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APPLICATION OF PFAHP-GTOPSIS METHODS FOR THIRD-PARTY LOGISTICS PROVIDER SELECTION

ÜÇÜNCÜ TARAF LOJİSTİK SAĞLAYICI SEÇİMİNDE PFAHP-GTOPSIS YÖNTEMLERİNİN UYGULANMASI

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Keywords
Grey TOPSIS, Multi-Criteria Decision-Making, Pythagorean Fuzzy AHP, Third-Party Logistics Provider.

ÖZ

Küresel pazarlardaki rekabet, daha kaliteli ürün kullanımı ve artan müşteri talepleri nedeniyle tedarik zincirlerini güncellemek için temel becerilerine odaklanarak riskten korunmanın maliyet yaratması ve verimliliği artırması nedeniyle şirketler artık dış kaynak kullanma seçeneğini değerlendiriyor. Bu şirketler lojistikle ilgili birçok görevi Üçüncü Taraf Lojistik Sağlayıcılarına (3TLS) devretmeden önce hangi şirketle iş birliği yapacaklarını dikkatlice seçmeli ve belirlemelidirler. Ancak 3TLS seçim problemlerinde belirsizliklerin ve insan etkisinin varlığı, bulanık veya ilgili küme teorilerinin kullanılmasına yol açmaktadır. Çok Kriterli Karar Verme (ÇKKV) yöntemlerinin bulanık sayılar ve gri sayılarla birleştirilmesiyle, öznel yargıların belirsizliğini giderecek pratik araçlar oluşturulabilir. Bu perspektiften bakıldığında, 3PLP değerlendirme ve seçimine ışık tutacak bütünleşmiş bir ÇKKV modeli önerilmiştir. Önerilen model, Pisagor bulanık sayıları ve gri sayılardan oluşan entegre bir çerçeveden oluşmaktadır ve ilgili model gıda endüstrisindeki bir şirkette müşteri siparişlerini teslim etmek için kullanılan 3TLS'ye uygulanmıştır. Değerlendirme kriterleri ağırlıkları, Pisagor Bulanık Analitik Hiyerarşi Süreci (PBAHS) yöntemi kullanılarak hesaplanır ve 3PLP'ler, en iyi 3TLS'yi bulmak için Gri İdeal Çözüme Benzerliğe Göre Sipariş Tercihi Tekniği (GTOPSIS) yöntemleri kullanılarak sıralanır. Analizler ve bulgular, maliyet, hizmet kalitesi ve zamanında teslimatın en büyük etkiye sahip üç kriter olduğu sonucuna varmıştır.

ABSTRACT

Companies are now considering the option of outsourcing as hedges cost and increase productivity by concentrating on their core skills to update their supply chains due to the competition in global markets, the use of higher-quality products, and rising customer demands. They must carefully select and identify which company to collaborate with before outsourcing their numerous logistics-related tasks to Third-Party Logistics Providers (3PLP). However, the existence of uncertainties and human influence in 3PLP selection problems leads to the usage of fuzzy or related set theories. By incorporating Multi-Criteria Decision Making (MCDM) methods with fuzzy numbers and grey numbers, practical tools can be composed to address the imprecision of subjective judgments. From this perspective, an integrated MCDM model is proposed to provide insight into the 3PLP evaluation and selection. The model comprises an integrated framework with Pythagorean fuzzy numbers and grey numbers. The proposed model has applied a 3PLP a company in the food industry to fulfill customer orders. The evaluation criteria weights are calculated using the Pythagorean Fuzzy Analytic Hierarchy Process (PFAHP) method, and the 3PLPs are ranked using the grey Technique for Order Preference by Similarity to Ideal Solution (GTOPSIS) methods to find the best 3PLP. The analyses and findings concluded that cost, service quality, and on-time delivery were the three criteria that had the greatest influence

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Introduction

Today, the logistics sector is one of the primary drivers of economic growth in the worldwide market due to changes in production processes, an increase in the competitive environment, and the growing relevance of customer demands (Gardas et al., 2019). As a result of increased prices and developments in information and communication technologies, businesses are focusing on their core strengths (Pamucar et al., 2019). As a result, they are outsourcing logistics tasks outside of their areas of expertise. (Pamucar et al., 2019). The primary goals of logistics outsourcing are improvement and cost minimization (Rajesh et al., 2012). These factors contribute to the usage of logistics outsourcing becoming more and more prevalent daily. Transportation, distribution, storage, and other operations may be delegated entirely or in part to third-party logistics providers (3PLPs) (Yazdani et al., 2017).

3PLPs can effectively and efficiently manage companies' logistics operations since they possess specific logistics competencies (Perçin, 2009). As a result, 3PLPs may enable the customer to save costs and reduce inventory through government regulation, giving them a significant advantage in a quick and volatile industry (Narkhede et al., 2017). Because of these, 3PLPs have a growing critical significance nowadays. For example, in the United States, 10 years of e-commerce growth were seen in just 90 days, particularly during and after the COVID-19 era. This growth was reflected in 3PLP as 79% (Skender, 2023). Another example is a powerful earthquake that occurred in Kahramanmaraş, Türkiye (Ghosh, 2023). This disaster harmed 11 cities. Roads crumbled due to the earthquake's strength, making it extremely challenging to deliver supplies to affected areas. Logistics, and in particular 3PLP selection, become increasingly important in such situations because the local populace there has a wide range of requirements that must be met somehow. If 3PLP is properly selected, there won't be any distribution problems. Nonetheless, it will be quite challenging to reach the area if the 3PLP selection is inadequate.

The significance of 3PLP selection is thus clearly stated. Companies need to select a 3PLP that can handle the growth, technological, and sustainability activities. 3PLP selection is a Multi-Criteria Decision Making (MCDM) problem involving many competing criteria and methods such as quality, cost, and delivery time (Y. Liu et al., 2020). Companies generally consider cost alone while making this decision, putting other factors like delivery time, brand perception, problem-solving capabilities, and long-term relationships with the company in the background. In particular, it is no longer sufficient to obtain cost, time, and quality criteria in a business environment that is growing and changing and places a focus on sustainable supply chain management (R. Raut et al., 2018).

Selecting an appropriate 3PLP is very complex and time-consuming as it involves many uncertainties. The number and complexity of factors affecting the decision-making process show that the selection of 3PLP is an MCDM problem (Akman & Baynal, 2014). However, classical MCDM methods may not be adequate to capture decision-makers' judgments. Fuzzy set theory and grey set theory may be employed to deal with the imprecision and vagueness of decision-makers. Therefore, both fuzzy set theory (Zadeh, 1978; Zadeh et al., 1996) and grey set theory (Yang et al., 2013; Yang & John, 2012) were implemented for the 3PLP selection problem. The integration of these sets has not been presented to the best of the authors' knowledge for 3PLP selection.

One of the most significant contributions of this study is the combination of fuzzy set theory with grey set theory for 3PLP selection. The information obtained from the people generally includes uncertainty in the real world. Fuzzy set theory and grey system theory are more effective than exact (crisp) approaches for dealing with uncertainty in data insufficiency (Çelikbilek & Tüysüz, 2016). As an extension of fuzzy sets, grey sets can be studied if the values of their characteristic functions are restricted to the interval (Yang & John, 2012). Additionally, some researchers believe grey sets are the generalization of an interval-valued fuzzy set (Khuman et al., 2014; Yang et al., 2013). Instead of expressing the people's preference for crisp numbers, a wider scope of the number may be established via intervals. Therefore, interval-valued numbers that ensure more flexibility Kuo and Liang (2012) are preferred in this study. The superiority of this study is integrating interval-valued Pythagorean fuzzy numbers that deal with higher degrees of uncertainty Zhang (2016), with interval-valued grey numbers which are convenient in the calculation process (Alkharabsheh et al., 2021). Another urgent contribution is specifying the key criterion and specifying appropriate 3PLP through increased attention within the food sector.

In this work, the integrated Pythagorean Fuzzy AHP (PFAHP) and Grey TOPSIS (GTOPSIS) approaches were used to calculate the weight of the criteria and the ranking of the alternatives. The methodologies are then applied to a case study of a food company, to demonstrate the proposed integrated method. The Fuzzy TOPSIS approach is then used to examine and compare the results. A sensitivity analysis is also performed to validate the proposed model and its outcomes.

