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Pharmaceutical 3PL supplier selection using interval-valued intuitionistic fuzzy TOPSIS

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Abstract: Third party logistics (3PL) supplier selection problem is a multi-criteria selection problem that is frequently discussed in the literature. Medicine is a fundamental element for human health and drug transportation must be carried out on time and under conditions that will ensure that the drug does not lose its physical properties. Therefore, the pharmaceutical industry is one of the foremost and most important sectors in 3PL. In this multi-criteria problem where the evaluation criteria are linguistic rather than numerical, vagueness and impreciseness in evaluations can only be handled with the help of fuzzy sets. With the help of intuitionistic fuzzy sets, one of the new extensions of fuzzy sets, the vagueness and impreciseness here will be discussed and the 3PL supplier selection problem will be tried to be solved with the TOPSIS method, which is one of the most used MCDM methods in the literature. The use of Interval-Valued Intuitionistic Fuzzy sets will add more flexibility and accuracy to the assessment. Thus, the Interval-Valued Intuitionistic Fuzzy TOPSIS method is used to solve the 3PL supplier selection problem and the robustness of the decisions taken is tested with a sensitivity analysis.

Keywords: 3PL, Pharmaceutical sector, Interval-valued, Intuitionistic fuzzy sets, TOPSIS, Sensitivity analysis.
2020 Mathematics Subject Classification: 60-08, 62B10.

1 Introduction

The supply chain is one of the most important processes in the pharmaceutical industry. The pharmaceutical supply chain ensures that the processes from the manufacturers to the final consumer of the drugs are transported and stored at the right time, in the right place, in the right quantity with acceptable quality, and at optimum cost. Errors in supply chain management cause financial losses and damage to business brand value for all sectors. However, the errors that may occur in the pharmaceutical industry are additionally very critical since it directly affects human health. For this reason, the pharmaceutical industry is considered as one of the strategically important industries [34, 37].

Pharmaceuticals are delivered from producer to regional warehouses, from regional warehouses to pharmaceutical warehouses, from pharmaceutical warehouses to hospitals / pharmacies, and from hospitals/pharmacies to consumers. From the producer to the consumers, the products must be delivered in accordance with the most economical and special transportation-protection conditions. In order to ensure the preservation of the physical and pharmacological properties of drugs from environmental effects such as temperature, humidity, light, ventilation, radiation, etc., transportation and storage processes must be done under the right conditions. For this reason, the process must be carried out accurately and precisely. It is possible for the drug to be at its destination with the same quality, preserving all its properties after the producer, if the distribution channels comply with all procedures. Manufacturers generally carry out the transportation process with the possibilities of third-party logistics (3PL) companies.

Atanassov [2] introduced intuitionistic fuzzy sets (IFSs) as an extension of ordinary fuzzy sets developed by Zadeh [43]. Atanassov and Gargov [3] later proposed interval-valued intuitionistic fuzzy sets (IVIFSs) based on IFSs. Then, both IFSs and IVIFSs have become very attractive for researchers in many areas. The selection of the 3PL company is an important step for pharmaceutical producers, as the distribution channels ensure that the product quality is maintained after the producer. Therefore, within the scope of the proposed study, Interval-Valued Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)-based method has been proposed to evaluate the performance of 3PL enterprises operating in drug supply.

The rest of this study is organized as follows: a literature review on pharmaceutical supply chain problem is given in Section 2. Preliminaries on interval-valued intuitionistic fuzzy sets and the main steps of interval-valued intuitionistic fuzzy TOPSIS method are given in Section 3 and Section 4, respectively. Section 5 presents the application and sensitivity analysis. Finally, concluding remarks are given in Section 6.

2 Literature review on pharmaceutical supply chain problem

In recent years, various studies have been carried out on the pharmaceutical supply chain and various dimensions of the problem have been discussed from different perspectives. The highlights of these studies are summarized below.

