Available online at www.alphanumericjournal.com

alphanumeric journal
The Journal of Operations Research, Statistics, Econometrics and Management Information Systems

Volume 11, Issue 1, 2023

Received: July 04, 2022
Accepted: May 16, 2023
Published Online: July 12, 2023

AJ ID: 2023.11.01.OR.01
DOI: 10.17093/alphanumeric.1136178
Research Article

A Quantitative Analysis for Prioritizing Success Elements in Agile Logistics Applications: The Case of Giresun and Ordu

Çağlar Karamaşa, Ph.D. *

Assoc. Prof., Department of Business Administration, Faculty of Economics and Administrative Sciences Anadolu University, Eskişehir, Turkiye, ckaramasa@anadolu.edu.tr

Selçuk Korucuk, Ph.D.

Assoc. Prof., Bulancak Kadir Karabaş School of Applied Disciplines Giresun University, Giresun, Turkiye, selcuk.korucuk@giresun.edu.tr

Ezgi Demir, Ph.D.

Assist. Prof., Department of Management Information Systems, Faculty of Business Administration Gebze Technical University, Kocaeli, Turkiye, dem_ezgi@hotmail.com

Salih Memiş, Ph.D.

Assoc. Prof., Bulancak Kadir Karabaş School of Applied Disciplines Giresun University, Giresun, Turkiye, salih.memis@giresun.edu.tr

* Anadolu Üniversitesi, İşletme Fakültesi Yunusemre Kampüsü, Eskişehir, Türkiye

ABSTRACT

In today's competitive market conditions, it is not enough to produce high-quality products at the cheapest price. Businesses are expected to deliver the product to the end user round the clock and around the world. One effective way to achieve this is through effective logistics management (Büyükçetin, 2003). Recently, agility has become a frequently discussed topic when it comes to creating an effective logistics management system. The word agility has become synonymous with a strategic response to the survival of businesses in today's competitive environment. However, it should be noted that every business has its unique philosophy and operates under the influence of different environmental factors. Therefore, there is no single agility concept that is suitable for all businesses or every situation (İlhan, 2007). Creating an agile logistics strategy can be achieved not only by minor changes but also by completely differentiating the methods of performing activities (Gunesakaran,1999). The creation of this differentiation depends on various success factors. The success factors of agile logistics considered in this study include: “Managing Change and Uncertainty”, “Flexibility and Responsiveness in Service”, “Increasing the Value Shown to the Customer”, “Information Technologies”, “Flexible Human Resources” and “Building Collaborations Among Service Providers”. These factors play a crucial role in the success of businesses and can increase their competitiveness. The absence of studies in the literature regarding the ranking of the success factors in agile logistics applications points to the important contribution of this study to the literature.To address this research gap, this study aims to rank the success factors of agile logistics practices in logistics firms in Giresun and Ordu provinces. The ranking will be done using the Spherical fuzzy sets based AHP. By prioritizing these success factors, businesses can identify the areas they need to focus on and improve, ultimately enhancing their competitiveness and success in the market.

Keywords: Logistics, Agile Logistics, Agile Logistics Success Elements, Spherical Fuzzy Sets, Spherical Fuzzy AHP

.

1. Introduction

In recent years, the business world has increasingly discussed the concept of agility as a strategic response for companies to survive in today's competitive environment. It is important to recognize that each business has a unique philosophy and produces or provides services under the influence of different environmental factors. Therefore, there is no single agility concept suitable for all businesses or situations (İlhan, 2007). Agility is the ability to obtain new opportunities with an innovative, sustainable, and competitive approach by integrating necessary capital components, knowledge, and relationships with technological elements. The agility of a business is a complicated situation formed depending on the external talent level of the related enterprise (suppliers, intermediaries, customers, consultants, etc.) as well as the level of internal talent (in-house expertise level). The essence of supply chain management is based on the phenomenon of agility whose goal is to harmonize and coordinate the "human", "technology", and the "organization" to attain a quick response to any stimuli. The main aim of agile logistics is to be “always ahead of the competitors”. The ability to adapt quickly to changes in the market is crucial in achieving competitive advantage, and “creativity”, “innovation”, and “knowledge management” are the main sources of this agility (Çancı & Erdal, 2003).

Agility in the supply chain is characterized by a company's new product launch speed, the ability to reduce product development cycle time, lower production times, the speed of improving customer service, and the speed to respond to changing market needs (Swafford et al., 2008). Thus, agility is the ability to respond quickly to customer expectations and keep up with market conditions.

Agile logistics aims to provide high levels of customer service and satisfaction by responding quickly to complex and different conditions. Two important focus points of agility are reacting quickly by closely monitoring changes in customer needs and rearranging logistics structure and processes in line with the information received from the customer. Agile logistics has two aspects: the ability to respond quickly to customer requests and the ability to organize logistics according to different customer requests. Although the latter may result in higher costs, customer satisfaction is the ultimate goal (Korucuk, 2018).