There are five sections to the research. The studies using the AHP and TOPSIS methodologies for selecting 3PL companies are included in the study's second section. The third section explains the PFAHP, GTOPSIS procedures used in the study. The fourth section presents the suggested MCDM model's application. The study's conclusion is discussed in the last section, along with recommendations for more research.

Literature Reviews

In this study, the literature section includes in two parts. A review of the research using the fuzzy set theory in the MCDM is presented in the first section, while a review of the research using the grey system theory in the MCDM for the selection of 3PLP is shown in the second.

Fuzzy Set Theory

Jovčić et al. (2019) investigated the 3PLP provider problem of the automotive company implementing the FAHP and TOPSIS approaches. The AHP method using graph theory and matrix method was proposed by Tuljak-Suban and Bajec (2020) to handle the 3PLP selection problem of Slovenian pharmaceutical manufacturers. To solve the 3PLP selection for a company that produces cakes and delicious biscuits, Bianchini (2018) combined the use of AHP and TOPSIS methodologies. Erdebilli et. al., (2023) implemented a sustainable supplier application for the healthcare sector by using Q-ROF-based fuzzy TOPSIS and VIKOR methods. Özcan and Ahıskalı (2020) solved the 3PLP order allocation problem using AHP, TOPSIS, and a multi-objective weighted goal programming model. Çalık et. al. (2023) applied an application for the sector with MCDM methods for the logistics performance index. Percin (2009) combined AHP and TOPSIS methods ranking of potential five 3PLPs. An interval type-2 fuzzy ANP approach for 3PLP selection was presented by Senturk (2017). Soh (2010) is practiced 3PL provider application in the logistics sector with 5 main and 13 sub-criteria. FAHP method is implemented in the study. Erkayman and Yılmaz (2012) applied FAHP and FTOPSIS methods for 3PL provider selection. The two most important factors are considered to be pricing and customer service. Yadav et al. (2020) applied the FAHP method for the selection of the best 3PLP focusing on assessment in the agricultural supply chain. (Daim et al., 2013) utilized the AHP method for the first time for 3PLP selection. Yayla et al., (2015) employed FAHP and FTOPSIS methods for 3PLP evaluation in a confectionary company. A novel model consists of AHP, DEA, and linear programming was created by Falsini et al., (2012). Ecer (2018) implemented FAHP and FEDAS methods for 3PL selection. It has been discovered that the main considerations in selecting a 3PL service are professionalism and quality. Ali et al., (2014) determined the reasons for outsourcing companies by AHP method. Bayazit and Karpak (2013) demonstrated how the AHP method can be used in 3PLP assessment for an aviation company. Raut et al. (2019) examined the 3PLP assessment with the AHP-DEA-GCOPRAS integrated method. The AHP approach was used by Chen et al., (2011) to determine which 3PLP in the garment supply chain was the best option. An integrated FAHP and FTOPSIS approach was developed by Chen et al., (2011) to choose the optimal 3PLP for India's cold chain business. Jung (2017) evaluated the social sustainability of 3PLPs with the FAHP method. Rahman et al., (2019)identified the challenges of multinational 3PLPs operating in China and prioritized them with the AHP method. Ho et al., (2012) developed an integrated QFD-FAHP approach to measure the performance of 3PLPs. Jovcic et. al. (2019) applied FAHP and FTOPSIS methods in 3PLP selection. Pamucar et al. (2019) used a multi-criteria decision-making method based on intervals of rough numbers to implement an assessment of 3PL providers. Roy et. al. (2020) implemented interval-valued fuzzy-rough approximations 3PLP selection. Wang et al. (2021) conducted a study on the selection of 3PL in the e-commerce sector in Vietnam. 3PL provider application is implemented with FAHP and FVIKOR. The application is implemented with 5 main and 15 sub-criteria. According to FVIKOR results, 3PL01, 3PL08, and 3PL02 are selected as the best 3PL providers. Wiangkam et al. (2022) employed a FMCDM application for the food industry. Fuzzy TOPSIS and ROC methods are implemented in the study with 11 main and 26 sub-criteria. The study's findings indicate that some of the most crucial factors include transportation system standards, on-time delivery, and transportation costs. Mohammadkhani and Mousavi (2023) performed reverse third-party logistics selection and FMCDM methods together. The study has been applied to the food industry and the FBWM method is implemented in the application section. There are 4 main and 17 sub-criteria in the study. Economic criteria are at the top of the list as the level of importance in the study. Chang (2023) 2-tuple linguistic representation method and CoCoSo and SWARA methods are implemented in the study in an integrated manner. The study is important for combining 3PL with different approaches. Cebi et al. (2023) has applied the Decomposed Fuzzy Analytic Hierarchy Process (DF-AHP) in the study. The study is conducted for the pharmaceutical industry. The most important criterion has been found to be quality.

Grey System Theory

Grey system theory has been implemented together with MCDM methods in recent studies. Recent grey system application studies are; (Alwan et al., 2023; Arunagiri et al., 2023; Badi et al., 2023; Biswas & Pamucar, 2023; Konstantinou & Gkritza, 2023; Lakshmi Narayana & Gopalan, 2023; Raji et al., 2023; Sorooshian, 2023; Zheng, 2023). A few Grey system theory is also applied in 3PL studies. Huo and Wei (2008a) implemented an application for the selection of 3PLP in an uncertain environment. AHP, ENTROPY, and grey system theories are all combined in the application section. The study includes 5 primary and 17 secondary criteria. The results demonstrated that service quality, service cost, and flexibility are the most important main criteria in this study. Huo and Wei (2008b) conducted a study on cooperation between manufacturers and 3PL providers through AHP and ENTROPY methods. Govindan (2016) has implemented a 3PLP application for the automobile industry. Grey system theories and DEMATEL methods are applied in this study. The most crucial factors in choosing a 3PLP are, in that order, timely delivery performance, technological proficiency, economic viability, and human resource policy and Zhou (2014) employed grey clustering and entropy methods in the selection of 3PLP. Finally, No. 9 is selected as the 3PL supplier result of analysis. Nguyen et al., (2022) have implemented a logistics service provider in Vietnam. GAHP and GCOPRAS methods are implemented in the study. According to the GCOPRAS result, CPL-05 is selected as the best cold logistics provider. The most crucial factors—product quality, customer fulfillment, logistical expenses, innovation, and the efficiency of cold chain procedures—are examined in this study.

Research Gaps

Reviews of the literature are detailed given in above and some gaps are revealed in this section. First, no study integrates the PFAHP and GTOPSIS methods. To show this gap the studies in the related literature relating the 3PLP selection are examined and illustrated in Table 1. The second issue is that there are few studies evaluating 3PLP in the food industry. Therefore, the purpose of this paper is to provide a systematic tool to fill these gaps.

Table 1. Grey and Fuzzy 3PL Literature Gap

Article	*Research Methodology*		*Weighting Method*	*Ranking Method*
	Fuzzy	*Grey*		
Govindan et al. (2016)		✓	DEMATEL	
Ulutas (2021)		✓	SWARA	
Pinar and Boran (2022)	✓			CODAS
Jovčić et al. (2019)	✓		AHP	TOPSIS
Huo and Wei (2008a)		✓	AHP- ENTROPY	
Ying and Chao (2010)		✓	ENTROPY	GRAP
Aydın (2021)	✓		ENTROPY	
Huo and Wei (2008b)		✓	AHP	
Zhou (2014)		✓	ENTROPY	
Luyen and Thanh (2022)	✓		AHP	TOPSIS
Sahu et al. (2017)		✓		TOPSIS
Yayla et al. (2015)	✓		AHP	TOPSIS
SoonHu (2010)	✓		AHP	
Nguyen et al. (2022)		✓	AHP	COPRAS

Vafaeipour et al. (2014)	✓		CRITIC	WASPAS
Erkayman et al. (2012)	✓		AHP	TOPSIS
Liu and Wang (2009)	✓		Inference System	Linear Assignment
Roy et al. (2020)	✓		FARE	MABAC
Pamucar et al. (2019)	✓		BWM	WASPAS- MABAC
Yazdani et al. (2017)		✓	COCOSO	
Ecer (2018)	✓		AHP	EDAS
Fan et al. (2020)	✓			MABAC
Wang et al. (2021)	✓		AHP	VIKOR
This study	✓	✓	**Pythagorean AHP**	**TOPSIS**

The Proposed Model

An integrated MCDM model is suggested in this section to investigate 3PLP selection. The suggested model involves three main steps: (i) specifying the relevant criteria for 3PLP selection using the nominal group technique; (ii) determining the weights of the criteria with Pythagorean fuzzy numbers; and (iii) ranking possible 3PLP companies with grey numbers. The following methodologies are an outline of the model:

Pythagorean Fuzzy AHP

The steps of PFAHP are presented as follows:

Step 1: The pairwise comparison matrix $A = (a_{ik})_{m\times m}$ is built using expert evaluations using the scale suggested by Ilbahar et al. (2018).