Yalcinkaya and Cebi (2022) proposed an integrated method including Pythagorean fuzzy sets and AHP to evaluate pharmaceutical supply chain risks and the provided an application of the approach in Türkiye, [41]. Sampat et al. (2021) proposed a stochastic optimization model for the production plan in the pharmaceutical supply chain. In the study, a stochastic model is developed considering uncertainties related the productivity, demand and unplanned machine downtime, [34]. Mokrini and Aouam (2020) investigated the risks of public-private cooperation in the pharmaceutical supply chain for Morocco and presented a case study. In the study, potential risks in logistics were evaluated by using the Delphi method, Fuzzy Analytic Hierarchy Process (AHP), Fuzzy TOPSIS, and Fuzzy Preference Ranking Organization Method for Encrichment Evaluations (PROMETHEE), [7]. Wang and Jie (2020) proposed a conceptual framework considering health sector supply chain risks and uncertainties together, [40]. Gomez and Espana (2020) presented an approach based on Fuzzy Quality Function Deployment (QFD) to eliminate/reduce risks in the pharmaceutical supply chain. The proposed approach has been implemented in a pharmaceutical manufacturing facility in Colombia. In the application, 15 operational risks have been identified, of which the highest risk level is improper fleet and primary packaging material failures. The root causes of these risks were investigated with the cause-and-effect diagram and suggestions were made to eliminate or reduce these risks, [16]. Torasa and Mekhum (2020) proposed an empirical study analyzing the relationship between the supply chain risks and corporate reputation in the Thai pharmaceutical industry. While supply chain risk factors are analyzed under 15 sub-titles, corporate reputation is investigated under 5 sub-titles, [36]. Cundell et al. (2020) evaluated the possible effects of the Covid-19 pandemic on the pharmaceutical supply chain. In the study, personnel recruitment, purchasing of pharmaceutical and packaging components, facility design and operation, cleaning and disinfection, utilities, production processes, packaging and labeling, storage, shipping, distribution and patient usage parameters were evaluated according to good manufacturing practices, [6]. Silva et al. (2020) defined the risks in the pharmaceutical supply chain of Brazil and proposed an approach based on the AHP method to define their risk magnitudes, [35]. Lawrence et al. (2020) conducted a study investigating the effect of severe weather conditions on the disruption of the pharmaceutical supply chain, [22]. Lin et al. (2020) conducted a study analyzing the factors affecting the distributor's decision to use cold chain or non-cold chain in transportation for highly temperature sensitive vaccines, [24]. Franco and Alfonzo-Lizarazo (2020) presented a simulation-optimization approach to determine replenishment time and acceptable expiration date for the hospital level of pharmaceutical supply chain, [13]. Paul et al. (2020) presented a Bayesian belief network-based approach to assessing transportation disruption risk in Bangladesh pharmaceutical supply chains, [32]. Karmaker and Ahmed (2020) present an approach based on the Delphi method and the Decision Making Trial and Evaluation Laboratory, (DEMATEL) method to measure Bangladesh flexible pharmaceutical supply chain performance, identify the most important performance indicators and define the relationship between indicators, [20]. Benazzouz et al. (2019) used the Ishikawa fishbone diagram to identify and analyze the risks that may be encountered in the delivery of pharmaceutical products to Moroccan public hospitals, [4]. Ganguly and Kumar (2019) conducted a study to define effective strategies in designing a flexible supply chain, and in this context, they discussed the Indian pharmaceutical industry. The importance degrees of the determined strategies were obtained using the Fuzzy AHP method, [15]. Vishwakarma et al. (2019) presented a study examining the obstacles to be overcome in order to improve the Indian pharmaceutical supply chain performance, [38]. Nasrollahi and Razmi (2019) developed a mathematical model that minimizes allocation costs for the design of a pharmaceutical supply chain in Iran, [29]. Kumar and Jha (2018) proposed an approach for pharmaceutical supply chain risks that aims at identifying risks, determining risk magnitudes, mitigating risks and conducting periodic risk controls, [21]. Moktadir et al. (2018) developed a model based on Delphi and AHP methods to identify risks in the pharmaceutical supply chain and to prioritize the identified risks, [28]. Sabouhi et al. (2018) presented a hybrid approach based on fuzzy data envelopment analysis (DEA) and mathematical programming method for the design of flexible pharmaceutical supply chain, [33]. Lücker and Seifert (2017) examined risk reduction measures that can be applied to ensure drug supply chain resilience, [25]. El Mokrini et al. (2016) proposed an integrated model based on Fuzzy AHP and Fuzzy PROMETHEE methods to evaluate the risks of outsourcing logistics for the pharmaceutical industry, [9]. Friemann and Schönsleben (2016) analyzed the current state and future requirements of strategic drug warehouse capacity planning using a deterministic simulation model, [14]. Vishwakarma et al. (2016) presented a study based on the fuzzy AHP approach in order to identify and analyze the risks in the Indian pharmaceutical industry, [39].

