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Service Provider Selection For Project Logistics Operations With Fuzzy Analytic Hierarchy Process

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ABSTRACT

The transportation of non-standard cargoes and the related logistics operations are considered niche field that requires expertise. The logistics operations of non-standard cargoes such as power plants, wind turbines, yachts, and military vehicles need to be carefully operated to deliver the cargo on time with undamaged conditions. Furthermore, some crucial decision criteria need to be considered before transportation and during the transportation processes. Although a considerable amount of literature has been published on service provider selection topics, there is no study in the project logistics field. Thus, it is necessary to research and determine the selection criteria for project logistics service providers. Selecting logistics service providers for project cargoes, oversize, and gauge cargoes become a delicate critical decision-making area regarding different decision characteristics. In this context, the logistics service providers' role becomes crucial to provide adequate transportation. In this study, a definition of project logistics and a literature review on the subject was conducted. In the implementation of the study, a series of half-structured interviews were conducted with the experts from the case company. A fuzzy analytic hierarchy process (FAHP) is used as the criteria for 3PL selection. The results imply that logistics service providers for project logistics management should focus on more operative aspects such as vehicle availability, cargo safety, on-time delivery, etc., to become more competitive.

Keywords: *Project Logistics, Project Transportation, Fuzzy Analytic Hierarchy Process, Logistics Service Providers Selection*
JEL Codes: *M110, M100*

Bulanık Analitik Hiyerarşi Süreci ile Proje Lojistik Operasyonları için Hizmet Sağlayıcı Seçimi

Süreç

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ÖZ

Standart dışı yüklerin taşınması ve buna bağlı lojistik operasyonlar uzmanlık gerektiren niş bir alan olarak kabul edilmektedir. Santraller, rüzgar türbinleri, yatlar, askeri araçlar gibi standart dışı yüklerin lojistik operasyonlarının, kargonun zamanında ve hasarsız koşullarda teslim edilmesi için dikkatli bir şekilde işletilmesi gerekmektedir. Ayrıca nakliye öncesinde ve nakliye süreçlerinde bazı önemli karar kriterlerinin dikkate alınması gerekmektedir. Hizmet sağlayıcı seçimi konularında önemli miktarda literatür yayınlanmış olmasına rağmen proje lojistiği alanında herhangi bir çalışma bulunmamaktadır. Bu nedenle proje lojistiği hizmet sağlayıcıları için seçim kriterlerinin araştırılması ve belirlenmesi gerekmektedir. Proje kargoları, gabari dışı ve gabari kargolar için lojistik hizmet sağlayıcı seçimi, farklı karar özellikleri açısından hassas ve kritik bir karar verme alanı haline gelmektedir. Bu bağlamda, yeterli ulaşımın sağlanabilmesi için lojistik hizmet sağlayıcıların rolü önem kazanmaktadır. Bu çalışmada proje lojistiğinin tanımı ve konu ile ilgili literatür taraması yapılmıştır. Çalışmanın uygulanmasında, vaka şirketinden uzmanlarla literatür taraması ve bir dizi yarı yapılandırılmış görüşme yapılmıştır. 3PL seçimi için yöntem olarak bulanık analitik hiyerarşi süreci (FAHP) kullanılmıştır. Sonuçlar, proje lojistiği yönetimi için lojistik hizmet sağlayıcılarının daha rekabetçi hale gelmek için araç mevcudiyeti, kargo güvenliği, zamanında teslimat vb. gibi daha işlevsel yönlere odaklanması gerektiğini göstermektedir.

Anahtar Kelimeler: *Proje Lojistiği, Proje Taşımacılığı, Bulanık Analitik Hiyerarşi Süreci, Lojistik Hizmet Sağlayıcı Seçimi*
JEL Kodları: *M110, M100*

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Introduction

Managing the value chain of heavy goods such as power plants, wind turbines, transformers, yachts, military vehicles, etc., is considered a significant challenge for the oversize transport market from a global perspective. It is possible that due to the many processes in value chains, various additional costs and significant losses may occur (Singh et al., 2018). The complexity of the project logistics management structure arises with the determinants such as weights of cargo, dimensions of the cargo, usable cargo space on the vehicle, etc. (Galor et al., 2011) as well as distribution of customers and the shape of cargo. In developing countries such as Türkiye, project logistics covers 10 % of the total logistics industry. Furthermore, it was concluded that the companies that give project logistics services have reached out to 150 companies in Türkiye. In such an environment, the selection of possible companies becomes a complex managerial problem. Galor and Galor (2010) stated the necessity of oversize transportation for economies which is highly connected with the infrastructural projects of the countries. From a micro perspective, Petraska and Palsaitis (2012) underlined that achieving a systematic approach for the transportation of oversized cargo allows reducing the cost of transportation of cargo several times and increase the attractiveness of the investments. Managing the transportation of out-of-gauge, non-standard goods are known as project logistics or oversize cargo transportation. Project logistics has been defined as cargoes that exceed the allowable parameters for its dimensions, geometry, or allowable loads on unit surface area (Galor and Galor, 2010). The focus of the project transportation is to deliver the oversize cargo from the origin point, which can be a production site, a warehouse, a hub, a port, or a vessel to the destination point or end customer undamaged without violation of regulations or rules. Apart from the critical points mentioned above, another subject that needs intensive attention is the project cargo loading, stowing, and unloading. It is necessary to consider that the infrastructure of the road and the appropriate equipment such as cranes used for loading or unloading the cargo or proper lashing operations become important decision areas (Sarı, 2016). According to Kopytov and Abramov (2013), the transportation of oversized cargoes should be treated individually and as a special project which eventually concluded that the responsible party should pay special attention to surroundings that would not be damaged.

Furthermore, the staff's experience in loading, transportation, and unloading operations also has a significant impact on the whole operation. For the safety and security of transportation, using a guidance vehicle is another decision point for the managers. Coordination and communication through the transportation process and giving relevant information to the public and private bodies such as road patrols, municipality officers, road control teams, and provincial and district authorities before, during, and after the transportation process for the possible risks are crucial. In Table 1, various possible decisions for project transportation can be seen.

Table 1. The possible decisions through the project transportation process
Çizelge 1. *Proje taşıma sürecinde olası kararlar*

Decision	Issues Covered	Authors
Vehicle selection	• Vehicle Availability • Vehicle-Haulage assignment • Full charter or part charter decisions	
Route selection	• Route-vehicle assignment • Optimal route selection • Route analysis • Warehouse operations	• Petraska and Palsaitis (2012)
Equipment selection	• Vehicle-equipment assignment • Purchasing, leasing decisions • Guidance vehicle assignment • Lashing	• Galor and Galor (2011) • Kopytov and Abramov (2013)
Staff Selection	• Staff-project assignment • Staff training	• Bazaras et al. (2013)
Documentation	• Documentation of relevant paper works • Route permits • Customs operations	• Allianz Global Corporate & Specialty (2014)
Communication	• Communication activities through the transportation process	
Information	• Legal bodies to be informed • Order monitoring	

Source: Adapted from Petraska and Palsaitis (2012), Galor and Galor (2011), Kopytov and Abramov (2013), Bazaras et al. (2013), Allianz Global Corporate & Specialty (2014).

Project logistics operations can be broadly divided into seven processes: planning, cost analysis, operational feasibility, compatibility with regulations, operation process, monitoring, and feedback. In this context, project logistics companies provided effective management of such activities and are regarded as 3PL providers.

A 3PL company can perform various logistics activities on behalf of the contracted company and allow companies to focus on their core competencies. As a result, 3PLs provide cost reduction, productivity profits, and service quality improvements (Aguezzoul, 2010). According to Gürcan et al. (2016), 3PL service providers contribute to economies of scale, process expertise, access to capital, and access to expensive technologies. Delfman et al. (2002) provided the significant functions of 3PLs as transportation, warehousing, packaging, order processing, inventory management, and information system. Although contracts in project logistics are frequently seen as one-time contracts and short-term relationships between two firms, this conclusion is often faulty. Thus, 3PL selection can be considered of primary importance in project logistics due to the specific requirements of customer needs.

Due to the subjectivity in complex decision-making processes, fuzzy set theory is one of the extensively used methods in decision support. One popular problem area engaged in fuzzy set theory is the supplier selection problem. Kar (2015) highlighted that due to the high complexity levels, the selection process includes a lot of subjectivity because there are multiple evaluation criteria for the problem. Furthermore, the author also stated that for the selection of a supplier, fuzzy set theory accommodates the subjectivity in the decision-making process arising out of the high complexity of problem definition.