Step 2: The difference matrices $D = (d_{ik})_{m\times m}$ between the lower and upper values are computed using Eqs. (1) and (2):

$$d_{ik_L} = \mu^2_{ik_L} - v^2_{ik_U}, \tag{1}$$

$$d_{ik_U} = \mu^2_{ik_U} - v^2_{ik_L}. \tag{2}$$

Step 3: Interval multiplicative matrix $S = (s_{ik})_{m\times m}$ is calculated using Eqs. (3) and (4):

$$s_{ik_L} = \sqrt{1000^{d_{ik_L}}}, \tag{3}$$

$$s_{ik_U} = \sqrt{1000^{d_{ik_U}}}. \tag{4}$$

Step 4: The determinacy value $\tau = (\tau_{ik})_{m\times m}$ is calculated using Eq. (5):

$$\tau_{ik} = 1 - \left(\mu^2_{ik_U} - \mu^2_{ik_L}\right) - \left(v^2_{ik_U} - v^2_{ik_L}\right). \tag{5}$$

Step 5: The determinacy degrees are multiplied with $S = (s_{ik})_{m\times m}$ matrix for obtaining the matrix of weights, $T = (t_{ik})_{m\times m}$ before normalization using Eq. (6).

$$t_{ik} = \left(\frac{s_{ik_L} + s_{ik_U}}{2}\right)\tau_{ik}. \tag{6}$$

Step 6: The weights of criteria (w_i) are normalized by using Eq. (7):

$$w_i = \frac{\sum_{k=1}^{m} t_{ik}}{\sum_{i=1}^{m}\sum_{k=1}^{m} t_{ik}}. \tag{7}$$

Grey TOPSIS

The steps of GTOPSIS are presented as follows (Oztaysi, 2014);

Step 1: Determining the most vital elements, and the alternatives, defining the decision criteria.

Step 2: Determining the decision matrix D,

$$D = \begin{bmatrix} \otimes x_{11} & \dots. & \otimes x_{1m} \\ \dots & \dots & \dots \\ \otimes x_{n1} & \dots & \otimes x_{nm} \end{bmatrix}; i = \overline{1,n}; j = \overline{1,m} \tag{8}$$

$\otimes x_{ij}$ represents the grey evaluations of ith alternative and jth attribute.

Step 3: Finding the weights of the criteria via PFAHP.

Step 4: Building the normalized grey decision matrix: Eq. (9) is used for the normalization of the benefit type of criteria, and the cost type of criteria Eq. (10).

$$\otimes r_{ij} = \frac{\otimes x_{ij}}{max_i(\bar{r}_{ij})} = \left(\frac{\underline{x}_{ij}}{max_i(\bar{r}_{ij})}; \frac{\bar{x}_{ij}}{max_i(\bar{r}_{ij})}\right) \quad (9)$$

$$\otimes r_{ij} = 1 - \frac{\otimes x_{ij}}{max_i(\bar{x}_{ij})} = \left(1 - \frac{x_{ij}}{max_i(\bar{x}_{ij})}; 1 - \frac{\underline{x}_{ij}}{max_i(\bar{x}_{ij})}\right) \quad (10)$$

$\underline{x}_{ij}$ represents the lower value of the interval, $\bar{x}_{ij}$ represents the higher value of the interval.

Step 5: Determining the positive and negative ideal alternatives. A^+ represents the positive ideal alternatives, A^- represents the negatives ideal alternatives.

$$A^+ = \{(\max \bar{r}_{ij} \mid j\epsilon J), (\min \underline{r}_{ij} \mid j\epsilon J') | i\epsilon n\} = [r_1^+, r_2^+, \dots, r_m^+] \quad (11)$$

$$A^- = \{(\min \underline{r}_{ij} \mid j\epsilon J), (\max \bar{r}_{ij} \mid j\epsilon J') | i\epsilon n\} = [r_1^-, r_2^-, \dots, r_m^-] \quad (12)$$

Step 6: Calculating the separation measure of the positive and negative ideal alternatives, d_i^+ and d_i^-

$$d_i^+ = \sqrt{\frac{1}{2}\sum_{j=1}^{m} w_i \left[\left|r_j^+ - \underline{r}_{ij}\right|^2 + \left|r_j^+ - \bar{r}_{ij}\right|^2 \right]} \quad (13)$$

$$d_i^- = \sqrt{\frac{1}{2}\sum_{j=1}^{m} w_i \left[\left|r_j^- - \underline{r}_{ij}\right|^2 + \left|r_j^- - \bar{r}_{ij}\right|^2 \right]} \quad (14)$$

Step 7: Calculating the relative closeness C_i^+

$$C_i^+ = \frac{d_i^-}{d_i^+ + d_i^-} \quad (15)$$

Step 8: Ranking the preference order. A set of alternatives now can be preference ranked by the descending order of the value of C_i^+.

Application of 3PLP Selection Problem

The suggested model's efficacy is implemented to an international food company for evaluating the 3PLP companies. The company is built in 2016 as a flour factory. It produces around 1000 tons per day and has a storage capacity of 75.000 tons. The second highest cost factor, 3PLs have an annual cost of about 500.000 currency unit. The most of this company's customers are Middle Eastern countries, and it has certifications for its quality and food safety management systems. After production is complete, distribution is handled by a 3PLP company in the firm where the product is produced in accordance with consumer demand. The company attempts to select the best 3PLP based on the quality of the service and the company culture. Another crucial issue is that the company aims to reduce risk over the long term in its operations.

A comprehensive literature analysis and field research were carried out in this study, whose main aims were the selection and evaluation of 3PLP, to identify the criterion. First of all, a form including all the criteria for the subject was prepared by reviewing the literature. Then, using expert opinion, a thorough evaluation of all the criteria used in previous studies on the subject was conducted. The evaluations resulted in the determination of the most essential factors for the food sector in general and the relevant company in particular. The expert group responsible for determining the criteria make up three experts (departmental leaders). As a result of all these evaluations, 10 main criteria were determined as given Table 2. These criteria are as follows: Reputation (C_1), Financial Position (C_2), Technological Capability (C_3), Risk management (C_4), Geographical location (C_5), Service Quality (C_6), Flexibility (C_7), Cost (C_8), On time-delivery (C_9) and Infrastructure (C_{10}). Experts selected eight 3PLP companies (A1, A2,..., A8) for the evaluation procedure of the logistics service providers.