In Table 1, the methods used in the literature is given. According to the table, AHP method is widely used method in the literature and the extension of fuzzy set has not been used before for the solution of the problem. Furthermore, the most considered criteria in the literature are Delivery reliability (C1), Quality (C2), Operations standardization (C3), Technology and communication (C4), Experience and reputation (C5), and Cost (C6).

Table 1. Methods used in the literature

Reference	**CRISP**	**FUZZY**	**METHODS**		
Aigbavboa and Mbohwa (2020) [1]	✓		Factorial Analysis		
El Mokrini and Aouam (2020) [7]		✓	AHP	TOPSIS	PROMETHEE
El Mokrini, Dafaoui (2016) [8]	✓		ELECTRE		
El Mokrini, Kafa et al.(2016) [9]		✓	AHP	DELPHI	PROMETHEE
Elleuch et al. (2013) [10]	✓		AHP	Simulation	FMEA
Enyinda (2018) [11]	✓		AHP		
Enyinda et al. (2009) [12]	✓		AHP	Mathematical Modeling	
Franco and Alfonso-Lizarazo (2020) [13]	✓		Simulation	Mathematical Modeling	
Friemann and Schönsleben (2016) [14]	✓		Simulation		
Ganguly and Kumar (2019) [15]		✓	AHP		
Gomez and Espana (2020) [16]		✓	QFD	Ishikawa D.	
Hatem and Habib (2011) [17]	✓		Simulation	FMEA	
Jaberidoost et al. (2015) [18]	✓		AHP	SAW	
Jnandev Kamath et al. (2012) [19]	✓		AHP		
Karmaker and Ahmed (2020) [20]		✓	DELPHI	DEMATEL	
Lawrence et al. (2020) [22]	✓		BAYES		
Li et al. (2015) [23]	✓		AHP		
Lin et al. (2020) [24]		✓	BAYES		
Marmolejo-Saucedo et al. (2019) [26]	✓		Mathematical Modeling		
Mehralian et al. (2012) [27]		✓	TOPSIS		
Moktadir et al. (2018) [28]	✓		AHP	DELPHI	

Contd.

Nasrollahi and Razmi (2019) [29]	✓		Mathematical Modeling		
Nsamzinshuti et al. (2017) [30]	✓		SCOR		
Ouabouch and Amri (2013) [31]	✓		Risk Matrix		
Paul et al. (2020) [32]	✓		AHP	BAYES	
Sabouhi et al. (2018) [33]	✓		DAE	Mathematical Modeling	
Sampat et al. (2021) [34]	✓		Stochastic Modeling		
Silva et al. (2020) [35]	✓		AHP		
Vishwakarma et al. (2019) [38]		✓	AHP		
Vishwakarma et al. (2016) [39]		✓	AHP		
Wang et al. (2013) [40]	✓		Factorial Analysis		

3 Interval-valued intuitionistic fuzzy sets (IVIFS)

Definition 1. Let $X \neq \emptyset$ be a given set. An intuitionistic fuzzy set in X is an object A given by

$$\tilde{A} = \{\langle x, \mu_{\tilde{A}}(x), v_{\tilde{A}}(x)\rangle; x \epsilon X\}, \tag{1}$$

where $\mu_{\tilde{A}}: X \to [0,1]$ and $v_{\tilde{A}}: X \to [0,1]$ satisfy the condition

$$0 \leq \mu_{\tilde{A}}(x) + v_{\tilde{A}}(x) \leq 1, \tag{2}$$

for every $x \epsilon X$. Hesitancy is equal to "1 – $\left(\mu_{\tilde{A}}(x) + v_{\tilde{A}}(x)\right)$"

Intuitionistic fuzzy sets introduced by Atanassov [2] enable defining both the membership and non-membership degrees of an element in a fuzzy set. Their sum can be equal to or less than 1. The difference from 1, if any, is called hesitancy.