The project logistics sector in Türkiye can be seen as a flourishing area. There are many newcomers to the market, and the competition has become fierce because of the development of information and communication technologies. In this context, this sector is not well-researched in Türkiye and foreign scenarios and lacks a modern supply chain perspective. Although decision techniques such as AHP (Analytic Hierarchy Process), and FAHP (Fuzzy Analytic Hierarchy Process) is not a new technique in deciding suppliers, the novelty of this paper offers a decision methodology for the selection of possible project logistics service providers. As the purpose of AHP is to capture the expert's knowledge, the conventional AHP still cannot reflect the human thinking style. Therefore, FAHP, a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems (Kahraman et al. (2003). On this occasion, Li et al. (2012) stated that the selection of logistics suppliers is highly related to perceptions and concluded that it is of practical value for establishing uncertain fuzzy 3PL selection models.

This study addressed issues for the selection of project logistics service providers by using FAHP. Thus, Section 2 includes the literature review, Section 3 deals with the study's methodology, Section 4 highlights the case study of the methodology, and the final section represents the results and the conclusion of the research.

Literature Review: Project Logistics Management

The project logistics management concept is a series of management procedures that aim to ensure the different structural equipment for industrial investments. Earlier perspectives on project logistics deal with the supply of construction projects. Caron et al. (1998) indicated the importance of the availability and delivery dates of the materials for project logistics which eventually ensures a sufficient stock of materials available at a building site to protect the construction. Sobotka and Czarnigowska (2005) analyzed the supply system for planning construction project logistics. The authors claimed that the selection of the logistics model determined for a project should be carefully analyzed in terms of supplier market limitations, material consumption structure, consumption planning accuracy, and minimization of logistics costs. The costs incurred during a project are heavily related to handling and transporting the materials and equipment. Henceforth, such materials may have a non-standard shape that needs special treatment.

In this context, project cargo is defined as cargoes or equipment which are large, heavy, or out of gauge and need specialized activities like lifting, handling, or stowage (Allianz Global Corporate & Specialty, 2014). In such processes, the safety and security of non-standard goods affect the quality of transportation (Palsaitis and Petraska, 2011). Furthermore, Galor and Galor (2011) identified oversize cargoes as those with parameters larger than standard ones. These parameter discrepancies arise from the design of the vehicles and the infrastructure of the road for the transportation route. For instance, the usable area of an airplane and the related dimensions are known in advance by the handling staff and the usable area constraints restricted the overloading. This case is also applicable to the vessels used in project cargo transportation; even if the cargo is distributed equally, one cannot exceed the vessel's capacity even if the vessel has enough strength to resist compression forces (Galor and Galor, 2011). Also, as can be seen frequently in road transportation, a cargo that exceeds the height constraint of a tunnel will eventually face accidents involving death or cargo damage risk. Sarı (2016) defined project transportation as a scheduled transportation program for cargoes with non-standard weight and non-standard dimensions from the point of origin to the destination point with special precautions and special vehicles. In this sense, project transportation must include the domestic and foreign transportation process for cargo with non-standard dimensions and coordinate the necessary equipment for the whole transportation process from the beginning to the end of the route. So, project logistics covers all the managerial operations starting with the origin point until the end customer to ensure the cargo are delivered undamaged and without violating the related regulations.

Palsaitis and Petraska (2012) evaluated various criteria for the route selection of oversize cargo. In their studies, the authors determined 16 criteria to evaluate possible oversize transportation routes. Kopytov and Abramov (2013) determined different transportation alternatives for various cargo types and employed an AHP method to choose transportation routes. Furthermore, Petraska et al. (2017) developed an algorithm that allows proper determination of transport modes, route selection, cargo transportation, and cargo handling technologies for oversize cargo transportation. Chmieliński (2017) underlined the safety of oversize cargoes in ports and sea transportation and provided that the transport of oversize cargoes has a significant impact on the economic development of countries. However, it is still very differently organized in many countries. A recent project funded by European Commission is the *HEAVYROUTE* project. The project was developed for route guidance and driver support system for heavy goods vehicles (HGVs) and based on the improvement in the generation and usage of digital maps as a tool for deriving the safest and most cost-effective routes for road freight transports. As this includes reducing fuel consumption, it also contributes to the reduction of greenhouse gases (Ihs et al., 2008). As mentioned by different authors, delivering oversize cargo requires both proper infrastructure and equipment. Furthermore, the transportation of such cargo both affects the economy and the environment itself. In this context, such initiatives are not enough, and some sector-specific steps should be necessary. Thus, this study differentiates itself by offering a managerial perspective on selecting proper project logistics service provider company.

Pisz and Łapuńka (2016) identifies key factors that need to be taken under consideration when planning oversized cargo transportation services and proposed a method that uses fuzzy set theory.

In their studies, Şakar et al. (2018) analyzed the barriers and highlighted the value-creation process of project cargo logistics. One of the main outcomes of the study is that to create value, managers should focus on partner selection and operations-related factors.

Zalluhoğlu et al. (2020) searched the challenges for project logistics in Türkiye and they highlighted four main areas for the challenges legal, infrastructure, human resources, and economics areas.

Turbaningsih et al. (2022) have studied the intermodal transportation of a railway carriage from Indonesia to Chittagong port and proposed a model for an optimum cost for the transportation. As this type of transportation is considered project logistics, the authors discussed that multi-modal transportation includes benefits such as decreasing the complexity of liability through using a single contract for project logistics operations. Existing studies, however, focus on the selection of routes for oversize cargoes and material suppliers for construction projects. Henceforth, this study will provide a method for the selection of 3PL for project logistics. Thus, there is a gap in terms of academic literature and provides a managerial perspective.

Selection of Project Logistics Service Provider

Selecting the best alternative from various alternatives creates a critical decision-making process for managers and professionals in different industries. Selecting the best alternative and choosing one from many is not limited to the manufacturing industry but also to logistics, marketing, and finance fields such as selecting a project portfolio (Kocamaz, 2014), selection of discounted products (Çiçekli et al. 2018), or supplier evaluation and order allocation problems (Demircan Keskin et al. 2017). Using different approaches to selecting the best alternatives such as AHP, FAHP, TOPSIS, and PROMETHEE provides an efficient environment for decision-makers regarding both cost and time. Various studies reveal that different approaches have been conducted to select the best alternatives for 3PLs. Project logistics is one of the required fields for logistics management and includes various operations, which can also be counted as a service-providing area.

For almost a decade, companies have focused on their core competencies by using third-party logistics (3PL) services. Furthermore, Leahy et al. (1995) indicated that 3PL companies provide transport and warehouse services and other multiple and bundled services. Jayaram and Tan (2010) stated that 3PL companies may offer some value-added activities such as sales support, customer service, and reverse logistics activities. Using 3PL companies' expertise, companies can increase their logistics capability and enhance their performance (Cho et al., 2008). According to Perçin (2009), quantitative, qualitative, and multiple criteria are considered due to the complex nature of 3PL provider selection. For evaluating and selecting 3PL criteria such as on-time delivery, service quality, communication, service speed, and flexibility (Spencer et al., 1994), on-time deliveries, lower errors, stable financing, creativity in management, top management availability, and flexibility have been used. In their research, Moberg and Speh (2004) found that the top four selection criteria are service requirement responses, management quality, ethical issues, and the ability to provide value-added services for selecting 3PL for warehouse operations. Thakkar et al. (2005) provided 26 selection criteria for selecting different 3PLs using interpretive structural modeling and analytic network process. In their studies, Govindan et al. (2009) proposed a selection procedure using an interpretive structural modeling and fuzzy technique for order preference to select a reverse logistics service provider. Perçin (2009) used two phases AHP and TOPSIS approach to evaluate the 3PL providers. Intending to select the best 3PL provider and with main criteria such as strategic factors, business factors, and risk factors, the author efficiently analyses the potential 3PL providers. Soh (2010) introduced a FAHP approach to evaluating third-party logistics providers. The author sets the level 2 criteria as finance, service level, relationship, management, and infrastructure. According to the results for selecting a 3PL provider, the most important criterion is the technology capability sub-criteria under the infrastructure criteria. Govindan and Murugesan (2011) also used a fuzzy extent analysis to select the best 3PL for reverse operations. Seven attributes and 34 sub-attributes for the interpretation of best reverse logistics providers are determined for the battery manufacturing industry in India. Kabir (2012) stated that logistics service provider selection is a complex multi-criteria decision-making process that decision-makers need to evaluate many criteria such as quality, cost, and delivery time. The author analyzed the selection of an appropriate logistics service provider using both FAHP and TOPSIS approaches. Gupta et al. (2012) proposed a multi-criteria decision-making (MCDM) method for selecting a logistics service provider using fuzzy PROMETHEE for the cement industry. Daim (2012) used AHP for logistics service provider selection with a total of 26 items divided as service effectiveness for shippers, operations efficiency for transport logistics service providers, and service effectiveness for consignee categories. Singh et al. (2018) provided that for compatible partner selection, culture, experience, organization size, technical capability, managerial capability, and access to markets are also becoming crucial and evaluating 3PLs according to their abilities to conduct logistics activities such as production planning, transportation, storage, project management, distribution efficiently which allows companies to increase customer satisfaction.