Agility can be classified into three types: customer agility, partnership agility, and operational agility in terms of interrelated capabilities (Sambamurthy et al., 2003; Korucuk, 2018). Although technology is the driving force behind customer agility, business partnership, and operational agility all depend on corporate capabilities. In other words, overall agility relies on the technological infrastructure employed by the company as well as the institutional structure, culture, and skills available therein. For example, customer agility requires an understanding of the process of creating customer participation, capturing and reusing customer feedback, and promoting customer participation through a culture that adds value to the customer’s voice through digitized processes. Similarly, inter-agency trust is vital in terms of business-partnership agility and the development of expanded business networks. Finally, operational agility requires metrics related to cycle time, continuous improvement of quality, and sharing of patented and strategic information within the partnership network (Baki, 2003).

As the need to act quickly due to competitive market conditions increases, logistics service providers use all their assets and abilities to develop their competitive structure with effective management philosophies. To make their assets and talents sustainable and compete in changing market conditions, businesses should determine their customers' requirements and review their positions based on their competitors' attitudes (Zerenler, 2007).

Various success factors are required for the realization of agile logistics practices, which play an important role in ensuring customer satisfaction, reducing costs, and positioning companies against their competitors. These success factors include the following elements (Gunesakaran, 1999; Christopher & Towill, 2000; Sharifi & Zhang, 2000; Maskell, 2001; Özparlak, 2003; Arslan, 2011; Korucuk, 2018):

Managing Change and Uncertainty, an agile logistics service provider should be able to keep up with uncertainty and change, and quickly change the workforce-equipment and management infrastructure against market change with a flexible approach. This flexibility should be not only to adapt to new conditions, but also to take advantage of the opportunities that this change can bring.

Flexibility and Responsiveness in Service, in order to achieve rapid change with agile logistics, infrastructure capabilities and technologies provide service flexibility to respond to changes in the variety of operations and the amount of operations, and to quickly change between different operations.

Increasing the Value Offered to the Customer, businesses that want to adopt agile logistics strategy should be able to offer customized services and operations that can meet the demands and expectations of customers and develop designs. This logistics design process should also be combined with market realities and the capabilities of other logistics service providers, and standard approaches should be rejected for fast and effective system design. In addition, customers should be included in the logistics planning and design process, and rapid adjustments should be made to the content of operations in line with changes in customers' demands and expectations.

Information Technologies, it is a fast, accurate and integrated information infrastructure that is indispensable for agile logistics strategies. Information technologies are very important for logistics service providers to achieve agility.

Flexible Human Resources; without proper human resources management and strategies, technologies and infrastructure systems are not sufficient to achieve agility unassisted. In order to achieve agility in the logistics sector, radical changes should be made in restructuring efforts. Authorization of employees and the support of senior management are essential for these radical changes.

Building Collaborations Between Service Providers; as the media and social media has occupied an important place in our lives, product life cycles have been extremely shortened. In order for a new product to be placed on the market to meet the changing and developing customer needs, the production possibilities must be agile.

The study is thus motivated by multiple issues that the authors seek to investigate.

Concepts such as expanding into new markets, promptly responding to customer demands, and making business processes more effective are important for all companies. The expertise, knowledge, perspective, and experience of the decision-makers involved can prove to be quite significant to businesses and other potential beneficiaries of such judgments. The sensitivity of logistics companies to agile practices had opened the doors to a new relationship between their pursuit of improved customer satisfaction and advanced employee performance with agile logistics success factors and has led to the emergence of new models.

This study seeks to become a critical component of this process by providing a means to find a real, effective, and applicable solution to the decision-making problem using agile logistics success factors in a vital area like logistics where production and service continuity are essential. Furthermore, by focusing on agility, agile logistics practices, and success factors, the study helps businesses gain efficiency and provides a framework that enables logistics companies to create a model for self-assessment on their agile logistics success factors. The study examines the similarities and differences in the levels of agile logistics practices in the relevant companies, and the extent to which these practices are reflected in the activities of the company, thereby providing a practical roadmap for developing agile logistics practices. Another theoretical and practical importance of the study is the proposal of an effective, efficient, and reliable decision-making model that can cope with the identified uncertainties. Therefore, in addition to contributing to a permanent solution for the relevant decision-making problem in the logistics sector, the study aims to provide a robust and strong methodological framework to fill theoretical gaps in the literature by utilizing the advantages of the methods used herein. Consequently, the study will contribute to the solution of similar problems in different fields.

In this regard, it is obvious that the success factors in the agile logistics practices mentioned above are extremely important for businesses and increase the competitiveness of the business. In this detailed literature review, the fact that no studies related to the prioritization of success elements in agile logistics applications have been encountered is a factor that increases the importance of the subject. In addition, it is thought that working with the method used will contribute to the literature.

The purpose of this study is to prioritize the success factors in agile logistics applications in logistics enterprises in Giresun and Ordu due to its emphasized importance. Spherical fuzzy AHP as a multi-criteria decision making method was used for weighting criteria.

In the following sections of the study, respectively; literature reaview on agile logistics has been included, theoretical explanations of spherical fuzzy sets and spherical fuzzy AHP that make up the methods of the study have been revealed, the findings have been presented by applying the method in Giresun and Ordu provinces, and the study has been concluded by making suggestions regarding the results and future studies.