Definition 2. Let U be a universe of discourse. An IVIFS $\tilde{A}$ is defined as follows:

$$\tilde{A} = \left\{\left(\mu_{\tilde{A}}(x), v_{\tilde{A}}(x)\right) \middle| x \in X\right\} \tag{3}$$

where $\mu_{\tilde{A}}(x) : X \to [0, 1]$ and $v_{\tilde{A}}(x) : X \to [0, 1]$ are the membership and non-membership degrees of the element x to the set $\tilde{A}$, respectively. The condition $\sup\left(\mu_{\tilde{A}}(x)\right) + \sup(v_{\tilde{A}}(x)) \leq 1$ must be satisfied.

For each $x \in X$, $\mu_{\tilde{A}}(x)$ and $v_{\tilde{A}}(x)$ denote $\mu_{\tilde{A}}(x) = \left[\mu_{\tilde{A}}^-, \mu_{\tilde{A}}^+\right]$ and $v_{\tilde{A}}(x) = \left[v_{\tilde{A}}^-, v_{\tilde{A}}^+\right]$, respectively. Thus, an IVIFS can be given as in Eq. (4):

$$\tilde{A} = \left\{\langle x, \left[\mu_{\tilde{A}}^-, \mu_{\tilde{A}}^+\right], \left[v_{\tilde{A}}^-, v_{\tilde{A}}^+\right]\rangle \middle| x \in X\right\} \tag{4}$$

The addition and multiplication operations are given as in Eq. (5) and Eq. (6):

$$\tilde{A}_1 \oplus \tilde{A}_2 = ([\mu_1^- + \mu_2^- - \mu_1^- \mu_2^-, \mu_1^+ + \mu_2^+ - \mu_1^+ \mu_2^+], [v_1^- v_2^-, v_1^+ v_2^+]) \tag{5}$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = ([\mu_1^- \mu_2^-, \mu_1^+ \mu_2^+], [v_1^- + v_2^- - v_1^- v_2^-, v_1^+ + v_2^+ - v_1^+ v_2^+]) \tag{6}$$

For any IVIFS, the score function is defined as in Eq. (7):

$$s(\tilde{A}) = \frac{1}{2}\left(\mu_{\tilde{A}}^- + \mu_{\tilde{A}}^+ - v_{\tilde{A}}^- - v_{\tilde{A}}^+\right) \tag{7}$$

where $s(\tilde{A}) \in [-1, 1]$.

4 Interval-valued intuitionistic fuzzy TOPSIS (IVIF TOPSIS)

The following IVIFS TOPSIS method steps can be applied to determine the scores of the alternatives, [42].

Step 1. Obtain interval-valued intuitionistic fuzzy decision matrix $[\tilde{Y}_k]$ as given in Eq. (8) and weights of the criteria $\widetilde{W}$ from each decision maker (k = 1, …, K) using the interval valued intuitionistic fuzzy scale given in Table 2.

Table 2. Interval valued intuitionistic fuzzy scale

Linguistic terms	Membership & Non-membership values
Very Poor (VP)	([0.15, 0.30], [0.60, 0.70])
Poor (P)	([0.20, 0.35], [0.55, 0.65])
Medium Poor (MP)	([0.25, 0.40], [0.50, 0.60])
Medium/Fair (F)	([0.45, 0.55], [0.30, 0.45])
Medium Good (MG)	([0.50, 0.60], [0.25, 0.40])
Good (G)	([0.55, 0.65], [0.20, 0.35])
Very Good (VG)	([0.60, 0.70], [0.15, 0.30])

$$\tilde{Y}_k = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{cccc} A_1 & A_2 & \cdots & A_m \\ ([\mu_{11k}^-, \mu_{11k}^+], [v_{11k}^-, v_{11k}^+]) & ([\mu_{12k}^-, \mu_{12k}^+], [v_{12k}^-, v_{12k}^+]) & \cdots & ([\mu_{1mk}^-, \mu_{1mk}^+], [v_{1mk}^-, v_{1mk}^+]) \\ ([\mu_{21k}^-, \mu_{21k}^+], [v_{21k}^-, v_{21k}^+]) & ([\mu_{22k}^-, \mu_{22k}^+], [v_{22k}^-, v_{22k}^+]) & \cdots & ([\mu_{2mk}^-, \mu_{2mk}^+], [v_{2mk}^-, v_{2mk}^+]) \\ \vdots & \vdots & \ddots & \vdots \\ ([\mu_{n1k}^-, \mu_{n1k}^+], [v_{n1k}^-, v_{n1k}^+]) & ([\mu_{n2k}^-, \mu_{n2k}^+], [v_{n2k}^-, v_{n2k}^+]) & \cdots & ([\mu_{nmk}^-, \mu_{nmk}^+], [v_{nmk}^-, v_{nmk}^+]) \end{array} \quad (8)$$

where n denotes the number of criteria (j = 1, …, n) and m denotes the number of alternatives (i = 1, …, m).