Although logistics operations have become more organized in Türkiye, there is still an area that needs to be operated more organized. In this context, the project logistics industry in Türkiye is a flourishing area in which necessary procedures and regulations are still developing. Based on the literature review and interviews with the company experts, this study reveals that transportation cost, handling cost, safety, cargo safety, time of delivery, customs, and other documentation costs, exchange rate fluctuations, vehicle availability, optimal route, equipment condition, carbon emission, qualified staff, noise and vibration on the environment can be listed as criteria for selection of a 3PL for project logistics.

Methodological Background

An approach consisting of FAHP is applied for 3PL selection in project logistics management in the present study. FAHP is employed to determine the relative weights of the criteria and is used to deploy the final rankings of 3PL alternatives. So (2006) used an approach for logistics outsourcing by using FAHP and a balanced scorecard. Zhang and Feng (2007) also used FAHP for the selection of reverse logistics providers. Cheng et al. (2008) used fuzzy Delphi and FAHP methods for the evaluation of fourth-party logistics. Soh (2009) used FAHP to determine the 3PL selection. Çelik et al. (2009) also used this methodology in shipping registry selection. Govindan and Murugesan (2011) used fuzzy extent analysis to select the logistics provider for reverse logistics.

Nydick (1992) introduced that AHP is used for prioritizing the best alternatives when multiple criteria must be considered. Bhutta (2002) stated that to cope with multiple criteria situations, including intuitive, rational qualitative, and quantitative aspects, AHP, developed and published in the book, the AHP by Saaty in 1980, serves as a framework. AHP is based on a system approach that attributes to analyzing the structure-function combination from a holistic perspective (Koçak, 2003). Buckley (1985) highlighted that FAHP was developed to help decision-makers solve the vague nature of alternative selection problems while AHP runs a multi-criteria decision-making problem by examining the pairwise comparison of decision items, which may cause the decision-maker to be unsure of the pairwise comparison. AHP is often criticized for failing to fully address the inherent uncertainty or uncertainty associated with mapping a decision maker's judgment (Chan and Kumar, 2007). AHP operates by giving relative importance values according to decision alternatives and criteria for dealing with complex decision-making problems but is also criticized regarding using exact numbers and the inability to efficient evaluation for vague situations (Özkan Özen and Koçak, 2017). Also, according to Demirel et al. (2008), because AHP fails to deal with the imprecision and subjectiveness in the pairwise comparison process, the FAHP is used. Soh (2010) concluded that expressing pairwise comparison judgments as exact numerical values on a ratio scale is difficult for a decision-maker, which leads decision-makers to express the comparison ratios as interval numbers or fuzzy sets because they are more suitable for representing uncertain human judgments. Hsieh et al. (2004) indicated that assessing the importance of criterion B compared to criterion A is easier than considering principle A and principle B within an importance scale of one to seven. Thus, in this study, Buckley's (1985) method is employed to allow fuzzy numbers for pairwise comparisons and find fuzzy weight.

Fuzzy Analytic Hierarchy Process Method

Numerous authors have put forward numerous FAHP techniques while these techniques employ the ideas of fuzzy set theory and hierarchical structure analysis as systematic approaches to the alternative selection and justification problem (Kahraman et al,. 2003). The related previous studies and applications on FAHP can be seen in the table below.

In classical logic, the binary code (0-1), which is entirely wrong or correct, ensures a mathematical solution. On the other hand, in real life, this occasion is not indeed reflected in this structure. It is quite difficult to refer to decisions and conclusions considered as absolute wrong or entirely correct in this case. The decisions of a human being can be considered partly correct or partly wrong. Zadeh (1965) stated that in the fuzzy set logic, each object is characterized by a membership function with a membership degree of 0-1. Şengül et al. (2013) indicated that the limits of fuzzy sets are not rigid as in the classic set logic, which refers that the objects belonging to a set being equal to 1, and if they do not belong, it is equal to 0. The membership function refers to the functional representation of the membership degree, which refers to the change between 0 and 1. Triangular and trapezoidal fuzzy numbers are considered the most critical fuzzy numbers (Lai and Hwang, 1992). Tanaka (1997) stated that fuzzy numbers are fuzzy sets with special characteristics which ease the calculation. Fuzzy logic eases rigid transitions such as 1 and 0 in classical logic, allowing the logic rules to be implemented flexibly (Çiçekli and Karaçizmeli, 2013). The use of verbal variables distinguishes fuzzy logic from other logic structures. Using verbal variables provides an approximation of the concepts that cannot be clearly expressed; thus, verbal variables allow verbal expressions to be represented mathematically (Şengül et al., 2013).

The subset of the real numbers is considered fuzzy numbers, and they impose the idea of the confidence of interval. If the membership function $\mu_{\tilde{A}}(x)\colon \mathrm{R} \rightarrow [0,1]$ is equal to equation (1) as below, a fuzzy number A on R is considered a triangular fuzzy number.

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-L)/(M-L), & L \leq x \leq M, \\ (U-x)/(U-M), & M \leq x \leq U, \\ 0, & otherwise, \end{cases} \quad (1)$$

As it can be seen in Figure 1, L is the upper, and U is the lower bound for the fuzzy number $\tilde{A}$. Moreover, the modal value corresponds to M. $\tilde{A}$ refers to the (L, M, U) and considering $\tilde{A}_1$ and $\tilde{A}_2$ as two fuzzy numbers, then the calculations for these as below:

Addition of a fuzzy number:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (L_1, M_1, U_1) \oplus (L_2, M_2, U_2) = (L_1 + L_2, M_1 + M_2, U_1 + U_2) \quad (2)$$

Multiplication of a fuzzy number:

$$\tilde{A}_1 \otimes \tilde{A}_2 \approx (L_1, M_1, U_1) \otimes (L_2, M_2, U_2) \approx (L_1 L_2, M_1 M_2, U_1 U_2)$$

for L_i>0, M_i>0, U_i>0. (3)

Subtraction of a fuzzy number:

$$\tilde{A}_1 \ominus \tilde{A}_2 = (L_1, M_1, U_1) \ominus (L_2, M_2, U_2) = (L_1 - U_2, M_1 - M_2, U_1 - L_2) \quad (4)$$

Division of a fuzzy number:

$$\tilde{A}_1 \oslash \tilde{A}_2 \approx (L_1, M_1, U_1) \oslash (L_2, M_2, U_2) \approx (L_1 / U_2, M_1 / M_2, U_1 / L_2)$$

for L_i>0, M_i>0, U_i>0. (5)

Reciprocal of a fuzzy number

$$\tilde{A}_1^{-1} = (L_1, M_1, U_1)^{-1} = (1 / U_1, 1 / M_1, 1 / L_1)$$

for L_i>0, M_i>0, U_i>0. (6)

Determination of linguistic variables

Zadeh (1975) introduced that linguistic variables are important when situations are complex and hard to define. Hsieh (2004) stated that linguistic variable corresponds to words or sentences in an artificial language. In this study, as shown in Table 2, absolutely important, very strongly important, essentially important, weakly important, equally important linguistic terms have been used concerning fuzzy five-level scales, as shown in Figure 2.

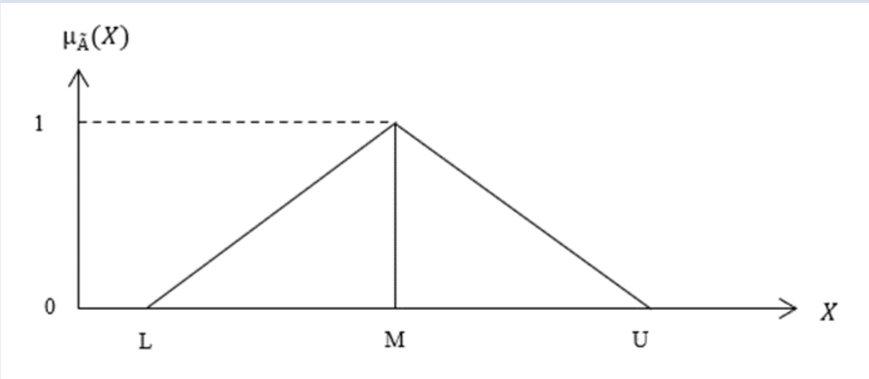

Figure 1. *Triangular fuzzy number for the membership function (Hsieh et al. 2004 and Fu & Tzeng, 2016).*
Şekil 1. Üyelik fonksiyonu için üçgen bulanık sayı (Hsieh et al. 2004 and Fu & Tzeng, 2016).