Table 2. Criteria of 3PLP Selection

Criteria	*Definition*	*Reference*
Reputation (C_1)	Good or bad market popularity of the 3PL provider to be cooperated by the actors in the sector	(Singh et al., 2022); (Ejem et al., 2021); (Gürcan et al., 2016); (Sharma & Kumar, 2015)
Financial Position (C_2)	Analysis of the financial situation of the 3PL company planned to be a business partnership	(Keshavarz Ghorabaee et al., 2017); (Gürcan et al., 2016); (Jovčić & Průša, 2021); (Percin, 2009); (Ejem et al., 2021); (Sharma & Kumar, 2015); (Pishdar et al., 2021)
Technological Capability (C_3)	Integration of the 3PL company to be partnered with the latest technology logistics systems	(R. Raut et al., 2018); (Pishdar et al., 2021); (Sharma & Kumar, 2015); (Jovčić & Průša, 2021); (Percin, 2009)
Risk management (C_4)	Risk management capability status of the partnered 3PL company	(Percin, 2009); (Keshavarz Ghorabaee et al., 2017); (Nel et al., 2018); (M. Wang et al., 2018);
Geographical location (C_5)	The proximity of the 3PL company to the logistics networks	(Jovčić & Průša, 2021); (Pamucar et al., 2019)
Service Quality (C_6)	The service quality of the 3PL company in logistics activities	(Pamucar et al., 2019); (Keshavarz Ghorabaee et al., 2017); (Ji-Feng & Chien-Chang, 2011); (Pishdar et al., 2021)
Flexibility (C_7)	3PL company's ability to adapt to instant demands	(M. Wang et al., 2018); (R. Raut et al., 2018); (Keshavarz Ghorabaee et al., 2017); (Jovčić & Průša, 2021); (Aguezzoul & Pires, 2016)
Cost (C_8)	The fee charged by the 3PL company for the logistics service	(Pamucar et al., 2019); (Jovčić & Průša, 2021); (Ji-Feng & Chien-Chang, 2011); (M. Wang et al., 2018);
On time-delivery (C_9)	Ability of 3PL company to perform deliveries on time	(Jovčić & Průša, 2021); (Ji-Feng & Chien-Chang, 2011); (Ejem et al., 2021)
Infrastructure (C_{10})	Whether the 3PL company has the infrastructure adequacy to carry out logistics activities	(Jovčić & Průša, 2021); (Percin, 2009); (Pamucar et al., 2019); (Singh et al., 2022); (Gürcan et al., 2016)

Following the criterion and alternative selection, the decision-makers were presented with a series of questions designed to establish the relative weights of the criteria and assess the 3PLP companies' performance. Decision makers utilized linguistic variables to evaluate criteria and alternatives due to face-to-face surveys.

Determination of Criteria Weights with PFAHP Method

Initially, a direct interview was conducted with three decision makers to get their assessment of the factors that were significant to them in choosing the third-party logistics provider for the survey. Matching comparison matrices were generated after the replies to the criteria given by each decision maker were assessed using the Pythagorean fuzzy numbers in Table 3. Table 3 displays the pairwise comparison matrix of the criteria, and Table 4 presents the Pythagorean fuzzy evaluation matrix. The procedures outlined in Section 3.2 were employed to ascertain the weights of these criteria following pairwise comparisons. As an example of calculations, the differences values of C_2 are calculated by Eqs. (1) and (2) and given below:

$$d_{21_L} = \mu_{21_L}^2 - v_{21_U}^2 = 0.3862^2 - 0.5623^2 = -0.1670$$

$$d_{21_U} = 0.5178^2 - 0.4488^2 = 0.0666.$$

Then, interval multiplicative values of C_2 are computed using Eqs. (3) and (4) and presented as follows:

$$s_{21_L} = \sqrt{1000^{-0.1670}} = 0.5615$$

$$s_{22_U} = \sqrt{1000^{0.0666}} = 1.2590$$

Finally, the other steps are performed, and the criteria weights produced by the PFAHP approach are shown in Table 5.

Table 3. Pairwise Comparison Matrix for Criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
C_1	EE, EE, EE	AAI, AI, LI	BAI, BAI, BAI	BAI, BAI, AAI	LI, BAI, HI	LI, BAI, LI	LI, BAI, HI	LI, LI, BAI	VLI, VLI, AAI	CLI, CLI, HI
C_2	BAI, AI, HI	EE, EE, EE	BAI, BAI, AAI	BAI, BAI, HI	BAI, BAI, CHI	LI, BAI, AAI	LI, BAI, VHI	VLI, LI, AAI	VLI, VLI, VHI	CLI, VLI, CHI
C_3	AAI, AAI, AAI	AAI, AAI, BAI	EE, EE, EE	BAI, BAI, AAI	BAI, BAI, VHI	LI, BAI, BAI	LI, BAI, HI	BAI, BAI, LI	CLI, LI, HI	VLI, LI, HI
C_4	AAI, AAI, BAI	AAI, AAI, LI	AAI, AAI, BAI	EE, EE, EE	BAI, BAI, HI	BAI, BAI, LI	LI, BAI, AAI	LI, BAI, LI	LI, BAI, AAI	LI, BAI, HI
C_5	HI, AAI, LI	AAI, AAI, CLI	AAI, AAI, VLI	AAI, AAI, LI	EE, EE, EE	BAI, BAI, CLI	BAI, BAI, BAI	BAI, BAI, CLI	LI, BAI, BAI	LI, BAI, BAI
C_6	HI, AAI, HI	HI, AAI, BAI	HI, AAI, AAI	AAI, AAI, HI	AAI, AAI, CHI	EE, EE, EE	AAI, BAI, HI	BAI, BAI, AAI	BAI, BAI, VHI	BAI, BAI, VHI
C_7	HI, AAI, LI	HI, AAI, VLI	HI, AAI, LI	HI, AAI, BAI	AAI, AAI, AAI	BAI, AAI, LI	EE, EE, EE	BAI, BAI, BAI	BAI, BAI, AAI	BAI, BAI, AAI
C_8	HI, HI, AAI	VHI, HI, BAI	AAI, AAI, HI	HI, AAI, HI	AAI, AAI, CHI	AAI, AAI, BAI	AAI, AAI, AAI	EE, EE, EE	BAI, BAI, HI	AI, BAI, HI
C_9	VHI, VHI, BAI	VHI, VHI, VLI	CHI, HI, LI	HI, AAI, BAI	HI, AAI, AAI	AAI, AAI, VLI	AAI, AAI, BAI	AAI, AAI, LI	EE, EE, EE	AI, AI, AAI
C_{10}	CHI, CHI, LI	CHI, VHI, CLI	VHI, HI, LI	HI, AAI, LI	HI, AAI, AAI	AAI, AAI, VLI	AAI, AAI, BAI	AI, AAI, LI	AI, AI, BAI	EE, EE, EE