2. Literature Review

The concept of agility has been often used in supplier and supply chain processes. The difference of this study is that it examined the concept of agility in logistics with all its dimensions. Within the framework of the concept of agility, national and international articles and papers from Web of Science, Science Direct, Google Scholar databases have been examined since 2001. Respectively, Damen (2001) defined the scope agile logistics with the classes of services, resources and operations. Kisperska-Moroń (2003) studied 143 small and medium companies in a service sector by appyling questionnare techniques to determine which supply chain suit current market requirements (integrated, agile or lean supply chains).Kasap and Peker (2009) conducted developments in manufacturing methods with the scope of agile logistics in automobile industry. Tao et al. (2009) explained the level of the customer service parameters and transport, storage distribution and package modules. In addition to this gray relational ranking was used for reconstruction model of agile logistics. Xu (2010) conducted agile manufacturing in automotive industry. Kahraman and Kaya (2010) determined supplier selection in agile manufacturing with fuzzy analytic hierarchy process. Mishra et al. (2010) conducted agile supply chains for multi-agent framework. Barahona et al. (2013) developed a simulation and optimization framework for managing the distribution of logistics with the concept of agility. Yarmohammadi et al. (2014) determined the criteria/sub-criteria influencing supply chain agility and evaluated four alternatives in automobile industry via ANP method. Taghizadeh et al. (2015) studied factors affecting the supply chain agility for specific pharmaceutical industry, after that ranked this businesses by using fuzzy TOPSIS. Xu et al. (2016) evaluated the mechanism related with agile suppy chain network by means of complex network. Lubinski et al. (2016) conducted products' complexity with respect to efficient delivery, functioning and agility of management. Malakouti et al. (2017) determined the agile supply chain management concept with respect to SMEs' characteristics. Shahriaria and Pilevarib (2017) conducted agile supplier selection based on Data Envelopment Analysis and made ranking via Fuzzy Delphi and Fuzzy VIKOR methods. Ghobakhloo and Azar (2018) has found out that advanced manufacturing technologies significantly contributes lean and agile logistics. Thanks to advanced manufacturing, businesses' marketing performance and financial performance are increased. Rahman et al. (2018) concluded the importance of logistics 4.0 through the logistics responsiveness, agility, positioning, distribution support, service recovery, digital competency and knowledge management with the sample of 117 people in military forces. Pool et al. (2018) conducted the implementation of business intelligence to the agile performance in supply chain. According to Atanacković (2019) fast fashion industries have a lot of competitor, so these firms have started mass production without considering prices. These industries try to produce in as little time as possible. Because of these effects, fashion companies have began to use project management and strategies such as agile supply chains and quick response systems to meet customer's demand, flexibility and needing communication to reach retail markets as soon as possible. Galankashi et al. (2019) conducted ranking and classifying the operational activities with respect to agile supply chain related criteria that are flexibility, market sensitivity, virtual enterprise application and accessibility, and reliability. Selvakumar and Jayashree (2020) handled the agile supply chains in respect of internet of things with following microservices architecture. Kalkan and Aydın (2020) conducted the role 4PL in the supply chain agility and business performance with the dimensions of integrator, firm performance, supply chain infomediary and supply chain agility.

3. Methodology

Methodology section consist of explanations related with spherical fuzzy sets and spherical fuzzy sets based AHP.

3.1. Spherical fuzzy sets

Intuitionistic and pythagorean fuzzy membership functions include three parameters namely membership, non-membership, and hesitancy. Suppose A as a fixed set. While $\mu_{\tilde{P}}(a): A \rightarrow [0,1]$ shows the degree of membership, $v_{\tilde{P}}(a): A \rightarrow [0,1]$ defines the degree of non-membership the element $a \in A$ to $\tilde{P}$. Hesitancy degree for intuitionistic fuzzy sets ($\pi_{\tilde{I}}(a)$) can be computed via Eq.(1) and hesitancy degree for pythagorean fuzzy sets ($\pi_{\tilde{P}}(a)$) can be calculated by using Eq.(2) (Kutlu Gündoğdu & Kahraman, 2020a; Candan & Cengiz Toklu, 2022).

$$\pi_{\tilde{I}}(a) = 1 - \mu_{\tilde{I}}(a) - v_{\tilde{I}}(a) \tag{1}$$

$$\pi_{\tilde{P}}(a) = \sqrt{1 - \mu_{\tilde{P}}(a)^2 - v_{\tilde{P}}(a)^2} \tag{2}$$

Neutrosophic membership functions are described via three parameters namely truthiness, falsity and indeterminacy, whose sum can be between 0 and 3, and the value of each is between 0 and 1 independently (Kutlu Gündoğdu & Kahraman, 2020a). For spherical fuzzy sets, while the squared sum of membership, non-membership and hesitancy parameters can be between 0 and 1, each of them can be defined between 0 and 1 independently to satisfy that their squared sum is at most equal to 1 (Candan & Cengiz Toklu, 2022; Kutlu Gündoğdu & Kahraman, 2020a).The shape of the new fuzzy sets is the outcome of these two conditions (Kutlu Gündoğdu & Kahraman, 2019d).