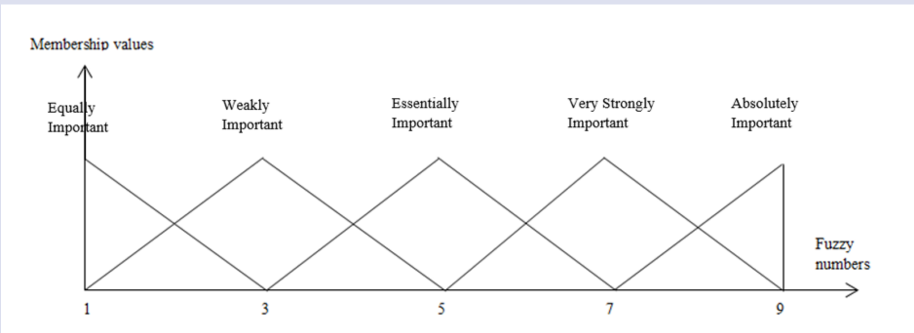

Figure 2. *Membership functions of linguistics variables (Hwai-Hui Fu & Shian-Yang Tzeng, 2016).*
Şekil 2. Dilsel değişkenlerin üyelik fonksiyonları

Table 2. Various developments for previous FAHP literature
Çizelge 2. *Geçmiş FAHP literatürü ile ilgili çeşitli gelişmeler*

Author	Application
van Laarhoven and Pedrycs (1983)	Comparison of the fuzzy rations through triangular membership functions.
Buckley (1985)	Determination of fuzzy priorities with trapezoidal membership functions.
Stam et al. (1996)	Used artificial intelligence techniques in AHP with fuzzy ration scale preferences.
Chang (1996)	Used triangular fuzzy numbers for pairwise comparison and extent analysis method for the synthetic extent values.
Ching- Hsue (1997)	Introduced a new evaluating system by using FAHP through the grade value of membership function.
Weck et al. (1997)	Presented a method by using the mathematics of fuzzy logic to classical AHP.
Kahraman et al. (1998)	Used a fuzzy weighted evaluation by using the fuzzy objective and subjective method.
Deng (1999)	Used fuzzy approach for dealing with qualitative multi-criteria analysis problems.
Lee et al. (1999)	They introduced a methodology that uses the comparison of intervals and proposed a methodology based on stochastic optimization.
Cheng et al. (1999)	Proposed a method by using linguistic variable weight.
Chan et al. (2000)	Presented an algorithm for technology selection to determine tangible and intangible benefits in a fuzzy environment.
Leung and Cao (2000)	Used a method that considers a tolerance deviation.
Kuo et al. (2002)	Used a hierarchical structure development for FAHP.

Source: Adapted from Kahraman et al.,2003

Fuzzy Analytic Hierarchy Process

The weights of evaluation criteria can be determined by FAHP as introduced below:

Step 1. Structure the matrices of comparison between the criteria in the dimensions of the hierarchy system. For instance

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix}, \quad (7)$$

where

$$\tilde{a}_{ij} = \begin{cases} \tilde{1},\tilde{3},\tilde{5},\tilde{7},\tilde{9},\ \textit{criterion i is relative importance to criterion j} \\ 1, i = j, \\ \tilde{1}^{-1},\tilde{3}^{-1},\tilde{5}^{-1},\tilde{7}^{-1},\tilde{9}^{-1}, \textit{criterion i is relative less importanceto criterion j} \end{cases}$$

Step 2. Implement the geometric mean to determine the fuzzy geometric mean and fuzzy weights of each criterion stated by Equation 7 (Buckley,1985) as below:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \ldots \otimes \tilde{a}_{in})^{1/n}, \tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \ldots \oplus \tilde{r}_n)^{-1}, \quad (8)$$

In equation (8), $\tilde{a}_{in}$ corresponds for the value criterion i to criterion n as a fuzzy comparison value. Furthermore, the geometric mean of fuzzy comparison value for i represents as $\tilde{r}_i$ and $\tilde{w}_i$ corresponds to a fuzzy weight of criterion i. The triangular fuzzy number can be indicated as $\tilde{w}_i = (Lw_i, Mw_i, Uw_i)$. Lw_i is the lower value for the fuzzy weight, Mw_i is the middle value for the fuzzy weight and Uw_i is the upper value for the fuzzy weight of the criterion i.

Case Study

The case company chosen for this study facilitates the renewable energy industry in Türkiye. The company was established in 2012 and tried to expand its market share due to the competitive environment. The company currently produces wind turbines and solar panels and facilitates domestic and foreign energy projects. The company seeks to maintain and increase customer satisfaction by responding accurately regarding global logistics operations. The managers of the company and the responsible staff believe that deciding on an effective service provider for project logistics operations will increase the customer satisfaction level and eventually their market share. The company is going to find a new production facility for wind turbines located in Europe. In this sense, the company needs to deliver the related equipment to the production site. There are five companies for project logistics operations on their agenda; thus, managers faced critical decision-making with selecting the most suitable service provider. To keep confidentiality, the companies have named Company A, Company B, Company C, Company D, and Company E. The case company evaluated the proposed methodology for selecting the best alternative with the help of related references and the decision-making group, which includes the operation staff in the company. To evaluate 3PL firms, four experts were selected according to their expertise. All experts have more than 8-year experience in the area of project logistics management. We identified three groups of criteria with 13 sub-criteria, as in Figure 3.

Figure 3 shows the evaluation criteria and the abbreviations of each criterion. The brief descriptions of the selected criteria are as below:

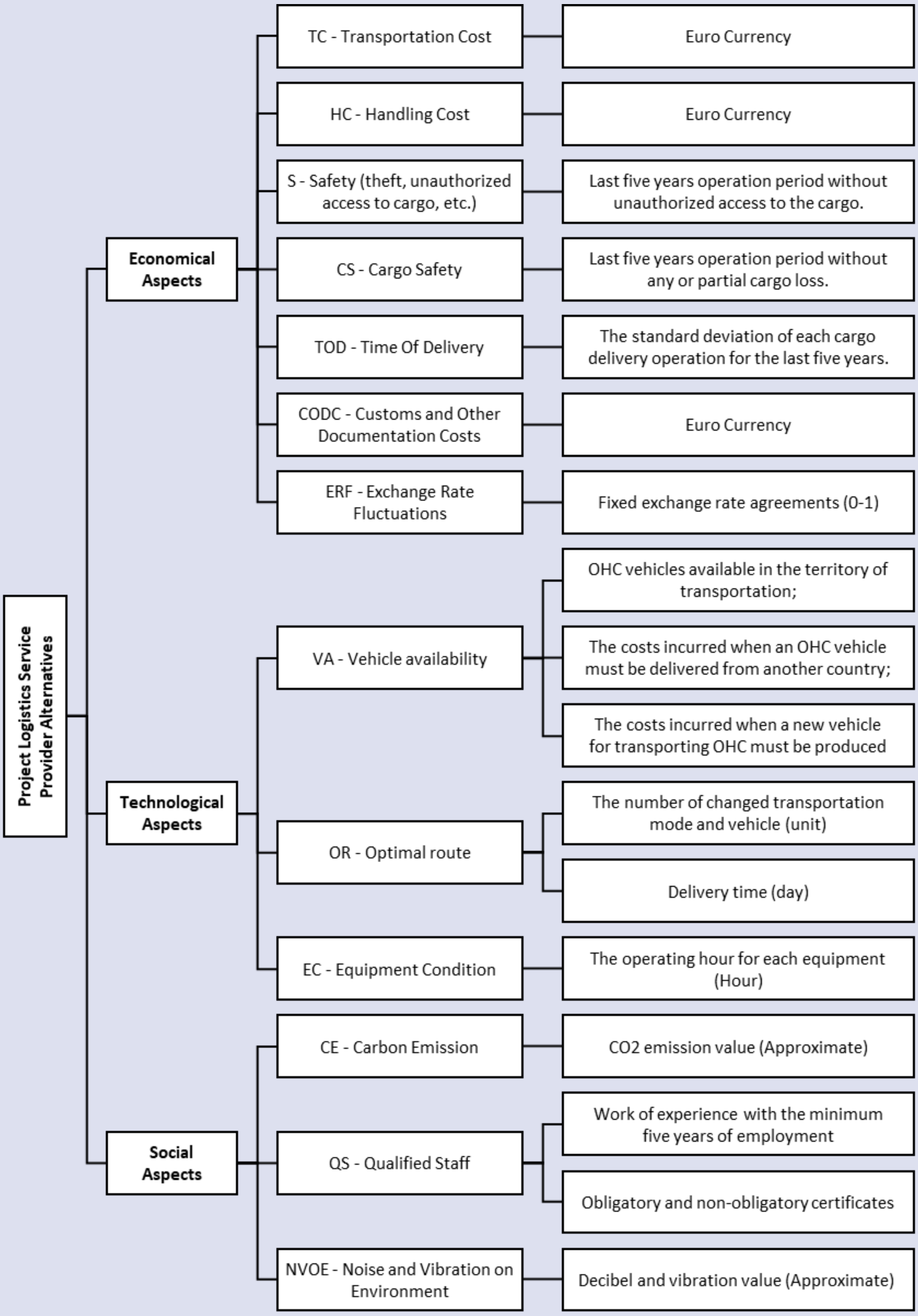

Figure 3. *Evaluation criteria and sub-criteria for selecting project logistics service providers*
Şekil 3. Proje lojistiği hizmet sağlayıcılarını seçmek için değerlendirme kriterleri ve alt kriterler

The transportation cost metric includes the financial cost of transporting goods from the origin location to the destination location (Kopytov and Abramov 2013, Kopytov and Abramov 2012(a), Kopytov and Abramov 2012(b)). In this case, the metric is selected as Euro currency due to the transportation from Türkiye to the EU member countries.

The handling cost metric is also considered a financial cost, but due to the different activities during handling operations, this metric is considered a separate activity. This metric's currency is also selected as Euro for the transportation from Türkiye to the EU member countries.

The safety metric involves the protection against unauthorized access to cargo and others (Kopytov and Abramov 2013, Kopytov and Abramov 2012(a), Kopytov and Abramov 2012(b)). This metric involves the last five years' operation period without unauthorized access to the cargo.

Cargo safety is another metric that includes cargo loss and deterioration of consumer properties (Kopytov and

Abramov 2012(a)). This metric involves the last five years' operation period without any or partial cargo loss.

The time of delivery includes the time for transporting goods from the origin to the destination location and includes all the necessary activities such as loading, handling, customs clearance, etc. (Kopytov and Abramov 2013, Kopytov and Abramov 2012(a), Kopytov and Abramov 2012(b)). Min (1994), Ghodsypour and O'Brien (1998), and Xia and Wu (2007) concluded that shipping delay and lead time are also significant concerns of global sourcing. The metric of this criterion constitutes the standard deviation of each cargo delivery operation for the last five years.

Customs and other documentation costs include the financial cost of customs clearance operations, documentation, storage, demurrage, and others. Min (1994) and Chan and Kumar (2007) concluded that different countries have various requirements for conducting customs duties. Therefore, this metric's currency is also selected as Euro for the transportation from Türkiye to the EU member countries.

Exchange rate fluctuations refer to the deviations between two related currencies. The currency rates, local prices, and other conditions can be affected by the economic status of the related country (Chan and Kumar 2007). The fixed and non-fixed exchange rate agreements affect customers' decisions due to the highly fluctuating economic environment. This metric operates as a binary that defines if there is a fixed exchange rate agreement or not.

The availability of vehicle criterion includes the metrics as the availability of the proper vehicle which may be in the transportation territory or a new production of OHC vehicle is produced (Petraka and Palsaitis, 2012).

Kopytov and Abramov 2012(b) referred to indices for efficient route selection as total transportation cost and delivery time. To this end, the optimal route criterion refers to the metrics like the number of changed transportation modes, vehicle, and delivery time (day) for the route.

The current state of the equipment used in transportation refers to the current condition of the leased or owned equipment by service providers. This metric is related to the operating hour for each piece of equipment. In addition, the current state of the equipment relates to the technology, which Min (1994) and Chan and Kumar (2007) related to satisfying the customer's changing requirements.

The criterion related to harmful substance emissions (Kopytov and Abramov 2013, Kopytov and Abramov 2012(a), Kopytov and Abramov 2012(b)) refers to the released carbon emission for each delivery of the related cargo. Furthermore, the approximate calculation of the planned transportation operation is also a preference of the customer. Therefore, this metric refers to the approximate carbon emission value for possible transportation operations.

The qualified staff refers to the experienced staff related to transportation operations. In this case, the experience covers a minimum of five years of employment. Furthermore, the obligatory and non-obligatory certificates for the related staff are also a reason for preference.

The released noise and vibration to the environment during the transportation criterion includes the approximate decibel and vibration value for possible transportation operation.

The preference scale for the weighted criteria's linguistic expressions and their corresponding triangular fuzzy numbers, used by experts in this study is depicted in Table 4-7.

As in Table 4, using the fuzzy geometric mean method (Buckley, 1985), the fuzzy pairwise comparison matrix was structured by integrating the fuzzy judgment values of various experts.

Table 3. Triangular fuzzy conversion scale (Hsieh et al., 2004; Chiou ve Tzeng, 2001; Mon et al., 1994).
Çizelge 3. *Üçgen bulanık çevrim ölçeği (Hsieh et al., 2004; Chiou ve Tzeng, 2001; Mon et al., 1994).*

Fuzzy Number	Linguistic Scales	Scale of Fuzzy Number
$\tilde{1}$	Equally important (Eq)	(1,1,3)
$\tilde{3}$	Weakly important (Wk)	(1,3,5)
$\tilde{5}$	Essentially important (Es)	(3,5,7)
$\tilde{7}$	Very strongly important (Vs)	(5,7,9)
$\tilde{9}$	Absolutely important (Ab)	(7,9,9)

Table 4. Fuzzy pairwise comparison of dimension for Expert 1
Çizelge 4. *Uzman 1 için bulanık ikili karşılaştırma*

	TC	HC	S	CS	TOD	CODC	ERF
TC	*1*	*Es*	*Wk*	*LEq*	*Eq*	*Wk*	*Es*
HC		*1*	*Eq*	*LEq*	*LWk*	*LEq*	*Eq*
S			*1*	*LEs*	*LWk*	*LEq*	*Vs*
CS				*1*	*Eq*	*Es*	*Vs*
TOD					*1*	*LWk*	*Es*
CODC						*1*	*LEq*
ERF							*1*

Table 5. Fuzzy pairwise comparison of dimension for Expert 2
Çizelge 5. *Uzman 2 için bulanık ikili karşılaştırma*

	TC	HC	S	CS	TOD	CODC	ERF
TC	*1*	*Wk*	*Es*	*LWk*	*Eq*	*Wk*	*Es*
HC		*1*	*LEq*	*LEq*	*LWk*	*Eq*	*Eq*
S			*1*	*LEs*	*LEs*	*LEq*	*Ab*
CS				*1*	*Eq*	*Es*	*Ab*
TOD					*1*	*LWk*	*Es*
CODC						*1*	*Eq*
ERF							*1*

Table 6. Fuzzy pairwise comparison of dimension for Expert 3
Çizelge 6. *Uzman 3 için bulanık ikili karşılaştırma*

	TC	HC	S	CS	TOD	CODC	ERF
TC	*1*	*Es*	*Wk*	*LEq*	*Eq*	*Wk*	*Vs*
HC		*1*	*LEq*	*LEq*	*LWk*	*LEq*	*Wk*
S			*1*	*LVs*	*LEs*	*LEq*	*Vs*
CS				*1*	*Eq*	*Es*	*Ab*
TOD					*1*	*LWk*	*Es*
CODC						*1*	*Eq*
ERF							*1*

Table 7. Fuzzy pairwise comparison of dimension for Expert 4
Çizelge 7. *Uzman 4 için bulanık ikili karşılaştırma*

	TC	HC	S	CS	TOD	CODC	ERF
TC	*1*	*Es*	*Wk*	*LEq*	*LEq*	*Eq*	*Es*
HC		*1*	*LEq*	*LEq*	*LEs*	*Eq*	*Eq*
S			*1*	*LEs*	*LEs*	*LEq*	*Vs*
CS				*1*	*LEq*	*Vs*	*Ab*
TOD					*1*	*Wk*	*Vs*
CODC						*1*	*Eq*
ERF							*1*

The weights calculation of the evaluation criteria

The computations of the procedure regarding dimensions of weights can be seen as follow:

As mentioned above, the interviews were conducted with four experts. According to these experts, pairwise comparison matrices were obtained for the evaluation of dimensions as follows:

By applying the fuzzy numbers depicted in Table 8-11, the corresponding fuzzy numbers can be transferred from the linguistic scales as below:

Using equation (7), the elements of synthetic pairwise comparison matrix by using the geometric mean method, for $\tilde{a}_{21}$ as an example:

$$\tilde{a}_{21} = (\tilde{a}_{21}^{1} \otimes \tilde{a}_{21}^{2} \otimes \tilde{a}_{21}^{3} \otimes \tilde{a}_{21}^{4})^{1/4}$$

$$\tilde{a}_{21} = \left(\left(\frac{1}{7},\frac{1}{5},\frac{1}{3}\right) \otimes \left(\frac{1}{5},\frac{1}{3},1\right) \otimes \left(\frac{1}{7},\frac{1}{5},\frac{1}{3}\right) \otimes \left(\frac{1}{7},\frac{1}{5},\frac{1}{3}\right)\right)^{1/4}$$

$$\tilde{a}_{21} = \left(\left(\frac{1}{7}\times\frac{1}{5}\times\frac{1}{7}\times\frac{1}{7}\right)^{\frac{1}{4}},\left(\frac{1}{5}\times\frac{1}{3}\times\frac{1}{5}\times\frac{1}{5}\right)^{\frac{1}{4}},\left(\frac{1}{3}\times 1\times\frac{1}{3}\times\frac{1}{3}\right)^{\frac{1}{4}}\right)$$

$$= (0.155, 0.227, 0.439)$$

In order to demonstrate the calculation procedure, the aspects with the most significant number of sub-criteria, which is the economic aspects, were calculated. Sub-criteria are shown as TC (1), HC (2), S (3), CS (4), TOD (5), CODC (6), ER (7), respectively.

Fuzzy weights of the dimensions for experts can be obtained by using Equations (8), such as:

$$\tilde{r}_1 = (\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \tilde{a}_{13} \otimes \tilde{a}_{14} \otimes \tilde{a}_{15} \otimes \tilde{a}_{16} \otimes \tilde{a}_{17})^{\frac{1}{7}}$$

$$= \left((1 \times 2.280 \times 1.316 \times 0.293 \times 0.760 \times 1 \times 3.409)^{\frac{1}{7}}, (1 \times 4.401 \times 3.409 \times 0.760 \times 1 \times 2.280 \times 5.439)^{\frac{1}{7}}, (1 \times 6.435 \times 5.439 \times 1 \times 2.280 \times 4.401 \times 7.454)^{\frac{1}{7}}\right)$$

$$= (1.125, 2.028, 3.078).$$

Furthermore, the remaining can be calculated $\tilde{r}_i$ such as,

$\tilde{r}_2 = (0.423, 0.706, 1.146)$
$\tilde{r}_3 = (0.492, 0.710, 1.149)$
$\tilde{r}_4 = (1.712, 2.289, 3.664)$
$\tilde{r}_5 = (0.927, 1.734, 2.537)$
$\tilde{r}_6 = (0.510, 0.755, 1.420)$
$\tilde{r}_7 = (0.224, 0.328, 0.441)$

For each dimension, the weights can be found as follows:

$$\tilde{w}_1 = \tilde{r}_1 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5 \oplus \tilde{r}_6 \oplus \tilde{r}_7)^{-1}$$

$$= (1.125, 2.028, 3.078) \otimes \begin{pmatrix} 1/(3.078 + 1.146 + 1.149 + 3.664 + 2.537 + 1.420 + 0.441), \\ 1/(2.028 + 0.706 + 0.710 + 2.289 + 1.734 + 0.755 + 0.328), \\ 1/(1.125 + 0.423 + 0.492 + 1.712 + 0.927 + 0.510 + 0.224) \end{pmatrix}$$

$$= (0.084, 0.237, 0.569).$$

Likewise, $\tilde{w}_2 = (0.031, 0.083, 0.212)$, $\tilde{w}_3 = (0.037, 0.083, 0.212)$, $\tilde{w}_4 = (0.127, 0.268, 0.677)$, $\tilde{w}_5 = (0.069, 0.203, 0.469)$, $\tilde{w}_6 = (0.038, 0.088, 0.262)$, $\tilde{w}_7 = (0.017, 0.038, 0.081)$.

The overall weights $(O\widetilde{w}_i)$ can be calculated by multiplying local weights with parent weights. An example of calculation of overall weights can be seen as follows. For all the overall weight calculations, please see Table 9.

$$O\widetilde{w}_1 = (0.084, 0.237, 0.569) \otimes (0.366, 0.685, 1.179)$$
$$= (0.031, 0.162, 0.671)$$

Since the calculation of fuzzy multiplication is rather complex, it is usually denoted by the approximate multiplied result of the fuzzy multiplication and the approximate fuzzy number $\tilde{R}_i$ of the fuzzy synthetic decision of each alternative can be shown as

$\tilde{R}_i = (LR_i, MR_i, UR_i)$ where LR_i, MR_i and UR_i are the lower, middle, and upper-performance values of alternative *i,* which are indicated below.

$$LR_i = \sum_{j=1}^{n} LE_{ij} \times Lw_j; \quad LR_i = \sum_{j=1}^{n} ME_{ij} \times Mw_j; \quad LR_i = \sum_{j=1}^{n} LE_{ij} \times Lw_j; \quad (12)$$

Lastly, by using the overall weights, the BNP (Best Nonfuzzy Performance) values can be determined. To apply the Center of Area (COA) method, the Best Nonfuzzy Performance of the fuzzy weights should be determined. Below, an example calculation of BNP for TC (1) can be seen. For all the overall weight calculations, please see Table 9.

$$BNP_{w_1} = (L_{w_1} + M_{w_1} + U_{w_1})/3$$
$$= (0.031 + 0.162 + 0.671)/3$$
$$= 0,288$$

Elements of the remaining fuzzy performance values for each expert criterion for each alternative can be obtained by the same procedure and are shown in Table 14.

Ranking the alternatives

The final fuzzy synthetic decision is processed through the criteria weights derived by four experts, the average of these four obtained by FAHP (Table 13), and the average fuzzy performance values of each criterion of experts for each alternative (Table 14). Then nonfuzzy ranking will be applied, and for the final, fuzzy numbers are changed to nonfuzzy numbers.

Eq. (12) is going to be used to obtain this value:

$$\tilde{R}_i = (LR_i, MR_i, UR_i)$$
$$= ((\textstyle\sum_{j=1}^{20} LE_{1j} \times Lw_j, \sum_{j=1}^{20} ME_{1j} \times Mw_j, \sum_{j=1}^{20} UE_{1j} \times Uw_j))$$
$$= ((0.038 \times 0.366 + \ldots + 0.162 \times 0.063),$$
$$(0,121 \times 0.685 + \ldots + 0.383 \times 0.117),$$
$$(0.313 \times 1.179 + \ldots + 0.795 \times 0.235))$$
$$= (0.022, 0.206, 2.063)$$

Then Eq. (13) is used to find out its BNP value as follows for Company A as below:

$$BNP_{w_1} = (L_{w_1} + M_{w_1} + U_{w_1})/3$$
$$= (0.022 + 0.206 + 2.063)/3$$
$$= 0,764$$

Table 8. Linguistic scales for Expert 1

Çizelge 8. *Uzman 1 için dilsel ölçekler*

	TC	HC	S	CS	TOD	CODC	ERF
TC	*1*	$\tilde{5}$	$\tilde{3}$	$\tilde{1}^{-1}$	$\tilde{1}$	$\tilde{3}$	$\tilde{5}$
HC	$\tilde{5}^{-1}$	*1*	$\tilde{1}$	$\tilde{1}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}^{-1}$	$\tilde{1}$
S	$\tilde{3}^{-1}$	$\tilde{1}^{-1}$	*1*	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}^{-1}$	$\tilde{7}$
CS	$\tilde{1}$	$\tilde{1}$	$\tilde{5}$	*1*	$\tilde{1}$	$\tilde{5}$	$\tilde{7}$
TOD	$\tilde{1}^{-1}$	$\tilde{3}$	$\tilde{3}$	$\tilde{1}^{-1}$	*1*	$\tilde{3}^{-1}$	$\tilde{5}$
CODC	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{5}^{-1}$	$\tilde{3}$	*1*	$\tilde{1}^{-1}$
ERF	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	$\tilde{7}^{-1}$	$\tilde{7}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}$	*1*

