm easily followed by decision-makers (Modarres and Sadi-Nezhad, 2005). However, fuzzy extensions of the SAW approach require defuzzification operations, taking much time and are laborious, but the defuzzification technique applied in the SAW

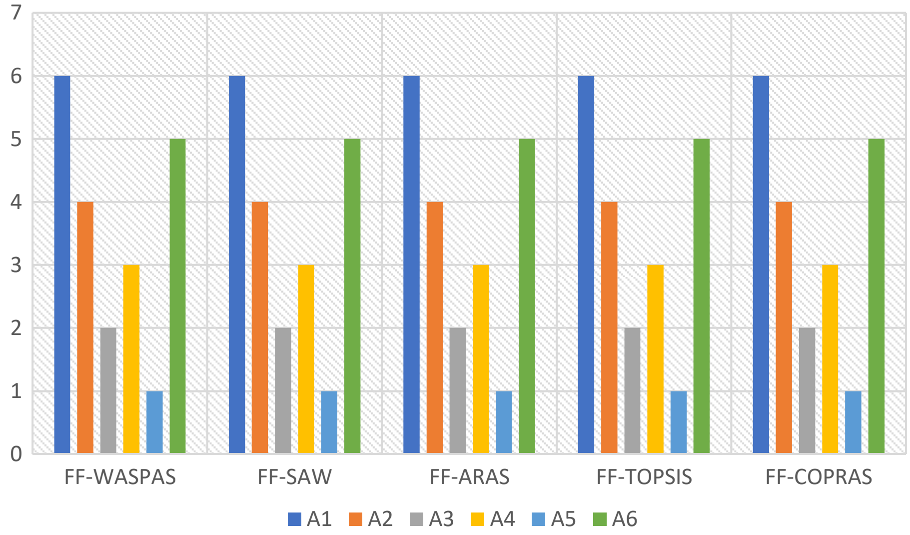


Figure 4.
The ranking results of the alternatives by applied MCDM frameworks

approach may cause to distort the obtained overall results. Hence, this approach may not produce logical and reasonable solutions in a fuzzy environment.

The ARAS method requires identifying the optimal values of the attributes. In case of uncertainty, these values are identified by experts or researchers (Ecer, 2018). However, there are some ambiguities concerning the determination of these values. Some authors recommended that these values should be identified by taking 20% better values than all values in the presented options if optimal values cannot be identified and are unknown (Liu and Xu, 2021). However, there is no sufficiently clear explanation for why these values should be taken 20% better than all values (i.e., it could have been 15% or 25%). Hence, it also increases the complexities and ambiguities concerning the implementation of the approach.

The TOPSIS and COPRAS techniques suffer from rank reversal problems (García-Cascales and Lamata, 2012; Ecer, 2014; Mousavi-Nasab and Sotoudeh-Anvari, 2018). Changes in indexes may cause dramatic changes in the ranking results. It causes to raise doubts about the reliability of these approaches. Although fuzzy extensions of these methods were applied to overcome this problem in the current literature, there is no sufficient evidence concerning fuzzy versions of these approaches that can entirely deal with the rank reversal problem. In addition, these approaches have very complicated and time-consuming algorithms and require many computations to reach the final results; also, the high subjectivity of the approaches is a significant disadvantage (Podviezko and Podvezko, 2014; Vladimirovna *et al.*, 2017).

The proposed model has valuable advantages compared to the other approaches, aside from not having these kinds of structural problems like the popular decision-making approaches applied in the current paper. The proposed model combines the advantages of the Fermatean fuzzy sets (refer to the first section) and the WASPAS approach. As the WASPAS technique has a high degree of reliability (Hashemkhani Zolfani *et al.*, 2013), it can help solve highly complicated decision-making problems for decision-makers. Also, it provides more reliable, logical, and reasonable results when they encounter complex real-world decision-making problems. Also, the WASPAS approach combining two powerful decision-making techniques, namely the WSM (Weighted Sum Model) and WPM (Weighted Product Model) techniques, increases the ranking accuracy (Zavadskas *et al.*, 2013). Moreover, it provides computational easiness to decision-makers due to its practical basic algorithm. Also, aside from being strongly resistant to the rank reversal problem, the results obtained using this approach are maximally consistent and stable (Chakraborty and Zavadskas, 2014; Simic *et al.*, 2021b; Zavadskas *et al.*, 2014).