Step 2. Determine fuzzy positive ideal solution ($\widetilde{PIS}_k$) and fuzzy negative ideal solution ($\widetilde{NIS}_k$) for each decision maker by using score function and accuracy function, if needed, in Eqs. (9) and (10). Let

$$\widetilde{PIS}_k = \left(([\mu_{1^*k}^-, \mu_{1^*k}^+], [v_{1^*k}^-, v_{1^*k}^+]), ([\mu_{2^*k}^-, \mu_{2^*k}^+], [v_{2^*k}^-, v_{2^*k}^+]), \cdots, ([\mu_{n^*k}^-, \mu_{n^*k}^+], [v_{n^*k}^-, v_{n^*k}^+])\right) \quad (9)$$

$$\widetilde{NIS}_k = \left(([\mu_{1^-k}^-, \mu_{1^-k}^+], [v_{1^-k}^-, v_{1^-k}^+]), ([\mu_{2^-k}^-, \mu_{2^-k}^+], [v_{2^-k}^-, v_{2^-k}^+]), \cdots, ([\mu_{n^-k}^-, \mu_{n^-k}^+], [v_{n^-k}^-, v_{n^-k}^+])\right) \quad (10)$$

where $([\mu_{i^*k}^-, \mu_{i^*k}^+], [v_{i^*k}^-, v_{i^*k}^+])$ is the maximum intuitionistic fuzzy set among the alternatives' values for the j-th criterion and $([\mu_{i^-k}^-, \mu_{i^-k}^+], [v_{i^-k}^-, v_{i^-k}^+])$ is the minimum intuitionistic fuzzy set among the alternatives' values for the j-th criterion.

Step 3. Calculate the separation measure between the i-th alternative and $\widetilde{PIS}_k$ for each decision maker by using Eq. (11).

$$Y_i^{*k} = \sqrt{\frac{1}{2}\sum_{j=1}^{n} w_i^T \left\{\left(\mu_{ijk}^- - \mu_{i^*k}^-\right)^2 + \left(\mu_{ijk}^+ - \mu_{i^*k}^+\right)^2 + \left(v_{ijk}^- - v_{i^*k}^-\right)^2 + \left(v_{ijk}^+ - v_{i^*k}^+\right)^2 + \left(\pi_{ijk}^l - \pi_{i^*k}^l\right)^2 + \left(\pi_{ijk}^u - \pi_{i^*k}^u\right)^2\right\}} \quad (11)$$

where w_i^T is the normalized weight of the criterion i.

Calculate the separation measure between the i-th alternative and $\widetilde{NIS}_k$ for each decision maker by using Eq. (12).

$$Y_i^{-k} = \sqrt{\frac{1}{2}\sum_{j=1}^{n} w_i^T \left\{\left(\mu_{ijk}^- - \mu_{i^-k}^-\right)^2 + \left(\mu_{ijk}^+ - \mu_{i^-k}^+\right)^2 + \left(v_{ijk}^- - v_{i^-k}^-\right)^2 + \left(v_{ijk}^+ - v_{i^-k}^+\right)^2 + \left(\pi_{ijk}^l - \pi_{i^-k}^l\right)^2 + \left(\pi_{ijk}^u - \pi_{i^-k}^u\right)^2\right\}} \tag{12}$$

where w_i^T is the normalized weight of the criterion i.

Step 4. Aggregate the separation measures for the decision makers group by using Eqs. (13) and (14) for alternative i.

$$Y_i^* = \sum_{k=1}^{K}\left(\lambda_k Y_i^{*k}\right) \tag{13}$$

$$Y_i^- = \sum_{k=1}^{K}\left(\lambda_k Y_i^{-k}\right) \tag{14}$$

where $i = 1, 2, \ldots, m$; $k = 1, 2, \ldots, K$, and λ_k is the weight of decision maker k and $0 \leq \lambda_k \leq 1$, $\sum_{k=1}^{K} \lambda_k = 1$.