Table 9. Linguistic scales for Expert 2

Çizelge 9. *Uzman 2 için dilsel ölçekler*

	TC	HC	S	CS	TOD	CODC	ERF
TC	*1*	$\tilde{3}$	$\tilde{5}$	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{3}$	$\tilde{5}$
HC	$\tilde{3}^{-1}$	*1*	$\tilde{1}^{-1}$	$\tilde{1}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{1}$
S	$\tilde{5}^{-1}$	$\tilde{1}$	*1*	$\tilde{5}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}$	$\tilde{9}$
CS	$\tilde{3}$	$\tilde{1}$	$\tilde{5}$	*1*	$\tilde{1}$	$\tilde{5}$	$\tilde{9}$
TOD	$\tilde{1}^{-1}$	$\tilde{3}$	$\tilde{5}$	$\tilde{1}^{-1}$	*1*	$\tilde{3}^{-1}$	$\tilde{5}$
CODC	$\tilde{3}^{-1}$	$\tilde{1}^{-1}$	$\tilde{1}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}$	*1*	$\tilde{1}$
ERF	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	$\tilde{9}^{-1}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	*1*

Table 10. Linguistic scales for Expert 3

Çizelge 10. *Uzman 3 için dilsel ölçekler*

	TC	HC	S	CS	TOD	CODC	ERF
TC	*1*	$\tilde{5}$	$\tilde{3}$	$\tilde{1}^{-1}$	$\tilde{1}$	$\tilde{3}$	$\tilde{7}$
HC	$\tilde{5}^{-1}$	*1*	$\tilde{1}^{-1}$	$\tilde{1}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}^{-1}$	$\tilde{3}$
S	$\tilde{3}^{-1}$	$\tilde{1}$	*1*	$\tilde{7}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	$\tilde{7}$
CS	$\tilde{1}$	$\tilde{1}$	$\tilde{7}$	*1*	$\tilde{1}$	$\tilde{5}$	$\tilde{9}$
TOD	$\tilde{1}^{-1}$	$\tilde{3}$	$\tilde{5}$	$\tilde{1}^{-1}$	*1*	$\tilde{3}^{-1}$	$\tilde{5}$
CODC	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{5}^{-1}$	$\tilde{3}$	*1*	$\tilde{1}$
ERF	$\tilde{7}^{-1}$	$\tilde{3}^{-1}$	$\tilde{7}^{-1}$	$\tilde{9}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	*1*

Table 11. Linguistic scales for Expert 4
Çizelge 11. *Uzman 4 için dilsel ölçekler*

	TC	HC	S	CS	TOD	CODC	ERF
TC	*1*	$\tilde{5}$	$\tilde{3}$	$\tilde{1}^{-1}$	$\tilde{1}^{-1}$	$\tilde{1}$	$\tilde{5}$
HC	$\tilde{5}^{-1}$	*1*	$\tilde{1}^{-1}$	$\tilde{1}$	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	$\tilde{1}$
S	$\tilde{3}^{-1}$	$\tilde{1}$	*1*	$\tilde{5}^{-1}$	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	$\tilde{7}$
CS	$\tilde{1}$	$\tilde{1}^{-1}$	$\tilde{5}$	*1*	$\tilde{1}^{-1}$	$\tilde{7}$	$\tilde{9}$
TOD	$\tilde{1}$	$\tilde{5}$	$\tilde{5}$	$\tilde{1}$	*1*	$\tilde{3}$	$\tilde{7}$
CODC	$\tilde{1}^{-1}$	$\tilde{1}$	$\tilde{1}$	$\tilde{7}^{-1}$	$\tilde{3}^{-1}$	*1*	$\tilde{1}$
ERF	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	$\tilde{7}^{-1}$	$\tilde{9}^{-1}$	$\tilde{7}^{-1}$	$\tilde{1}^{-1}$	*1*

Table 12. Fuzzy pairwise comparison of sub-criteria dimensions
Çizelge 12. *Alt kriterler için bulanık ikili karşılaştırmalar*

	TC	HC	S	CS	TOD	CODC	ER
TC (1)	1	(2.280, 4.401, 6.435)	(1.316, 3.409, 5.439)	(0.293, 0.760, 1)	(0.760, 1, 2.280)	(1, 2.280, 4.401)	(3.409, 5.439, 7.454)
HC (2)	(0.155, 0.227, 0.439)	1	(0.439, 1, 1.316)	(0.439, 1, 1.316)	(0.184, 0.293, 0.760)	(0.439, 1, 1.316)	(1, 1.316, 3.409)
S (3)	(0.184, 0.293, 0.760)	(0.760, 1, 2.280)	1	(0.134, 0.184, 0.293)	(0.155, 0.227, 0.439)	(0.439, 1, 1.316)	(5.439, 7.454, 9)
CS (4)	(1, 1.316, 3.409)	(0.760, 1, 2.280)	(3.409, 5.439, 7.454)	1	(0.760, 1, 2.280)	(3.409, 5.439, 7.454)	(6.435, 8.452, 9)
TOD (5)	(0.439, 1, 1.316)	(1.316, 3.409, 5.439)	(2.28, 4.401, 6.435)	(0.439, 1, 1.316)	1	(0.299, 0.577, 1.495)	(3.409, 5.439, 7.454)
CODC (6)	(0.227, 0.439, 1)	(0.760, 1, 2.280)	(0.760, 1, 2.280)	(0.134, 0.184, 0.293)	(0.669, 1.732, 3.344)	1	(0.760, 1, 2.280)
ER (7)	(0.134, 0.184, 0.293)	(0.293, 0.760, 1)	(0.111, 0.134, 0.184)	(0.111, 0.118, 0.155)	(0.134, 0.184, 0.293)	(0.439, 1, 1.316)	1

Table 13. Weights of dimensions and criteria
Çizelge 13. *Boyutların ve kriterlerin ağırlıkları*

Dimension and criteria	Local weights	Overall weights	BNP
Economical Aspects	(0.366,0.685,1.179)		
TC	(0.084,0.237,0.569)	(0.031,0.162,0.671)	0.288
HC	(0.031,0.083,0.212)	(0.012,0.057,0.25)	0.106
S	(0.037,0.083,0.212)	(0.013,0.057,0.25)	0.107
CS	(0.127,0.268,0.677)	(0.047,0.183,0.798)	0.343
TOD	(0.069,0.203,0.469)	(0.025,0.139,0.553)	0.239
CODC	(0.038,0.088,0.262)	(0.014,0.06,0.309)	0.128
ERF	(0.017,0.038,0.081)	(0.006,0.026,0.096)	0.043
Technological Aspects	(0.144,0.250,0.510)		
VA	(0.332,0.694,1.308)	(0.048,0.174,0.667)	0.296
OR	(0.101,0.175,0.464)	(0.015,0.044,0.237)	0.098
EC	(0.062,0.13,0.246)	(0.009,0.033,0.125)	0.056
Social Aspects	(0.043,0.065,0.118)		
CE	(0.088,0.167,0.415)	(0.004,0.011,0.049)	0.021
QS	(0.359,0.716,1.31)	(0.015,0.047,0.155)	0.072
NVOE	(0.063,0.117,0.235)	(0.003,0.008,0.028)	0.013

Table 14. Average fuzzy values of each criterion of experts for each company
Çizelge 14. *Her işletme için ortaya çıkan ortalama bulanık değerler*

Dimension and criteria	Company A	Company B	Company C	Company D	Company E
TC	(0.038,0.121,0.313)	(0.062,0.169,0.432)	(0.114,0.323,0.795)	(0.066,0.234,0.596)	(0.082,0.151,0.606)
HC	(0.090,0.225,0.475)	(0.172,0.415,0.738)	(0.018,0.025,0.046)	(0.080,0.152,0.311)	(0.112,0.181,0.535)
S	(0.080,0.168,0.393)	(0.077,0.217,0.515)	(0.096,0.174,0.580)	(0.020,0.038,0.085)	(0.147,0.400,0.800)
CS	(0.069,0.180,0.543)	(0.020,0.039,0.090)	(0.095,0.180,0.611)	(0.116,0.299,0.712)	(0.093,0.299,0.571)
TOD	(0.144,0.303,0.787)	(0.061,0.183,0.379)	(0.055,0.165,0.489)	(0.126,0.303,0.685)	(0.021,0.044,0.108)
CODC	(0.027,0.047,0.118)	(0.133,0.361,0.710)	(0.079,0.174,0.489)	(0.024,0.054,0.116)	(0.166,0.361,0.885)
ERF	(0.057,0.115,0.387)	(0.110,0.278,0.918)	(0.046,0.115,0.387)	(0.051,0.143,0.310)	(0.088,0.346,0.816)
VA	(0.053,0.147,0.305)	(0.113,0.229,0.814)	(0.047,0.118,0.380)	(0.091,0.356,0.802)	(0.066,0.147,0.380)
OR	(0.217,0.328,0.739)	(0.030,0.045,0.113)	(0.024,0.045,0.090)	(0.174,0.409,0.657)	(0.058,0.170,0.376)
EC	(0.215,0.471,0.897)	(0.053,0.115,0.252)	(0.017,0.024,0.048)	(0.046,0.083,0.192)	(0.156,0.303,0.650)
CE	(0.158,0.375,0.965)	(0.074,0.218,0.525)	(0.034,0.066,0.207)	(0.027,0.066,0.166)	(0.102,0.272,0.654)
QS	(0.197,0.453,0.851)	(0.103,0.188,0.447)	(0.024,0.032,0.072)	(0.019,0.032,0.057)	(0.143,0.292,0.617)
NVOE	(0.162,0.383,0.795)	(0.117,0.198,0.452)	(0.025,0.052,0.089)	(0.102,0.167,0.291)	(0.094,0.198,0.363)