In the third phase of the validation test, we examined the stability of the proposed model by testing its resistance to the rank reversal problem by forming five scenarios (i.e., *n*). For this purpose, we eliminated the worst options in each scenario and re-calculated the relative significance scores of the remaining alternatives. Then we ranked these alternatives by considering their significance scores. The first scenario shows the initial ranking results obtained by applying the proposed model. We eliminated weaknesses and undesirable alternatives in the second scenario and examined the remaining alternatives' new ranking positions. This approach was repeated similarly for other scenarios. Obtained results demonstrating the resistance of the proposed model to the rank reversal problem are presented in Table 10.

As shown in Table 10, there are no deviations in the ranking performances of the alternatives, and all options have remained in the same ranking position for all scenarios. It proves that the proposed model is maximally consistent, and any change occurring in the number of the alternatives cannot cause a difference in the alternatives' ranking performance. Because of that, the proposed FF-MCDM framework can be accepted as a robust and reliable approach for practitioners and decision-makers, as the results are stable and consistent maximally, and it is resistant to the rank reversal problem.

6. Discussion and contributions

The PSCs have encountered many troubles in the global pandemic, and they try to manage highly complex manufacturing, supplying, and logistics activities in this turbulent period. In previous times, everybody accepted that drug makers were the PSCs' most significant and determinative actors. However, drug distributors have become more significant actors in the drug supply chains than in the past.

Selecting appropriate drug distribution companies has become a more crucial and strategic decision for the success and performance of the PSCs. However, managing these evaluation and selection processes as there are many conflicting criteria. This paper manifested that drug distribution companies have ever-increasing strategic importance depending on the PSCs' advanced logistics systems and networks. In addition, drug distributors are under pressure to continuously improve their logistics systems and technological structure since technological advancements do not stop and occur a new technological instrument, providing competitive advantages each passing day. Otherwise, drug distribution companies may quickly lose competition in these highly competitive business environments. Therefore, the current paper revealed that the technological advancement level for these companies is an essential indicator for giving more flexible logistics services.

Besides, the current paper provides a new viewpoint to identify the significance of the attributes and evaluate the decision alternatives on drug distributors having strategic

Scenarios	Ranking
Original	*A5>A3>A4>A2>A6>A1*
S1	*A5>A3>A4>A2>A6*
S2	*A5>A3>A4>A2*
S3	*A5>A3>A4*
S4	*A5>A3*

Table 10. Ranking the decision alternatives with respect to the scenarios

importance in PSCs. Thus, it can provide more manageable evaluation processes to make more rational and realistic decisions for decision-makers in PSCs. The findings of the current paper would be helpful for PSCs and their components of the supply chains to improve the service quality and overall performance.

Besides, the proposed FF model can help make optimal and logical decisions concerning selecting proper PSCs for decision-makers in the health industry. It provides a more flexible, reliable and robust decision-making environment and can overcome many complicated uncertainties. Aside from decision-makers considering the findings of the current paper, they can use the proposed model as a roadmap to make a self-evaluation about themselves to improve their abilities and competencies. Moreover, the paper's managerial implications and theoretical contributions can help to re-construct health supply chains that are more resilient.

Moreover, the sensitivity analysis results prove that the proposed FF-WASPAS approach is a maximally robust, practical and powerful decision-making frame, as there are no severe and significant changes in the ranking results of the model despite many excessive modifications. Also, it has been proven that the proposed model is entirely resistant to rank reversal. Hence, it provides a more reliable decision-making environment for decision-makers.