Hesitancy degree showing the ignorance or indeterminacy caused from the lack of information is based degrees of membership and non-membership for both intuitionistic and pythagorean fuzzy sets. So it is more suitable to be explained unrelated to membership and non-membership degrees (Sharaf, 2021).

Spherical fuzzy sets (SFS) as an extension of intuitionistic, neutrosophic and pythagorean fuzzy sets proposed by Kutlu Gündoğdu and Kahraman (2019a, b,c,d) to obtain the hesitancy of decision maker (DM) separate from membership and non-membership degrees. Thus, SFS can reveal DMs' judgements and preferences explicitly and efficiently (Sharaf, 2021). SFS can be considered as a synthesis of pythagorean and neutrosophic sets. SFS meet the following conditions:

$$0 \leq \mu_{\tilde{X}}^2(a) + v_{\tilde{X}}^2(a) + \pi_{\tilde{X}}^2(a) \leq 1 \qquad \forall a \in A \tag{3}$$

Where $\mu_{\tilde{X}}(a), v_{\tilde{X}}(a)\ and\ \pi_{\tilde{X}}(a)$ show the degrees of membership, non-membership and hesitancy of $a\ to\ \tilde{X}$ for each a respectively. Each parameter can be defined between 0 and 1.

According to the surface of sphere Eq 3 turns into the

$$\mu_{\tilde{X}}^2(a) + v_{\tilde{X}}^2(a) + \pi_{\tilde{X}}^2(a) = 1 \qquad \forall a \in A \tag{4}$$

Refusal degree for SFS can be computed as below (Kutlu Gündoğdu & Kahraman, 2019a; Ashraf & Abdullah, 2019):

$$RD_{\tilde{X}}(a) = \sqrt{1 - \mu_{\tilde{X}}^2(a) - v_{\tilde{X}}^2(a) - \pi_{\tilde{X}}^2(a)} \tag{5}$$

DMs can generalize other extensions of fuzzy sets by defining membership function on a spherical surface and independently assign parameters of that membership function with larger domain (Kutlu Gündoğdu & Kahraman, 2019a,b,c,d). The advantage of the spherical fuzzy set theory is bringing together scientifically accepted aspects of pythagorean fuzzy sets and neutrosophic sets by excluding the criticized aspect of neutrosophic theory, *i.e.* a sum of μ, v, and π larger than 1 and the criticized aspect of pythagorean fuzzy set theory, *i.e.* disregarding an independent hesitancy (Kutlu Gündoğdu & Kahraman, 2019a,b,d).

Hesitancies of DMs are being assigned to decision environment with a larger domain via spherical fuzzy sets. Positive sides of other fuzzy sets extensions are being collected in a unique theory by spherical fuzzy sets (Kutlu Gündoğdu & Kahraman, 2019d).

Let E_1 and E_2be two universe and $\tilde{C}_S$ and $\widetilde{D}_S$ as two spherical fuzzy sets of the universe of discourse E_1 and E_2 that can be explained as below:

$$\tilde{C}_S = \left\{x, \left(\mu_{\tilde{C}_S}(x), v_{\tilde{C}_S}(x), \pi_{\tilde{C}_S}(x)\right) | x \in E_1\right\} \tag{6}$$

Where $\mu_{\tilde{C}_S}(x): E_1 \to [0,1]$, $v_{\tilde{C}_S}(x): E_1 \to [0,1]$, $\pi_{\tilde{C}_S}(x): E_1 \to [0,1]$ and

$$0 \leq \mu^2_{\tilde{C}_S}(x) + v^2_{\tilde{C}_S}(x) + \pi^2_{\tilde{C}_S}(x) \leq 1 \qquad \forall x \in E_1 \tag{7}$$

For each x, the $\mu_{\tilde{C}_S}(x), v_{\tilde{C}_S}(x)$ and $\pi_{\tilde{C}_S}(x)$ represent the degrees of membership, non-membership and hesitancy of x to C_S.

$$\widetilde{D}_S = \left\{y, \left(\mu_{\widetilde{D}_S}(y), v_{\widetilde{D}_S}(y), \pi_{\widetilde{D}_S}(y)\right) | y \in E_2\right\} \tag{8}$$

Where $\mu_{\widetilde{D}_S}(y): E_2 \to [0,1]$, $v_{\widetilde{D}_S}(y): E_2 \to [0,1]$, $\pi_{\widetilde{D}_S}(y): E_2 \to [0,1]$ and

$$0 \leq \mu^2_{\widetilde{D}_S}(y) + v^2_{\widetilde{D}_S}(y) + \pi^2_{\widetilde{D}_S}(y) \leq 1 \qquad \forall y \in E_2 \tag{9}$$

For each y, the $\mu_{\widetilde{D}_S}(y), v_{\widetilde{D}_S}(y)$ and $\pi_{\widetilde{D}_S}(y)$ represent the degrees of membership, non-membership and hesitancy of y to D_S (Kutlu Gündoğdu & Kahraman, 2019a,b,c,d).