Step 5. Calculate the closeness coefficient of each alternative using Eq. (15)

$$U_i = \frac{Y_i^-}{Y_i^- + Y_i^*},\ i = 1,2,\ldots,m \tag{15}$$

Step 6. Rank the preference order of all alternatives according to the closeness coefficient of the alternatives and select the best one. Perform a sensitivity analysis in order to check the robustness of decisions.

5 Application

5.1 Problem definition

Eight pharmaceutical 3PL suppliers are evaluated with respect to five criteria, which are Delivery reliability (C1), Quality (C2), Operations standardization (C3), Technology and communication (C4), and Cost (C5). Three experts evaluate the alternatives based on these criteria as given in Table 3 as a compromised matrix. Then, score function results and minimum and maximum values are presented in Table 4.

Table 3. Compromised Decision matrix

Experts' compromised evaluations	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**
C1	MP	AH	F	MG	P	MG	VG	F
C2	MG	G	MG	P	VG	G	VG	MG
C3	P	P	F	VG	VG	VG	P	MG
C4	AH	MP	VG	G	F	MG	F	F
C5	VG	G	G	G	F	F	G	G

Table 4. Score Function results and minimum and maximum values

Criteria	A1	A2	A3	A4	A5	A6	A7	Max	Min
C1	–0.23	0.53	0.13	0.23	–0.33	0.23	0.43	0.53	–0.33
C2	0.23	0.33	0.23	–0.33	0.43	0.33	0.43	0.43	–0.33
C3	–0.33	–0.33	0.13	0.43	0.43	0.43	–0.33	0.43	–0.33
C4	**0.53**	–0.23	0.43	0.33	0.13	0.23	0.13	0.53	–0.23
C5	0.43	0.33	0.33	0.33	0.13	0.13	0.33	0.43	0.13

From the minimum and maximum values in Table 4, we obtain the corresponding IVIF values of Positive (PIS) and negative (NIS) ideal solutions as in Table 5.

Table 5. Positive and negative ideal solutions with respect to criteria

Criteria	PIS	NIS
C1	[0.65, 0.75], [0.10, 0.25]	[0.20, 0.35], [0.55, 0.65]
C2	[0.60, 0.70], [0.15, 0.30]	[0.20, 0.35], [0.55, 0.65]
C3	[0.60, 0.70], [0.15, 0.30]	[0.20, 0.35], [0.55, 0.65]
C4	[0.65, 0.75], [0.10, 0.25]	[0.25, 0.40], [0.50, 0.60]
C5	[0.60, 0.70], [0.15, 0.30]	[0.45, 0.55], [0.30, 0.45]

The next Table 6 gives the distances of the alternatives to positive and negative ideal solutions.

Table 6. Distances to positive and negative ideal solutions

Alternatives	A1	A2	A3	A4	A5	A6	A7
Distance to PIS	0.342	0.339	0.176	0.266	0.312	0.187	0.273
Distance to NIS	0.311	0.345	0.344	0.349	0.354	0.377	0.360

The following Table 7 gives the closeness coefficients and ranking of the alternatives.

Table 7. Closeness coefficients and ranking of the alternatives

Alternatives	A1	A2	A3	A4	A5	A6	A7
Closeness coefficients	0.48	0.50	0.66	0.57	0.53	0.67	0.57
Rank	7	6	2	4	5	1	3

According to the obtained results given in Table 7, the best alternative is A7. The ranking of the alternatives is A6 > A3 > A7 > A4 > A5 > A2 > A1.

5.2 Sensitivity analysis

In this subsection, a sensitivity analysis for observing the robustness of the given decisions by changing the criteria weights slightly is presented. In other words, the effects of the criteria weights on the ranking results will be observed. Table 8 shows the new sets of criteria weights and the corresponding ranking results are presented in Table 9.