Table 4. Pythagorean Fuzzy Evaluation Matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
C_1	([0.1965, 0.1965], [0.1965, 0.1965])	([0.3862, 0.5178], [0.4488, 0.5623])	([0.3500, 0.4500], [0.5500, 0.6500])	([0.4008, 0.5025], [0.4803, 0.5821])	([0.3276, 0.4776], [0.4377, 0.5927])	([0.2300, 0.3727], [0.6234, 0.7595])	([0.3276, 0.4776], [0.4377, 0.5927])	([0.2366, 0.3774], [0.6182, 0.7517])	([0.1668, 0.2848], [0.6243, 0.7310])	([0.0000, 0.0000], [0.5732, 0.7298])
C_2	([0.4488, 0.5623], [0.3862, 0.5178])	([0.1965, 0.1965], [0.1965, 0.1965])	([0.4008, 0.5025], [0.4803, 0.5821])	([0.4214, 0.5348], [0.4060, 0.5398])	([0.4646, 0.5718], [0.0000, 0.3707])	([0.3116, 0.4488], [0.5178, 0.6391])	([0.3487, 0.4948], [0.3556, 0.5011])	([0.1983, 0.3276], [0.5927, 0.7098])	([0.1866, 0.3140], [0.4287, 0.5732])	([0.0000, 0.0000], [0.0000, 0.4882])
C_3	([0.5500, 0.6500], [0.3500, 0.4500])	([0.4803, 0.5821], [0.4008, 0.5025])	([0.1965, 0.1965], [0.1965, 0.1965])	([0.4008, 0.5025], [0.4803, 0.5821])	([0.4485, 0.5540], [0.3298, 0.4564])	([0.2721, 0.4019], [0.5929, 0.7137])	([0.3276, 0.4776], [0.4377, 0.5927])	([0.2959, 0.4173], [0.5783, 0.6918])	([0.0000, 0.0000], [0.5284, 0.6902])	([0.2085, 0.3487], [0.5011, 0.6583])
C_4	([0.4803, 0.5821], [0.4008, 0.5025])	([0.4060, 0.5398], [0.4214, 0.5348])	([0.4803, 0.5821], [0.4008, 0.5025])	([0.1965, 0.1965], [0.1965, 0.1965])	([0.4214, 0.5348], [0.4060, 0.5398])	([0.2959, 0.4173], [0.5783, 0.6918])	([0.3116, 0.4488], [0.5178, 0.6391])	([0.2300, 0.3727], [0.6234, 0.7595])	([0.3116, 0.4488], [0.5178, 0.6391])	([0.3276, 0.4776], [0.4377, 0.5927])
C_5	([0.4377, 0.5927], [0.3276, 0.4776])	([0.0000, 0.0000], [0.4646, 0.5718])	([0.3298, 0.4564], [0.4485, 0.5540])	([0.4060, 0.5398], [0.4214, 0.5348])	([0.1965, 0.1965], [0.1965, 0.1965])	([0.0000, 0.0000], [0.6376, 0.7397])	([0.3500, 0.4500], [0.5500, 0.6500])	([0.0000, 0.0000], [0.6376, 0.7397])	([0.2721, 0.4019], [0.5929, 0.7137])	([0.2721, 0.4019], [0.5929, 0.7137])
C_6	([0.6234, 0.7595], [0.2300, 0.3727])	([0.5178, 0.6391], [0.3116, 0.4488])	([0.5929, 0.7137], [0.2721, 0.4019])	([0.5783, 0.6918], [0.2959, 0.4173])	([0.6376, 0.7397], [0.0000, 0.2866])	([0.1965, 0.1965], [0.1965, 0.1965])	([0.5165, 0.6310], [0.3313, 0.4575])	([0.4008, 0.5025], [0.4803, 0.5821])	([0.4485, 0.5540], [0.3298, 0.4564])	([0.4485, 0.5540], [0.3298, 0.4564])
C_7	([0.4377, 0.5927], [0.3276, 0.4776])	([0.3556, 0.5011], [0.3487, 0.4948])	([0.4377, 0.5927], [0.3276, 0.4776])	([0.5178, 0.6391], [0.3116, 0.4488])	([0.5500, 0.6500], [0.3500, 0.4500])	([0.3313, 0.4575], [0.5165, 0.6310])	([0.1965, 0.1965], [0.1965, 0.1965])	([0.3500, 0.4500], [0.5500, 0.6500])	([0.4008, 0.5025], [0.4803, 0.5821])	([0.4008, 0.5025], [0.4803, 0.5821])
C_8	([0.6182, 0.7517], [0.2366, 0.3774])	([0.5927, 0.7098], [0.1983, 0.3276])	([0.5783, 0.6918], [0.2959, 0.4173])	([0.6234, 0.7595], [0.2300, 0.3727])	([0.6376, 0.7397], [0.0000, 0.2866])	([0.4803, 0.5821], [0.4008, 0.5025])	([0.5500, 0.6500], [0.3500, 0.4500])	([0.1965, 0.1965], [0.1965, 0.1965])	([0.4214, 0.5348], [0.4060, 0.5398])	([0.4719, 0.5853], [0.3710, 0.5007])
C_9	([0.6243, 0.7310], [0.1668, 0.2848])	([0.4287, 0.5732], [0.1866, 0.3140])	([0.5284, 0.6902], [0.0000, 0.2552])	([0.5178, 0.6391], [0.3116, 0.4488])	([0.5929, 0.7137], [0.2721, 0.4019])	([0.3298, 0.4564], [0.4485, 0.5540])	([0.4803, 0.5821], [0.4008, 0.5025])	([0.4060, 0.5398], [0.4214, 0.5348])	([0.1965, 0.1965], [0.1965, 0.1965])	([0.4779, 0.5783], [0.4173, 0.5179])
C_{10}	([0.5732, 0.7298], [0.0000, 0.1866])	([0.0000, 0.0000], [0.0000, 0.2373])	([0.5011, 0.6583], [0.2085, 0.3487])	([0.4377, 0.5927], [0.3276, 0.4776])	([0.5929, 0.7137], [0.2721, 0.4019])	([0.3298, 0.4564], [0.4485, 0.5540])	([0.4803, 0.5821], [0.4008, 0.5025])	([0.3710, 0.5007], [0.4719, 0.5853])	([0.4173, 0.5179], [0.4779, 0.5783])	([0.1965, 0.1965], [0.1965, 0.1965])

Table 5. Weights of Criteria

C_1	0.0427
C_2	0.0686
C_3	0.0664
C_4	0.0617
C_5	0.0475
C_6	0.1672
C_7	0.0867
C_8	0.1857
C_9	0.1478
C_{10}	0.1256

Cost (C_8) was found to be the most important criterion in the 3PLP selection problem, followed by Service Quality (C_6) and On-time Delivery (C_9). Following is the priority order of the 3PLP selection criteria used in this study: $C_8>C_6>C_9>C_{10}>C_7>C_2>C_3>C_4>C_5>C_1$.

Evaluation of 3PLPs with GTOPSIS Method

The PFAHP process steps for selecting a third-party logistics provider were followed, and lastly, the GTOPSIS method was employed to select a provider. The GTOPSIS method at this point employed the weights obtained in the previous step.

Using the linguistic scale shown in Table 6, experts were asked to evaluate service providers in accordance with the 3PLP criteria. Following this evaluation result, grey numbers were created using expressions (Table 6), and the final combined grey decision matrix is shown in Table 7. The grey decision matrix was subsequently normalized (Table 8).

The normalization for A_1-C_1 is computed by Eq. (10) and given below:

$$\otimes r_{11} = \frac{\otimes x_{11}}{max_i(\bar{r}_{i1})} = \left(\frac{4.33}{10}; \frac{5.33}{10}\right) = (0.43; 0.53)$$

Then, A^+ and A^- are calculated by Eqs. (11) and (12) and presented in below:

$$A^+ = [1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00]$$

$$A^- = [0.03\ ,0.04\ \ ,0.36\ ,0.10\ ,0.04\ ,0.20\ ,0.26\ ,0.17\ ,0.09\ ,0.03]$$

After, d_i^+ and d_i^- values are calculated by Eqs. (13) and (14) for A_1 and presented as follows:

$$d_1^+ = \sqrt{\frac{1}{2}\sum_{j=1}^{m} w_i \left[\left|r_j^+ - \underline{r}_{ij}\right|^2 + \left|r_j^+ - \bar{r}_{ij}\right|^2 \right]}$$

$$= \sqrt{\frac{1}{2}\cdot\left\{\begin{matrix}0.0427\cdot[\,|1-0.43|^2+|1-0.53|^2] + 0.0686\cdot[\,|1-0.58|^2+|1-0.79|^2] + \cdots + \\ 0.1256\cdot[\,|1-0.55|^2+|1-0.79|^2]\end{matrix}\right\}}$$

$$= 0.0460$$

$$d_1^- = \sqrt{\frac{1}{2}\sum_{j=1}^{m} w_i \left[\left|r_j^- - \underline{r}_{ij}\right|^2 + \left|r_j^- - \bar{r}_{ij}\right|^2 \right]}$$

$$= \sqrt{\frac{1}{2}\cdot\left\{\begin{matrix}0.0427\cdot[\,|0.03-0.43|^2+|0.03-0.53|^2] + 0.0686\cdot[\,|0.04-0.58|^2+|0.04-0.79|^2] + \cdots + \\ 0.1256\cdot[\,|0.03-0.55|^2+|0.03-0.79|^2]\end{matrix}\right\}}$$

$$= 0.4546$$

Using these values, FPIS and FNIS were calculated once the weighted normalized matrix was produced. After determining the positive and negative ideal distances of the alternatives based on the criteria, the distances of the alternatives according to the ideal solution are established. The outcomes are displayed in Table 9.