Basic operations for SFS can be explained as follows:

Union of two spherical fuzzy sets as $\tilde{C}_S$ and $\widetilde{D}_S$:

$$\tilde{C}_S \cup \widetilde{D}_S = \left\{ max\{\mu_{\tilde{C}_S}, \mu_{\widetilde{D}_S}\}, min\{v_{\tilde{C}_S}, v_{\widetilde{D}_S}\}, min\left\{\left(1 - \left(\left(max\{\mu_{\tilde{C}_S}, \mu_{\widetilde{D}_S}\}\right)^2 + \left(min\{v_{\tilde{C}_S}, v_{\widetilde{D}_S}\}\right)^2\right)\right)^{\frac{1}{2}}, max\{\pi_{\tilde{C}_S}, \pi_{\widetilde{D}_S}\}\right\}\right\} \tag{10}$$

Intersection of two spherical fuzzy sets as $\tilde{C}_S$ and $\widetilde{D}_S$:

$$\tilde{C}_S \cap \tilde{D}_S = \left\{ min\{\mu_{\tilde{C}_S}, \mu_{\tilde{D}_S}\}, max\{v_{\tilde{C}_S}, v_{\tilde{D}_S}\}, max\left\{ \left(1 - \left(\left(min\{\mu_{\tilde{C}_S}, \mu_{\tilde{D}_S}\}\right)^2 + \left(max\{v_{\tilde{C}_S}, v_{\tilde{D}_S}\}\right)^2 \right) \right)^{\frac{1}{2}}, min\{\pi_{\tilde{C}_S}, \pi_{\tilde{D}_S}\} \right\} \right\} \quad (11)$$

Addition of two spherical fuzzy sets as $\tilde{C}_S$ *and* $\tilde{D}_S$:

$$\tilde{C}_S \oplus \tilde{D}_S = \left\{ \left(\mu^2_{\tilde{C}_S} + \mu^2_{\tilde{D}_S} - \mu^2_{\tilde{C}_S}\mu^2_{\tilde{D}_S}\right)^{1/2}, v_{\tilde{C}_S}v_{\tilde{D}_S}, \left(\left(1 - \mu^2_{\tilde{D}_S}\right)\pi^2_{\tilde{C}_S} + \left(1 - \mu^2_{\tilde{C}_S}\right)\pi^2_{\tilde{D}_S} - \pi^2_{\tilde{C}_S}\pi^2_{\tilde{D}_S} \right)^{1/2} \right\} \quad (12)$$

Multiplication of two spherical fuzzy sets as $\tilde{C}_S$ *and* $\tilde{D}_S$:

$$\tilde{C}_S \otimes \tilde{D}_S = \left\{ \mu_{\tilde{C}_S}\mu_{\tilde{D}_S}, \left(v^2_{\tilde{C}_S} + v^2_{\tilde{D}_S} - v^2_{\tilde{C}_S}v^2_{\tilde{D}_S}\right)^{1/2}, \left(\left(1 - v^2_{\tilde{D}_S}\right)\pi^2_{\tilde{C}_S} + \left(1 - v^2_{\tilde{C}_S}\right)\pi^2_{\tilde{D}_S} - \pi^2_{\tilde{C}_S}\pi^2_{\tilde{D}_S} \right)^{1/2} \right\} \quad (13)$$

Multiplication by a scalar ($\lambda > 0$):

$$\lambda.\tilde{C}_S = \left\{ \left(1 - \left(1 - \mu^2_{\tilde{C}_S}\right)^{\lambda}\right)^{1/2}, v^{\lambda}_{\tilde{C}_S}, \left(\left(1 - \mu^2_{\tilde{C}_S}\right)^{\lambda} - \left(1 - \mu^2_{\tilde{C}_S} - \pi^2_{\tilde{C}_S}\right)^{\lambda} \right)^{1/2} \right\} \quad (14)$$

Power of $\tilde{C}_S$ ($\lambda > 0$):

$$\tilde{C}_S^{\lambda} = \left\{ \mu^{\lambda}_{\tilde{A}_S}, \left(1 - \left(1 - v^2_{\tilde{C}_S}\right)^{\lambda}\right)^{1/2}, \left(\left(1 - v^2_{\tilde{C}_S}\right)^{\lambda} - \left(1 - v^2_{\tilde{C}_S} - \pi^2_{\tilde{C}_S}\right)^{\lambda} \right)^{1/2} \right\} \quad (15)$$