7. Managerial implications and limitations

This study used the FF-MCDM approach to evaluate the performance and effectiveness of the drug distribution and warehousing companies to reach higher competitive advantages for PSCs in these kinds of turbulent times. Hence, the proposed model can help the decision-makers and practitioners responsible for selecting the appropriate drug distributors to make more rational, reasonable, and optimal decisions. The paper's findings offer implications for supporting all attempts to improve the drug distribution companies by constructing healthier and well-operating logistics systems. Besides, managing a logistics system in the field of the pharmaceutical industry causes exceptionally high costs, and sources used for that are not unlimited. An expert system or methodological frame is necessary for decision-makers to reduce costs and provide sustainability, higher effectivity, and productivity for the entire supply chain and drug distributors.

Its geographic limitation can be accepted as the main limitation of the study. Hence, the current paper's results may change if applied to different regions or countries. However, it also can provide some advantages in identifying the differences among countries and regions in this issue. Thus, it may benefit supply chains to discover new logistics service suppliers in different markets. We conducted a comprehensive preparation process to identify the attributes for drug distributor selection; for this purpose, we performed a comprehensive literature review, organized many face-to-face interviews with decision-makers, and examined regulations, legislations, and standards identified by international bodies relating to the health industry. Since the experts determined criteria, attributes, and decision alternatives are partly subjective and open to arguments.

8. Conclusion and future research directions

Although the drug distributors are the critical and vital actors of the PCSs, evaluation of these supply chain actors has been a neglected subject in the literature. After a detailed literature review, we noticed severe and significant gaps in the existing literature. First, there are theoretical gaps in the literature, as the approaches used in the previous papers did not sufficiently meet the industry's requirements. Aside from the decision-making techniques proposed in these studies having some limitations and structural problems, most of these works overlooked existing complicated ambiguities. Secondly, a few papers focused on selecting pharmaceutical distribution and warehousing companies even though many papers deal with the drug supply chains are available in the literature. Hence, more research and studies are required to fill the gaps noticed in the literature. In addition, it is not sufficiently clear how the selection criteria were identified in the previous works, and there is no evidence about the applied methodologies to identify the criteria. The current paper aims to fill these gaps by proposing a robust and powerful decision-making approach that overcomes many complicated uncertainties by keeping the requirements and strong motivations in mind. Also, the criteria set has been identified by performing comprehensive fieldwork with highly experienced professionals by considering the criteria used in the literature.

This study presents a comprehensive and novel evaluation tool from a broader perspective. This paper has many valuable contributions and managerial and methodological implications for drug supply chains to identify the competitive advantages. For almost all PSCs, the performance of the drug distributors providing logistics services would mean the performance, effectiveness, and productivity of entire the drug supply chain.

Though the current paper presents a detailed evaluation and examination concerning identifying the criteria and their weights, there are still some gaps that the authors who carry out future works can fill. First, the proposed FF approach can be combined with the SWOT analysis (Baykasoğlu and Golcuk, 2014; Büyüközkan *et al.*, 2021) to define strategies which can help to determine the influential criteria in the current industry. Hence, the model's compatibility with real-life decision-making problems and sustainability strategies of the companies in the health industry can be demonstrated clearly. Secondly, selecting the right and influential criteria is a critical and significant task for decision-makers to make logical and optimal decisions. The authors generally preferred to follow two ways to identify the criteria in the existing literature concerning the multi-criteria decision-making approaches. The first is to identify the criteria by considering the criteria used in the previous studies. The second is to determine the factors by performing fieldwork with experts and professionals. The current paper has followed a mixed approach that is entirely original. Also, efficient approaches such as the Delphi technique (Dalkey and Helmer, 1963) can be extended with the help of Fermatean fuzzy sets, and the criteria suitable for real-life decision-making problems can be identified using the FF Delphi approach. Aside from the proposed technique that can capture many complicated uncertainties in the evaluation process to determine the criteria, the FF-Delphi approach can be a practical and valuable tool to describe the criteria, especially in uncertainty.