Table 6. Linguistic Scale 3PLP Selection

Linguistic Variables	Grey numbers for alternative assessment
Very Poor (VP)	[0, 1]
Poor (P)	[1, 3]
Medium Poor (MP)	[3, 4]
Fair (F)	[4, 5]
Medium Good (MG)	[5, 6]
Good (G)	[6, 9]
Very Good (VG)	[9, 10]

Table 7. Linguistic Assessments for GTOPSIS

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A1	F, MG, F	F, G, F	F, F, MP	MP, F, G	F, MP, F	F, MG, MP	G, G, G	F, F, MP	MP, MP, F	G, F, G
A2	VP, VP, P	VP, P, VP	MP, F, F	F, MP, MP	P, VP, VP	MP, MP, VP	P, F, MP	VP, MP, P	VP, P, P	P, MP, MP
A3	VG, VG, VG	G, F, G	G, MG, MG	MG, G, G	G, VG, F	VG, VG, VG	G, G, F	MG, G, MG	G, F, G	MG, G, G
A4	MP, VP, F	P, F, P	MP, MP, MP	VP, MP, MP	P, P, F	F, F, F	F, VP, MP	MP, F, F	VP, MP, VP	P, MP, VP
A5	G, MG, MG	G, MG, MG	VG, P, G	MG, F, G	MG, F, MP	F, MG, MP	F, F, F	MG, G, F	F, G, G	G, G, G
A6	F, MP, MP	F, F, P	MG, MP, VP	MP, VP, VP	P, F, F	P, F, MP	MP, MP, MP	F, F, F	MP, P, P	VP, VP, P
A7	VG, VG, VG	G, VG, F	VG, MG, F	VG, VG, G	G, G, G	VG, G, G	G, VG, MG	G, G, MG	MG, MG, VG	VG, VG, G
A8	F, F, P	MP, MP, F	MG, G, MP	F, P, P	P, MG, MP	MP, MG, G	MP, F, F	P, MP, F	F, G, G	P, P, P

Table 8. The Aggregated Grey Decision Matrix for GTOPSIS

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A1	[4.33, 5.33]	[4.67, 6.33]	[3.67, 4.67]	[4.33, 6.00]	[3.67, 4.67]	[4.00, 5.00]	[6.00, 9.00]	[3.67, 4.67]	[3.33, 4.33]	[5.33, 7.67]
A2	[0.33, 1.67]	[0.33, 1.67]	[3.67, 4.67]	[3.33, 4.33]	[0.33, 1.67]	[2.00, 3.00]	[2.67, 4.00]	[1.33, 2.67]	[0.67, 2.33]	[2.33, 3.67]
A3	[9.00, 10.00]	[5.33, 7.67]	[5.33, 7.00]	[5.67, 8.00]	[6.33, 8.00]	[9.00, 10.00]	[5.33, 7.67]	[5.33, 7.00]	[5.33, 7.67]	[5.67, 8.00]
A4	[2.33, 3.33]	[2.00, 3.67]	[3.00, 4.00]	[2.00, 3.00]	[2.00, 3.67]	[4.00, 5.00]	[2.33, 3.33]	[3.67, 4.67]	[1.00, 2.00]	[1.33, 2.67]
A5	[5.33, 7.00]	[5.33, 7.00]	[5.33, 7.33]	[5.00, 6.67]	[4.00, 5.00]	[4.00, 5.00]	[4.00, 5.00]	[5.00, 6.67]	[5.33, 7.67]	[6.00, 9.00]
A6	[3.33, 4.33]	[3.00, 4.33]	[2.67, 3.67]	[1.00, 2.00]	[3.00, 4.33]	[2.67, 4.00]	[3.00, 4.00]	[4.00, 5.00]	[1.67, 3.33]	[0.33, 1.67]
A7	[9.00, 10.00]	[6.33, 8.00]	[6.00, 7.00]	[8.00, 9.67]	[6.00, 9.00]	[7.00, 9.33]	[6.67, 8.33]	[5.67, 8.00]	[6.33, 7.33]	[8.00, 9.67]
A8	[3.00, 4.33]	[3.33, 4.33]	[4.67, 6.33]	[2.00, 3.67]	[3.00, 4.33]	[4.67, 6.33]	[3.67, 4.67]	[2.67, 4.00]	[5.33, 7.67]	[1.00, 3.00]

Table 9. Normalized Grey Decision Matrix for GTOPSIS

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
A1	[0.43, 0.53]	[0.58, 0.79]	[0.50, 0.64]	[0.45, 0.62]	[0.41, 0.52]	[0.40, 0.50]	[0.67, 1.00]	[0.46, 0.58]	[0.43, 0.56]	[0.55, 0.79]
A2	[0.03, 0.17]	[0.04, 0.21]	[0.50, 0.64]	[0.34, 0.45]	[0.04, 0.19]	[0.20, 0.30]	[0.30, 0.44]	[0.17, 0.33]	[0.09, 0.30]	[0.24, 0.38]
A3	[0.90, 1.00]	[0.67, 0.96]	[0.73, 0.95]	[0.59, 0.83]	[0.70, 0.89]	[0.90, 1.00]	[0.59, 0.85]	[0.67, 0.88]	[0.69, 1.00]	[0.59, 0.83]
A4	[0.23, 0.33]	[0.25, 0.46]	[0.41, 0.55]	[0.21, 0.31]	[0.22, 0.41]	[0.40, 0.50]	[0.26, 0.37]	[0.46, 0.58]	[0.13, 0.26]	[0.14, 0.28]
A5	[0.53, 0.70]	[0.67, 0.88]	[0.73, 1.00]	[0.52, 0.69]	[0.44, 0.56]	[0.40, 0.50]	[0.44, 0.56]	[0.63, 0.83]	[0.69, 1.00]	[0.62, 0.93]
A6	[0.33, 0.43]	[0.38, 0.54]	[0.36, 0.50]	[0.10, 0.21]	[0.33, 0.48]	[0.27, 0.40]	[0.33, 0.44]	[0.50, 0.63]	[0.22, 0.43]	[0.03, 0.17]
A7	[0.90, 1.00]	[0.79, 1.00]	[0.82, 0.95]	[0.83, 1.00]	[0.67, 1.00]	[0.70, 0.93]	[0.74, 0.93]	[0.71, 1.00]	[0.83, 0.96]	[0.83, 1.00]
A8	[0.30, 0.43]	[0.42, 0.54]	[0.64, 0.86]	[0.21, 0.38]	[0.33, 0.48]	[0.47, 0.63]	[0.41, 0.52]	[0.33, 0.50]	[0.69, 1.00]	[0.10, 0.31]

Table 10. The Positive, Negative Ideal Values and Relative Closeness Values in GTOPSIS

	d^+	d^-	C^+	Rank
A1	0.460	0.455	0.497	4
A2	0.744	0.170	0.186	8
A3	0.236	0.691	0.746	2
A4	0.662	0.244	0.269	7
A5	0.375	0.578	0.607	3
A6	0.659	0.269	0.290	6
A7	0.172	0.748	0.813	1
A8	0.549	0.413	0.430	5

A7 company received the highest value with 0.813, as shown in Table 10. In light of this, the corporation need to select 3PLP as A7. The scores for the additional options, A3 and A5 logistics providers, were 0.746 and 0.603, respectively. among all possibilities. The 3PLP companies are listed in the following manner when the C^+ values are compared and ordered descending: A7>A3>A5>A1>A8>A6>A4>A2. To compare the results using the same weight of the criterion, we used Fuzzy TOPSIS to solve the problem. Table 11 presents the findings. As a result, the rankings are as follows: A7>A3>A1>A5>A8>A6>A2>A4.

Table 11. The Positive, Negative Ideal Values and Relative Closeness Values in Fuzzy TOPSIS

	d^+	d^-	C^+	Rank
A1	0,0533	0,1384	0,7218	3
A2	0,1772	0,013	0,0725	8
A3	0,0352	0,1565	0,8162	2
A4	0,1475	0,0436	0,2283	6
A5	0,0786	0,1126	0,5887	4
A6	0,1500	0,0413	0,2158	7
A7	0,0052	0,1876	0,9728	1
A8	0,1093	0,0821	0,4290	5

The first, second, fifth, and sixth selections in the Fuzzy TOPSIS results are the same as those in the GTOPSIS results. However, the third, fourth, seventh, and eighth selections are different. The reason for the discrepancies is that the GTOPSIS's linguistic scale is a sparse array rather than a triangular one, giving decision-makers more flexibility.