Considering two spherical fuzzy sets as $\tilde{C}_S = \left(\mu_{\tilde{C}_S}, v_{\tilde{C}_S}, \pi_{\tilde{C}_S}\right)$ and $\tilde{D}_S = \left(\mu_{\tilde{D}_S}, v_{\tilde{D}_S}, \pi_{\tilde{D}_S}\right)$ following conditions are valid for $\lambda, \lambda_1, \lambda_2 > 0$ (Kutlu Gündoğdu & Kahraman, 2019a,b,c,d):

a) $\tilde{C}_S \oplus \tilde{D}_S = \tilde{D}_S \oplus \tilde{C}_S$ (16)

b) $\tilde{C}_S \otimes \tilde{D}_S = \tilde{D}_S \otimes \tilde{C}_S$ (17)

c) $\lambda(\tilde{C}_S \oplus \tilde{D}_S) = \lambda\tilde{C}_S + \lambda\tilde{D}_S$ (18)

d) $\lambda_1\tilde{C}_S \oplus \lambda_2\tilde{C}_S = (\lambda_1 + \lambda_2)\tilde{C}_S$ (19)

e) $\left(\tilde{C}_S \otimes \tilde{D}_S\right)^{\lambda} = \tilde{C}_S^{\lambda} \otimes \tilde{D}_S^{\lambda}$ (20)

f) $\tilde{C}_S^{\lambda_1} \otimes \tilde{C}_S^{\lambda_2} = \tilde{C}_S^{\lambda_1+\lambda_2}$ (21)

Spherical Weighted Arithmetic Mean (SWAM) with regard to $w = (w_1, w_2, \dots, w_n)$; $w_i \in [0,1]$; $\sum_{i=1}^{n} w_i = 1$, SWAM can be identified as (Kutlu Gündoğdu & Kahraman, 2020b);

$$SWAM_w\left(\tilde{C}_{S_1}, \tilde{C}_{S_2}, \dots, \tilde{C}_{S_n}\right) = w_1\tilde{C}_{S_1} + w_2\tilde{C}_{S_2} + \dots + w_n\tilde{C}_{S_n} = \left\{ \left[1 - \prod_{i=1}^{n}\left(1 - \mu^2_{\tilde{C}_{Si}}\right)^{w_i}\right]^{1/2}, \prod_{i=1}^{n} v^{w_i}_{\tilde{C}_{Si}}, \left[\prod_{i=1}^{n}\left(1 - \mu^2_{\tilde{C}_{Si}}\right)^{w_i} - \prod_{i=1}^{n}\left(1 - \mu^2_{\tilde{C}_{Si}} - \pi^2_{\tilde{C}_{Si}}\right)^{w_i}\right]^{1/2} \right\} \quad (22)$$

Spherical Weighted Geometric Mean (SWGM) with regard to $w = (w_1, w_2, \dots, w_n)$; $w_i \in [0,1]$; $\sum_{i=1}^{n} w_i = 1$, SWGM can be identified as (Kutlu Gündoğdu & Kahraman, 2020b);

$$SWGM_w(\tilde{C}_{S_1},\tilde{C}_{S_2},\ldots,\tilde{C}_{S_n}) = \tilde{C}_{S_1}{}^{W_1} + \tilde{C}_{S_2}{}^{W_2} + \cdots + \tilde{C}_{S_n}{}^{W_n} = \left\{\prod_{i=1}^{n}\mu_{\tilde{C}_{Si}}^{w_i}, \left[1-\prod_{i=1}^{n}\left(1-v_{\tilde{C}_{Si}}^2\right)^{w_i}\right]^{1/2}, \left[\prod_{i=1}^{n}\left(1-v_{\tilde{C}_{Si}}^2\right)^{w_i} - \prod_{i=1}^{n}\left(1-v_{\tilde{C}_{Si}}^2-\pi_{\tilde{C}_{Si}}^2\right)^{w_i}\right]^{1/2}\right\} \quad (23)$$

Score and accuracy functions for sorting spherical fuzzy sets can be identified as below (Kutlu Gündoğdu & Kahraman, 2019b,d):

$$Score(\tilde{C}_S) = \left(\mu_{\tilde{C}_S} - \pi_{\tilde{C}_S}\right)^2 - \left(v_{\tilde{C}_S} - \pi_{\tilde{C}_S}\right)^2 \quad (24)$$

$$Accuracy(\tilde{C}_S) = \mu_{\tilde{C}_S}^2 + v_{\tilde{C}_S}^2 + \pi_{\tilde{C}_S}^2 \quad (25)$$

Additionally consider that $\tilde{C}_S < \tilde{D}_S$ if and only if

$Score(\tilde{C}_S) < Score(\tilde{D}_S)$ or

$Score(\tilde{C}_S) = Score(\tilde{D}_S)\ and\ Accuracy(\tilde{C}_S) < Accuracy(\tilde{D}_S)$

3.2. Spherical fuzzy sets based AHP

AHP was proposed by Saaty (1980) as one of the most widely used MCDM method and preferred by researchers due to its practicality, flexibility, and understandability. AHP aims to consider alternatives in terms of certain criteria systematically. As a structured approach in decision making, AHP provides measurement by pairwise comparisons and relies on judgments of DMs for obtaining priority scales (Saaty, 2008; Sharaf, 2021). According to AHP, factors related to decision-making problem are categorized and formed a hierarchy (Kutlu Gündoğdu & Kahraman, 2020a). AHP composed of decomposition, comparative judgments, and synthesis of priorities helps DMs for solving complex problems (Xu & Liao, 2014; Sharaf, 2021).