Table 15. Performance value and ranking
Çizelge 15. *Performans değerleri ve sıralamalar*

Dimension and criteria	Synthetic Fuzzy Decision	BNP
Company A	(0.022,0.206,2.063)	0.764
Company B	(0.018,0.183,1.903)	0.702
Company C	(0.015,0.159,1.942)	0.706
Company D	(0.020,0.239,2.252)	0.838
Company E	(0.021,0.210,2.171)	0.801

In this context, the BNP values of other alternatives can be obtained for comparison; For the final, Table 15 presents the details of the results. From Table 15, the alternative evaluation results indicate that considering the weights, the best alternative is Company 5. To this end, the best alternative for the company for project logistics operations is LSP5.

Conclusion and Further Research

The literature on project logistics is quite limited although there is a vast amount of study in the context of the logistics area. This study attempted to generate attention in terms of the selection of project logistics service providers. It is obvious that project logistics operations and management require extreme experience and caution and it is different from other transportation operations in terms of various aspects. Thus, there is a need of interest for both practitioners and academicians to identify and analyze project logistics networks. On this occasion, this study differentiated itself by analyzing the selection process of providers in terms of project logistics service providers. Many of the researchers analyzed the route selection of this research area but on the other hand, it is extremely important to choose adequately the service providers.

In terms of managerial implications, it is notably important that select of proper service provider for project logistics operations. Henceforth, managers consider the providers through various aspects. However, this process is both time-consuming and difficult to consider for choosing the appropriate service provider. The process of logistics service provider selection gains extreme importance. Making the right decision for logistics service provider selection becomes increasingly complex. Therefore, decision-makers use different value systems. One of these systems is the fuzzy decision-making theory. Decision-makers prefer to use FAHP because the assignment of evaluation scores in crisp AHP is often uncertain. This paper proposes a FAHP approach to the selection of service providers for project logistics operations. Since project transportation is specific to the destination and the goods to be transported, the logistics service provider should be repeated in each project. The developed system has the flexibility to support the selection decision for each project. It can be concluded that the decision-maker will make an easy decision because the model could help in reducing time-consuming efforts.

Considering the limitations of the study, it can be said that there is a scarcity of studies on project logistics in the literature. So, one of the objectives of this study is to increase the attention to project logistics for practitioners and academicians. Furthermore, qualitative analysis can be used to support the outputs of the study. In future studies, other multi-criteria methods can be used to select service providers for project logistics operations. Also, we can investigate approaches for determining the correct fuzzy numbers for different applications. Finally, we can develop the proposed method as intelligent software for visualization, performance, and user-friendliness.

Extended Summary

The transportation of non-standard cargoes and the related logistics operations are considered niche field that requires expertise. The logistics operations of non-standard cargoes such as power plants, wind turbines, yachts, and military vehicles need to be carefully operated to deliver the cargo on time with undamaged conditions. Furthermore, some crucial decision criteria need to be considered before transportation and during the transportation processes. Although a considerable amount of literature has been published on service provider selection topics, there is no study in the project logistics field. Thus, it is necessary to research and determine the selection criteria for project logistics service providers. Selecting logistics service providers for project cargoes, oversize, and gauge cargoes become a delicate critical decision-making area regarding different decision characteristics. In this context, the logistics service providers' role becomes crucial to provide adequate transportation. The focus of the project transportation is to deliver the oversize cargo from the origin point, which can be a production site, a warehouse, a hub, a port, or a vessel to the destination point or end customer undamaged without violation of regulations or rules. Apart from the critical points mentioned above, another subject that needs intensive attention is the project cargo loading, stowing, and unloading. Furthermore, the staff's experience in loading, transportation, and unloading operations also has a significant impact on the whole operation. For the safety and security of transportation, using a guidance vehicle is another decision point for the managers. Coordination and communication through the transportation process and giving relevant information to the public and private bodies such as road patrols, municipality officers, road control teams, and provincial and district authorities before, during, and after the transportation process for the possible risks are crucial. In this study, a definition of project logistics and a literature review on the subject was conducted. In the implementation of the study, a literature review and a series of half-structured interviews were conducted with the experts from the case company. The project logistics sector in Türkiye can be seen as a flourishing area. There are many newcomers to the market, and the competition has become fierce because of the development of information and communication technologies. In this context, this sector is not well-researched in Türkiye and foreign scenarios and lacks a modern supply chain perspective. Although decision techniques such as AHP, and FAHP is not a new technique in deciding suppliers, the novelty of this paper offers a decision methodology for the selection of possible project logistics service providers. This study addressed issues for the selection of project logistics service providers by using FAHP. Thus, Section 2 includes the literature review, Section 3 deals with the study's methodology, Section 4 highlights the case study of the methodology, and the final section represents the results and the conclusion of the research. A fuzzy analytic hierarchy process (FAHP) is used as the criteria for 3PL selection. The results imply that logistics service providers for project logistics management should focus on more operative aspects such as vehicle availability, cargo safety, on-time delivery, etc., to become more competitive. The process of logistics service provider selection gains extreme importance. Making the right decision for logistics service provider selection becomes increasingly complex. delivering oversize cargo requires both proper infrastructure and equipment. Furthermore, the transportation of such cargo both affects the economy and the environment itself. In this context, such initiatives are not enough, and some sector-specific steps should be necessary. Thus, this study differentiates itself by offering a managerial perspective on selecting proper project logistics service provider company. Existing studies, however, focus on the selection of routes for oversize cargoes and material suppliers for construction projects. Henceforth, this study will provide a method for the selection of 3PL for project logistics. Thus, there is a gap in terms of academic literature and provides a managerial perspective. Therefore, decision-makers use different value systems. One of these systems is the fuzzy decision-making theory. Decision-makers prefer to use FAHP because the assignment of evaluation scores in crisp AHP is often uncertain. Although logistics operations have become more organized in Türkiye, there is still an area that needs to be operated more organized. In this context, the project logistics industry in Türkiye is a flourishing area in which necessary procedures and regulations are still developing. Based on the literature review and interviews with the company experts, this study reveals that transportation cost, handling cost, safety, cargo safety, time of delivery, customs, and other documentation costs, exchange rate fluctuations, vehicle availability, optimal route, equipment condition, carbon emission, qualified staff, noise and vibration on the environment can be listed as criteria for selection of a 3PL for project logistics. The case company chosen for this study facilitates the renewable energy industry in Türkiye. The company was established in 2012 and tried to expand its market share due to the competitive environment. The company currently produces wind turbines and solar panels and facilitates domestic and foreign energy projects. The company seeks to maintain and increase customer satisfaction by responding accurately regarding global logistics operations. The managers of the company and the responsible staff believe that deciding on an effective service provider for project logistics operations will increase the customer satisfaction level and eventually their market share. The company is going to find a new production facility for wind turbines located in Europe. In this sense, the company needs to deliver the related equipment to the production site. There are five companies for project logistics operations on their agenda; thus, managers faced critical decision-making with selecting the most suitable service provider. This paper proposes a FAHP approach to the selection of service providers for project logistics operations. Since project transportation is specific to the destination and the goods to be transported, the logistics service provider should be repeated in each project. The developed system has the flexibility to support the selection decision for each project. It can be concluded that the decision-maker will make an easy decision because the model could help in reducing time-consuming efforts. In future studies, other multi-criteria methods can be used to select service providers for project logistics operations. Also, we can investigate approaches for determining the correct fuzzy numbers for different applications. Finally, we can develop the proposed method as intelligent software for visualization, performance, and user-friendliness.

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