Table 8. Sets of weights for sensitivity analysis

Criteria	Weights Set 1	Weights Set 2	Weights Set 3	Weights Set 4	Weights Set 5
C1	0.15	0.20	0.20	0.20	0.20
C2	0.25	0.25	0.20	0.20	0.20
C3	0.20	0.15	0.15	0.20	0.20
C4	0.20	0.20	0.25	0.25	0.15
C5	0.20	0.20	0.20	0.15	0.25

Table 9. Ranking of the Alternatives with respect to the sets of weights

Set of weights	Alternatives rankings from the best to the worst						
	A1	A2	A3	A4	A5	A6	A7
SET1	6	7	2	5	3	1	4
SET2	7	5	2	6	4	1	3
SET3	6	7	2	4	5	1	3
SET4	6	7	2	3	5	1	4
SET5	7	6	2	4	5	1	3

Figure 1 illustrates the set of weights and the ranking of the alternatives. For instance, Alternative 3 takes the second ranking in all set of weights and Alternative 6 is always in the first ranking in all sets. The rankings of Alternatives 1, 2, 4, 5, and 7 change with respect to the set of weights. That means the rankings of A3 and A6 are not sensitive but the others are.

Table 10 presents the closeness coefficients with respect to the sets of weights. Figure 2 illustrates the positions of alternatives with respect to the closeness coefficients. Alternatives A3 and A6 are clearly dominant to the other alternatives and A6 is the best alternative in all cases. The case that Alternative A3 is better than Alternative A6 is observed when the criteria weights are 0.1, 0.1, 0.2, 0.2 and 0.3, respectively. If the weights are assigned as 0.3, 0.2, 0.2, 0.1, and 0.1, respectively, Alternative 6 is still the best. That means criteria C4 and C5 are more important for the success of A3.

Table 10. Sets of weights and closeness coefficients

Set of weights	A1	A2	A3	A4	A5	A6	A7
SET1	0.501	0.496	0.675	0.540	0.570	0.708	0.569
SET2	0.501	0.531	0.668	0.530	0.532	0.695	0.607
SET3	0.510	0.504	0.674	0.559	0.515	0.683	0.589
SET4	0.491	0.489	0.670	0.573	0.532	0.702	0.565
SET5	0.460	0.521	0.652	0.562	0.531	0.695	0.573