Spherical fuzzy AHP provide DMs to depict their hesitancies seperately in decision process via spherical fuzzy sets based scale. Spherical fuzzy AHP provides the DMs with a reliable structure showing their cognition (Sharaf, 2021). More comprehensive domain of membership function definitions is presented to DMs via spherical fuzzy AHP. Steps of spherical fuzzy AHP can be identified as below (Kutlu Gündoğdu & Kahraman, 2020a,b):

1- Hierarchical structure is formed for weighting criteria.

2- Pairwise comparisons are made by using spherical fuzzy sets based scale shown in Table 1. Equations (26) and (27) are considered for acquiring the score indices given in the last column of Table 1.

Linguistic terms	Spherical fuzzy number (μ, v, π)	Score Index (SI)
Absolutely more importance (AMI)	(0.9,0.1,0)	9
Very high importance (VHI)	(0.8,0.2,0.1)	7
High importance (HI)	(0.7,0.3,0.2)	5
Slightly more importance (SMI)	(0.6,0.4,0.3)	3
Equally importance (EI)	(0.5,0.4,0.4)	1
Slightly low importance (SLI)	(0.4,0.6,0.3)	1/3
Low importance (LI)	(0.3,0.7,0.2)	1/5
Very low importance (VLI)	(0.2,0.8,0.1)	1/7
Absolutely low importance (ALI)	(0.1,0.9,0)	1/9

Table 1. Spherical fuzzy sets based scale for criteria weighting (Kutlu Gündoğdu & Kahraman 2020a,b)

$$SI = \sqrt{\left|100 * \left[\left(\mu_{\tilde{C}_S} - \pi_{\tilde{C}_S}\right)^2 - \left(v_{\tilde{C}_S} - \pi_{\tilde{C}_S}\right)^2\right]\right|} \text{ for AMI,VHI,HI,SMI, and EI} \quad (26)$$

$$\frac{1}{SI} = \frac{1}{\sqrt{\left|100*\left[\left(\mu_{\tilde{C}_S}-\pi_{\tilde{C}_S}\right)^2-\left(v_{\tilde{C}_S}-\pi_{\tilde{C}_S}\right)^2\right]\right|}} \text{ for EI,SLI,LI,VLI, and ALI} \quad (27)$$

3- Consistency of each pairwise comparison matrix is checked via converting the linguistic terms in the pairwise comparison matrix to their corresponding score indices. Following to that classical consistency check is applied by taking threshold of CR (less than 0.1) into the account.

4- Spherical fuzzy weights of criteria $(\tilde{w}_j^s)$ are computed by using SWAM given in Eq.(22) where $w = 1/n$.

5- The judgments of DMs related to criteria prioritization are aggregated via applying geometric mean.

6- Criteria weights are defuzzified by using the score function in Eq.(28):

$$S(\tilde{w}_j^s) = \sqrt{\left|100 * \left[\left(3\mu_{\tilde{C}_S} - \frac{\pi_{\tilde{C}_S}}{2}\right)^2 - \left(\pi_{\tilde{C}_S} - \frac{v_{\tilde{C}_S}}{2}\right)^2\right]\right|} \quad (28)$$

7- Final criteria weights are obtained via normalization shown as below:

$$\overline{w}_j^s = \frac{S(\tilde{w}_j^s)}{\sum_{j=1}^{n} S(\tilde{w}_j^s)} \quad (29)$$

4. Results

In this study eight critical success factors for agile logistic applications are determined according to the literature review. These are defined as managing change (C1), elasticity in service (C2), reactiveness (C3), increasing value presenting to customer (C4), information technologies (C5), flexible human resources (C6), managing indeterminacy (C7) and cooperation with service providers (C8). For this aim, 5 DMs with at least 10 years experience in general logistics were surveyed independently. In this context, information and details related to DMs are given in Table 2.

DMs	Duties	Experience (Years)
DM1	Customer Representative (Export-Import)	13
DM2	Logistics Operation Executive	16
DM3	Operation Executive	11
DM4	Logistics Operation Executive	10
DM5	Academician	16

Table 2. Detailed information related to DMs

Evaluations related to agile logistic are taken into the account. Equal importance weights are given to each DMs. Pairwise comparison of criteria for DM1 with their CR value obtained from the consistency test are given in Table 3.

DM1	C1	C2	C3	C4	C5	C6	C7	C8
C1	EI	EI	VLI	EI	VLI	SMI	EI	ALI
C2	EI	EI	VHI	EI	VLI	SMI	SMI	ALI
C3	VHI	VLI	EI	EI	VLI	SMI	SLI	ALI
C4	EI	EI	EI	EI	EI	SMI	EI	ALI

C5	VHI	VHI	VHI	EI	EI	SMI	SMI	ALI
C6	SLI	SLI	SLI	SLI	SLI	EI	LI	ALI
C7	EI	SLI	SMI	EI	SLI	HI	EI	ALI
C8	AMI	AMI	AMI	AMI	AMI	AMI	AMI	EI

CR=0.034

Table 3. Pairwise comparison of criteria for DM1

Similarly pairwise comparisons of criteria for DM2, DM3, DM4 and DM5 with their CR values are given in Tables 4,5,6, and 7 respectively.