Sensitivity Analysis

Different scenarios are created, and their results are investigated utilizing the method in the sensitivity analysis. Therefore, the method's resilience is examined. Thus, the weight of the most important criterion was decreased and increased by 10% in each scenario, and these processes were repeated until the weight of the criterion became zero. At the same time, the difference is equally distributed to the other criteria, and the sum of total weight is equal to 1.

The ranking of the alternatives as shown in Figure does not change in any of the scenarios, according to the sensitivity analysis. Consequently, these rankings of the alternatives are appropriate in these scenarios.

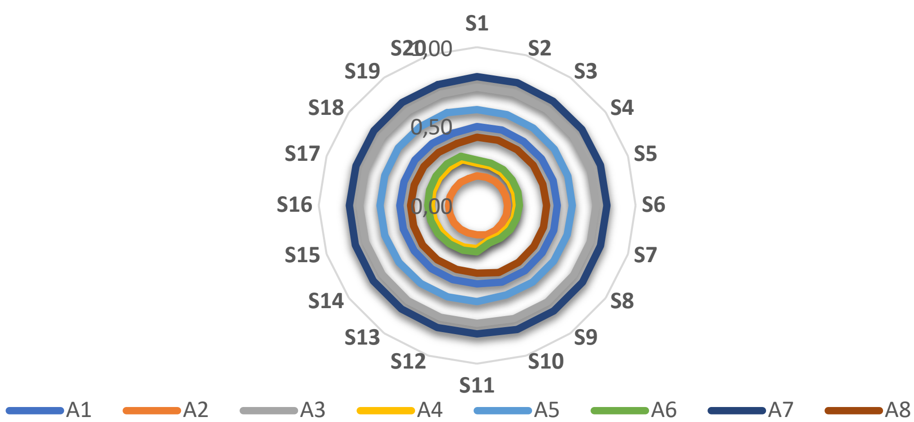

Figure 1. Sensitivity Analyses

Managerial Implication

With the development of Industry 4.0, companies have begun to digitize their production processes. The supply chain area is the most crucial part of competitiveness, and there are various profits may be acquired in this process. Outsourcing is one of the key issues and promotes corporate and large organizational better conditions. The profit margins of the companies can rise at the same rate regardless of how well this problem is solved. Hence, one of the practical aspects of the supply chain the selection of appropriate 3PLP presents a critical problem.

This study examines the problem of selecting a 3PLP because it has become a significant factor. This study aims to develop a novel model to resolve this problem and propose a novel MCDM framework. PFAHP and GTOPSIS, which had never been exploited entirely in the literature before, were employed together and we used a case study to demonstrate the method's feasibility. Additionally, sensitivity analysis was carried out to evaluate the method's sensitivity, and the results were explained.

Table 11 displays the weights of the 3PLP selection criteria that were determined using the PFAHP approach. A total of 10 criteria were evaluated and among them, Cost *(C_8)* ranked first with a criterion weight of 0.1857. Thus, cost has been accepted as the most important factor for 3PLP selection. Logistics operations play an important role in supply chain operations due to the huge costs and opportunities to improve inefficiencies (Dey et al., 2011). Experts in this study believed that cost is most important for 3PLP selection because of Türkiye's economic troubles. According to (So et al., 2006) responsiveness was the most crucial element in 3PL consumers' perceptions; however, Mohammadkhani and Mousavi (2023) concluded from their investigation that the most crucial factors in 3PLP choosing are economic ones. Jovčić and Průša (2021) analysed the price criteria as the most important factor in the selection of 3PLP. According to Wiangkam et al. (2022) the most crucial factor in choosing a 3PLP is on-time delivery. As stated by (Narkhede et al., 2017) the important factors are management caliber, information technology capability, and expertise with comparable products.. Cebi et al. (2023) identified the quality criteria as the most important factor for the selection of 3PLP in the field study. Ecer (2018) found that quality is the most important factor for 3PLP selection.(Pamucar et al., 2019) found that intangible is one of the most important criteria for 3PLP selection. Financial performance was examined by

Gürcan (2016) as one of the key factors in the 3PLP selection process. According to their sub-criteria analysis, we can conclude that the firm's image and experience, customers' satisfaction index, and distribution cost are ranked as one of the most important criteria. The results obtained are in conformance with some past studies ((Ecer, 2018; Özcan & Ahıskalı, 2020; Tuljak-Suban & Bajec, 2020) whereas are not similar in some studies (Bianchini, 2018; Bulgurcu & Nakiboglu, 2018; Pamucar et al., 2019; Wiangkam et al. (2022); So et al., 2006)). There can be variations depending on the industry and period of the study, even if all of the researchers' conclusions are consistent with those of the present study.

When comparing research in the literature, it is apparent that selecting a 3PL provider is becoming ever more dependent on economic criteria. Other criteria become less important as the cost criteria become more important. This circumstance is likely to lessen the weight given to sustainability-related factors that have an impact on the planet's future when selecting a 3PLP. Our environment is directly impacted by this condition. Also, it is now possible to notice that in import-dependent economies, the economic criteria for 3PLP selection increases. Because the cost factor is crucial in nations where the raw materials needed for logistics and transportation industry operations are imported from other countries.

Some advantages of the proposed integrated model from a theoretical viewpoint can be inferred from the case study. The results indicate that the proposed model is a powerful tool that respects uncertainty in people's judgments. The proposed model is the first study that combines the PFAHP and GTOPSIS methods in the related literature. It enables taking advantage of fuzzy and grey theories by depicting uncertainty in subjective assessments. Traditional crisp and fuzzy numbers do not have the opportunity to process the judgments of decision-makers flexibly, as is the case with interval numbers. The applicability of the interval values in the MCDM models affects the realistic perception of the preferences of the decision-makers. The usage of intervals gets over many uncertainties existing in subjective assessments by virtue of it creating more freedom and a flexible environment for decision-makers. Thus, interval-valued numbers are chosen both Pythagorean fuzzy numbers and grey numbers. Integration of different sets increases the ability to adapt the model with different multi-criteria decision-making methods. Therefore, the proposed model has the chance to develop new models in terms of applicability to different multi-criteria decision-making problems. A real-world case study is carried out to show the model's efficacy and efficiency. The obtained results verify that the model can reach more desirable solutions and can sort out decision-making problems in food industry fields.

Conclusion

Companies are under pressure from strong competition because of globalization to provide their consumers with high-quality products quickly and on schedule. Logistics operations of companies are the hey of operational excellence to expand their market share and guarantee sustained consumer satisfaction. Therefore, companies aim to achieve these goals by concentrating on their core capabilities and outsourcing high-cost logistical tasks to industry leaders.

New logistics capabilities and solutions are demanded from companies that struggle to manage their supply chain processes successfully. Problems such as being unable to respond to sudden changes, being unable to deliver on time, and losing consumers are observed with 3PLP selections that solely consider cost and quality. It has become necessary to develop new methods as well as integrated methods since the decision-maker's subjective decisions while selecting 3PLP increase uncertainty. To support companies in making decisions about the 3PLP selection problem, an integrated fuzzy MCDM model composed of PFAHP and GTOPSIS methods is developed in this study.

The 3PLP selection problem from this study was utilized by an international food company in Turkey to evaluate the proposed method and demonstrate possible applications of the stated MCDM model. The results of the PFAHP analysis indicated that the three factors with the most effects were price, level of service, and on-time delivery. Based on observations, the criterion that is most affected by these factors is the company's reputation. Still, the most affected criterion is usually the company image. Because of this, it is possible to state that every aspect of a logistics company's activities, whether positive or negative, directly or indirectly, affects the company's reputation. Using the weights derived from the PFAHP approach, one of the alternatives was chosen using the GTOPSIS method.

The company's preference for the seventh logistics provider has been ascertained.

In subsequent research, the methodology presented in this work can be applied to address many decision-making issues, including staff and supplier selection. In addition, it can employ additional fuzzy numbers in various contexts, like interval type-2, hesitant, and image.