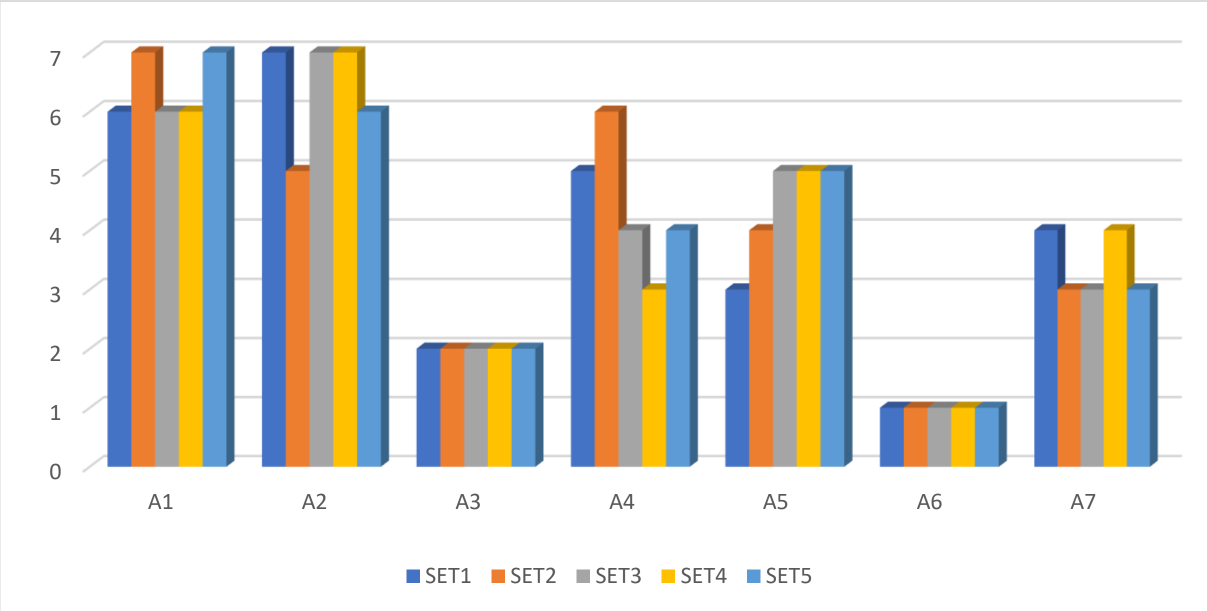

Figure 1. Sensitivity of weight sets

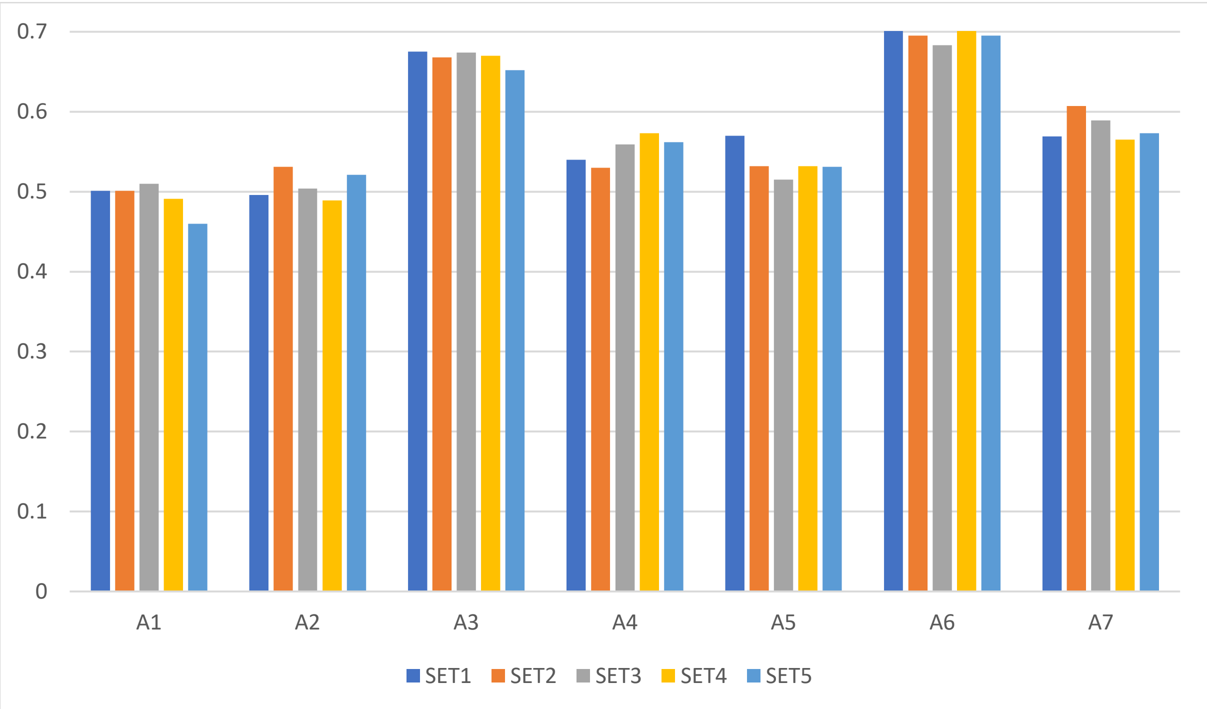

Figure 2. Positions of alternatives with respect to closeness coefficients

6 Conclusion

Pharmaceuticals are strategic products that must be monitored under certain conditions in the process from production to the point of consumption. Especially in the transport step after leaving the manufacturer, the physical properties of the drug must be transported without deterioration and delivered to the point of consumption on time. At this point, the task of 3PL companies gains importance. For this reason, businesses need to be very selective when choosing 3PL companies. However, due to the subjective nature of the evaluation criteria in the process, there are vagueness and impreciseness in the evaluation process. In this study, an interval-valued Intuitionistic fuzzy TOPSIS-based method was used to take into account the uncertainty in the linguistic evaluation processes of 3PL enterprises. Different criteria weights and different decision matrices have been considered in the model. For future studies, other fuzzy set extensions such as spherical fuzzy sets or neutrosophic sets can be used for comparison. In particular, decomposed fuzzy sets (DFS) proposed by Cebi et al. [5] can be used to address the indeterminacy arising from contrasts in the decision maker's assessments.

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