In addition, although there is much valuable progress in MCDM, there are some severe and significant gaps concerning group decision-making processes. First, the same linguistic terms can have different means for different decision-makers, and these differences may cause distortions and deviations in the overall results. Many researchers still have not identified a linguistic scale having the same semantics for all decision-makers (Li *et al.*, 2019; Zhang *et al.*, 2020, 2021). Hence, it is essential to consider experts' personalized individual semantics (PISs) (Gao and Zhang, 2021). In addition, some experts may refuse to reach a consensus with others by considering their interests; they may also indicate their preferences, which are not proper for real-life conditions. Gao and Zhang (2021) proposes an algorithm for reaching a consensus to manage decision-makers' non-cooperative behaviours. Besides, Zhang and Li (2021) also indicate that there are still severe and significant research gaps even though great progress has been made for PIS-based linguistic GDM. For this purpose, they developed some PIS-based models to improve the consistency and increase consensus in linguistic group decision-making. Similarly, Wu *et al.* (2021) examined this problem and suggested a two-fold personalized feedback mechanism to help inconsistent experts reach the consensus threshold value in social network group decision-making. Besides, Wu *et al.* (2022) proposed a novel group consensus-based travel destination evaluation method with online reviews by handling the missing preference estimating and group consensus reaching process.

Recently, scholars have started to deal with this problem increasingly. It proves that there are still strong doubts about the consistency and stability of the experts' preferences. Thus, attempts to solve this problem are a valuable and noteworthy topic for the academic circles. Hence, investigations to solve this problem would be promising for the scholars dealing with decision-making approaches. Therefore, the proposed model in the current paper may be enriched with the proposed model to solve the problem concerning the linguistic terms' means and reach a consensus among decision-makers. Also, the criteria can be identified by an improved approach in future works with the help of these models developed to solve these problems by the authors (Gao and Zhang, 2021; Wu *et al.*, 2021; Zhang and Li, 2021).

PSCs can focus on improvement to the performance of drug distributors, which are the crucial and strategic component of the supply chain to have higher competitive advantages and customers' (i.e., patients, medics, health institutes, and governments) satisfaction. This research can be accepted as a starting point for subsequent studies, which deal with the difference among countries and regions. It can be replicated for different countries keeping in mind other and particular conditions of the nations. Also, pharmaceutical distributors and warehousing companies' performance and impacts on the PSC can be measured using the proposed mathematical tool concerning attributes identified in the current paper. Moreover, future work can be conducted with various MCDM methods such as CODAS, MABAC, CoCoSo, etc., and different extensions of fuzzy sets like spherical and picture fuzzy sets, Pythagorean fuzzy sets, and so on.

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Appendix

Table A1. Evaluations of pharmaceutical warehouses

Alternatives	DMs	Max C1	Max C2	Max C3	Max C4	Max C5	Min C6	Max C7	Max C8	Max C9	Max C10
A1	DM-1	EL	EL	L	EL	H	H	H	EL	EL	H
	DM-2	EL	EL	EL	VL	MH	H	H	EL	L	H
	DM-3	VL	EL	EL	EL	MH	H	MH	EL	EL	MH
	DM-4	EL	L	EL	EL	MH	MH	MH	VL	EL	MH
	DM-5	EL	EL	EL	EL	H	MH	MH	EL	VL	MH
	DM-6	EL	EL	VL	VL	MH	MH	MH	EL	EL	MH
	DM-7	EL	EL	EL	EL	MH	MH	MH	EL	EL	MH

(continued)