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GENİŞLETİLMİŞ ÖZET

Günümüz iş dünyasında, küresel rekabetin artması ve müşteri taleplerinin değişimi, şirketlerin tedarik zincirlerini sürekli olarak güncellemelerini zorunlu kılmaktadır. Bu süreçte, riskten korunmanın maliyet yaratması ve verimliliği artırması gibi nedenlerle, şirketler dış kaynak kullanımı seçeneğini değerlendirmekte ve lojistikle ilgili bazı görevleri Üçüncü Taraf Lojistik Sağlayıcılarına (3TLS) devretme eğilimindedirler. Ancak, hangi şirketle iş birliği yapacaklarını seçerken karşılaşılan belirsizlikler ve insan etkisi, karar verme sürecini karmaşık hale getirmektedir.

3TLS'ler özgün lojistik yetkinliklere sahip oldukları için şirketlerin lojistik operasyonlarını etkin ve verimli bir şekilde yönetebilirler (Perçin, 2009). 3TLS'ler müşterinin maliyetlerden tasarruf etmesini, müşteri memnuniyetinin artmasını ve envanteri azaltmasını sağlayabilir, bu da onlara hızlı ve değişken bir sektörde önemli bir avantaj sağlamaktadır (Narkhede vd., 2017). Bu nedenlerle, 3TLS seçimi gün geçtikçe kritik bir konu haline gelmektedir. Şirketler için mali, teknolojik ve sürdürülebilirlik faaliyetlerinin üstesinden gelebilecek doğru bir 3TLS seçmek esastır. 3TLS seçimi, kalite, maliyet ve teslimat süresi gibi birbiriyle yarışan birçok kriter ve yöntemi içeren bir Çok Kriterli Karar Verme (ÇKKV) problemidir (Y. Liu vd., 2020). Şirketler bu kararı verirken genellikle tek başına maliyeti dikkate almakta, teslimat süresi, marka algısı, sorun çözme kabiliyetleri ve şirketle uzun vadeli ilişkiler gibi diğer faktörleri arka plana atmaktadır. Özellikle büyüyen ve değişen, sürdürülebilir tedarik zinciri yönetimine odaklanan bir iş ortamında maliyet, zaman ve kalite kriterlerini sağlamak artık yeterli olmamaktadır (R. Raut vd., 2018).

Bu noktada, Çok Kriterli Karar Verme (ÇKKV) yöntemleri önemli bir rol oynamaktadır. Çok Kriterli Karar Verme (ÇKKV) yöntemleri, işletmelerin karmaşık kararlar almasına yardımcı olan önemli araçlardır. Özellikle tedarik zinciri yönetimi gibi alanlarda, bir dizi faktörü dikkate alarak en uygun seçenekleri belirlemek zor olabilir. Bu nedenle, ÇKKV yöntemleri, farklı kriterler arasında denge kurmak ve belirsizlikleri azaltmak için kullanılır.

3TLS seçim sürecine ışık tutacak bütünleşik bir ÇKKV modeli önerilmiştir. Bu model, Pisagor bulanık sayıları ve gri sayılar üzerine kurulu bir bütünleşmiş çerçeve kullanmaktadır. Önerilen model, bir gıda endüstrisi şirketinin müşteri siparişlerini yerine getirmek için 3TLS'yi uygulamış ve değerlendirme kriterlerinin ağırlıklarını belirlemek için Pisagor Bulanık Analitik Hiyerarşi Prosesi (PBAHP) yöntemini kullanmıştır. Daha sonra, 3PLP'ler arasında en uygun olanını seçmek için Gri İdeal Çözüme Benzerliğe Göre Sipariş Tercihi Tekniği (GTOPSIS) yöntemlerini kullanarak sıralama yapmıştır.

Türkiye'deki uluslararası bir gıda firması, belirtilen ÇKKV modelinin nasıl kullanılabileceğini göstermek ve önerilen yaklaşımı doğrulamak için 3TLS seçim problemini kullanmıştır. PFAHP analizinin bulguları, en büyük etkiye sahip üç değişkenin maliyet, hizmet kalitesi ve zamanında teslimat olduğunu göstermiştir. Gözlemler, şirketin itibarının bu kriterlerden en çok etkilenen kriter olduğunu göstermiştir. Bununla birlikte, şirket imajı kriteri genellikle en çok etkilenen kriterdir. Bu nedenle, lojistik şirketinin faaliyetlerinin her bileşeninin şirketin itibarı üzerinde doğrudan ya da dolaylı, olumlu ya da olumsuz bir etkiye sahip olduğu söylenebilir. PFAHP yaklaşımından elde edilen ağırlıklar kullanılarak GTOPSIS yöntemi ile alternatiflerden biri seçilmiştir. Şirketin yedinci lojistik sağlayıcıyı tercih ettiği tespit edilmiştir.

Gıda sektöründe, tedarik zinciri yönetimi ve lojistik operasyonları son derece kritik öneme sahiptir. Ürünlerin taze ve güvenilir bir şekilde tedarik edilmesi, depolanması ve dağıtılması, müşteri memnuniyeti ve işletme başarısı açısından hayati önem taşır. Bu bağlamda, doğru üçüncü taraf lojistik sağlayıcısını seçmek, işletmelerin rekabet avantajını korumasına ve operasyonel etkinliği artırmasına yardımcı olur. PBAHP yöntemi, gıda sektöründeki işletmeler için farklı lojistik sağlayıcılar arasında değerlendirme yaparken, kriterlerin önceliklerini belirlemede kullanılabilir. Örneğin, zamanında teslimat, ürün kalitesi ve maliyet gibi kriterler, işletmenin önceliklerine göre ağırlıklandırılabilir. Bu, işletmenin kendi önceliklerine uygun olarak lojistik sağlayıcılar arasında daha objektif bir değerlendirme yapmasına olanak tanır. GTOPSIS yöntemi ise farklı lojistik sağlayıcıları arasında en uygun olanını seçerken kullanılabilir. Bu yöntem, işletmenin önceden belirlenen kriterlere dayalı olarak lojistik sağlayıcıları arasında karşılaştırma yapmasına olanak tanır. Önceden belirlenen kriterlere en uygun olan sağlayıcı belirlenir ve işletmenin gereksinimlerini en iyi şekilde karşılayacak olan seçenek ortaya çıkar.

Bu bütünleşik yaklaşım, işletmelere karar verme sürecinde daha bilimsel, objektif ve verimli bir yol sunar. Öncelikle, işletme ihtiyaçlarına uygun kriterler belirlenir ve ağırlıklandırılır. Daha sonra, bu kriterlere göre farklı lojistik sağlayıcılar arasında karşılaştırma yapılır ve en uygun olanı seçilir. Bu şekilde, işletmeler lojistik operasyonlarını daha etkin bir şekilde yönetir ve rekabet avantajlarını korurken, müşteri memnuniyetini artırabilirler.

Yapılan analizler ve bulgular, maliyet, hizmet kalitesi ve zamanında teslimat gibi faktörlerin, 3TLS seçiminde en büyük etkiye sahip olduğunu ortaya koymuştur. Bu sonuçlar, şirketlerin 3PLP seçiminde daha bilimsel ve objektif bir yaklaşım benimsemelerine olanak tanımaktadır. Tedarik zinciri yönetimi ve 3PLP seçimi, günümüz iş dünyasında giderek daha önemli hale gelmektedir. Şirketler, rekabet avantajı sağlamak ve müşteri memnuniyetini artırmak için doğru lojistik ortaklarını seçmek zorundadır. Bu nedenle, ÇKKV yöntemleri gibi analitik araçlar, karar verme sürecinde belirsizlikleri azaltmak ve daha iyi sonuçlar elde etmek için kritik öneme sahiptirler.

Sonuç olarak, tedarik zinciri yönetimindeki bu gelişmeler, şirketlerin rekabet avantajını sürdürmek ve büyümeyi desteklemek için sürekli olarak stratejilerini gözden geçirmelerini ve optimize etmelerini gerektirmektedir. Bu bağlamda, bütünleşik ÇKKV modelleri, karar verme sürecini iyileştirerek şirketlere daha rekabetçi olma ve müşteri taleplerini karşılama konusunda bu çalışmadaki gibi yardımcı olmaktadır.