Alternatives	DMs	Max C1	Max C2	Max C3	Max C4	Max C5	Min C6	Max C7	Max C8	Max C9	Max C10
	DM-8	L	EL	EL	EL	M	MH	MH	EL	L	MH
	DM-9	EL	EL	VL	EL	M	M	M	VL	EL	M
	DM-10	EL	L	EL	EL	M	M	M	EL	EL	M
A2	DM-1	VL	L	VL	EL	VH	EH	H	VL	L	H
	DM-2	EL	VL	VL	EL	VH	EH	H	VL	L	H
	DM-3	EL	VL	VL	EL	H	VH	H	VL	L	H
	DM-4	EL	EL	VL	VL	H	VH	H	VL	L	H
	DM-5	VL	VL	VL	EL	H	VH	H	EL	L	H
	DM-6	EL	VL	VL	EL	H	VH	MH	EL	VL	MH
	DM-7	EL	VL	VL	EL	MH	H	MH	EL	VL	MH
	DM-8	L	VL	EL	VL	MH	H	MH	EL	VL	MH
	DM-9	EL	VL	EL	EL	MH	H	MH	EL	VL	MH
	DM-10	EL	VL	EL	EL	MH	MH	M	EL	VL	M
A3	DM-1	L	VL	MH	EL	VH	ML	H	L	H	H
	DM-2	L	VL	MH	EL	VH	ML	H	L	H	H
	DM-3	L	EL	MH	VL	H	ML	H	L	H	H
	DM-4	L	VL	MH	EL	H	ML	H	L	H	H
	DM-5	M	VL	MH	EL	H	ML	MH	VL	H	MH
	DM-6	VL	VL	MH	EL	H	ML	MH	VL	MH	MH
	DM-7	VL	VL	M	EL	MH	ML	MH	VL	MH	MH
	DM-8	EL	VL	M	VL	MH	L	MH	VL	MH	MH
	DM-9	VL	L	M	EL	MH	L	M	VL	MH	M
	DM-10	VL	VL	M	L	MH	L	M	VL	M	M
A4	DM-1	VL	EL	L	EL	H	MH	MH	VL	H	MH
	DM-2	VL	EL	L	EL	MH	MH	MH	VL	H	MH
	DM-3	VL	EL	VL	EL	MH	MH	MH	VL	H	M
	DM-4	EL	L	VL	L	MH	M	MH	VL	MH	MH
	DM-5	VL	EL	VL	EL	MH	M	MH	VL	MH	MH
	DM-6	VL	EL	M	EL	MH	M	MH	VL	MH	MH
	DM-7	L	EL	VL	EL	MH	M	M	VL	MH	M
	DM-8	VL	VL	VL	VL	M	M	M	VL	MH	M
	DM-9	VL	EL	VL	EL	M	ML	M	VL	M	M
	DM-10	EL	EL	EL	EL	M	ML	M	VL	M	M
A5	DM-1	EH	EH	EH	EH	EH	EL	EH	EH	EH	EH
	DM-2	EH	EH	EH	EH	EH	L	EH	EH	EH	EH
	DM-3	VH	VH	VH	VH	VH	EL	VH	VH	VH	VH
	DM-4	VH	VH	VH	VH	VH	EL	VH	VH	VH	VH
	DM-5	VH	VH	VH	VH	VH	EL	VH	VH	VH	VH
	DM-6	VH	VH	VH	VH	VH	VL	VH	VH	VH	VH
	DM-7	H	H	H	H	H	EL	H	H	H	H
	DM-8	H	H	H	H	H	EL	H	H	H	H
	DM-9	H	H	H	H	H	VL	H	H	H	H
	DM-10	MH	MH	MH	MH	MH	EL	MH	MH	MH	MH
A6	DM-1	EL	EL	EL	EL	H	MH	H	EL	EL	H
	DM-2	EL	EL	L	EL	MH	M	H	EL	L	H
	DM-3	L	EL	EL	L	MH	M	H	EL	EL	H
	DM-4	EL	VL	L	EL	MH	M	H	L	EL	H
	DM-5	EL	EL	EL	EL	MH	M	MH	EL	EL	MH
	DM-6	VL	L	EL	VL	MH	M	MH	EL	L	MH
	DM-7	EL	EL	EL	EL	MH	M	MH	VL	EL	MH
	DM-8	EL	EL	VL	EL	M	M	MH	EL	EL	MH
	DM-9	L	L	EL	EL	M	ML	MH	EL	L	MH
	DM-10	EL	EL	EL	EL	M	ML	M	EL	EL	M

Table A1.

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