DM2	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1	EI	SMI	VLI	SLI	LI	HI	SMI	SLI
C2	SLI	EI	VHI	SLI	LI	HI	SMI	VLI
C3	VHI	VLI	EI	SLI	LI	HI	LI	VLI
C4	SMI	SMI	SMI	EI	SMI	SMI	SLI	VLI
C5	HI	HI	HI	SLI	EI	SMI	HI	VLI
C6	LI	LI	LI	SLI	SLI	EI	VLI	LI
C7	SLI	SLI	HI	SMI	LI	VHI	EI	VLI
C8	SMI	VHI	VHI	VHI	VHI	HI	VHI	EI

CR=0.038

Table 4. Pairwise comparison of criteria for DM2

DM3	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1	EI	ALI	ALI	ALI	ALI	SLI	VLI	ALI
C2	AMI	EI	VLI	ALI	LI	LI	ALI	ALI
C3	AMI	VHI	EI	ALI	VLI	LI	ALI	ALI
C4	AMI	AMI	AMI	EI	LI	LI	ALI	ALI
C5	AMI	HI	VHI	HI	EI	LI	ALI	ALI
C6	SMI	HI	HI	HI	HI	EI	VLI	ALI
C7	VHI	AMI	AMI	AMI	AMI	VHI	EI	ALI
C8	AMI	AMI	AMI	AMI	AMI	AMI	AMI	EI

CR=0.089

Table 5. Pairwise comparison of criteria for DM3

DM4	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1	EI	VLI	VLI	VLI	VLI	ALI	VLI	ALI
C2	VHI	EI	VLI	ALI	ALI	VLI	ALI	ALI
C3	VHI	VHI	EI	VLI	LI	VLI	ALI	ALI
C4	VHI	AMI	VHI	EI	ALI	VLI	ALI	ALI
C5	VHI	AMI	HI	AMI	EI	VLI	ALI	ALI
C6	AMI	VHI	VHI	VHI	VHI	EI	ALI	ALI
C7	VHI	AMI	AMI	AMI	AMI	AMI	EI	ALI
C8	AMI	AMI	AMI	AMI	AMI	AMI	AMI	EI

CR=0.098

Table 6. Pairwise comparison of criteria for DM4

DM5	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
C1	EI	SMI	LI	SMI	LI	SLI	SMI	VLI
C2	SLI	EI	HI	SMI	LI	SMI	SMI	LI
C3	HI	LI	EI	SLI	LI	HI	SLI	LI
C4	SLI	SLI	SMI	EI	SLI	SMI	SLI	VLI
C5	HI	HI	HI	SMI	EI	SMI	HI	LI
C6	SMI	SLI	LI	SLI	SLI	EI	LI	VLI
C7	SLI	SLI	SMI	SMI	LI	HI	EI	VLI
C8	VHI	HI	HI	VHI	HI	VHI	VHI	EI

CR=0.030

Table 7. Pairwise comparison of criteria for DM5

All CR values are smaller than the threshold so consistency of pairwise comparisons related to criteria is consistent. Following to that spherical fuzzy evaluation matrix by taking linguistic terms given in Table 1 into the account. Spherical fuzzy evaluation matrix of criteria for DM1,DM2,DM3,DM4 and DM5 are given in Tables 8,9,10,11, and 12 respectively.

DM1	C1	C2	C3	C4	C5	C6	C7	C8
C1	(0.5,0.4,0.4)	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.6,0.4,0.3)	(0.5,0.4,0.4)	(0.1,0.9,0)
C2	(0.5,0.4,0.4)	(0.5,0.4,0.4)	(0.8,0.2,0.1)	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.6,0.4,0.3)	(0.6,0.4,0.3)	(0.1,0.9,0)
C3	(0.8,0.2,0.1)	(0.2,0.8,0.1)	(0.5,0.4,0.4)	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.6,0.4,0.3)	(0.4,0.6,0.3)	(0.1,0.9,0)
C4	(0.5,0.4,0.4)	(0.5,0.4,0.4)	(0.5,0.4,0.4)	(0.5,0.4,0.4)	(0.5,0.4,0.4)	(0.6,0.4,0.3)	(0.5,0.4,0.4)	(0.1,0.9,0)
C5	(0.8,0.2,0.1)	(0.8,0.2,0.1)	(0.8,0.2,0.1)	(0.5,0.4,0.4)	(0.5,0.4,0.4)	(0.6,0.4,0.3)	(0.6,0.4,0.3)	(0.1,0.9,0)
C6	(0.4,0.6,0.3)	(0.4,0.6,0.3)	(0.4,0.6,0.3)	(0.4,0.6,0.3)	(0.4,0.6,0.3)	(0.5,0.4,0.4)	(0.3,0.7,0.2)	(0.1,0.9,0)
C7	(0.5,0.4,0.4)	(0.4,0.6,0.3)	(0.6,0.4,0.3)	(0.5,0.4,0.4)	(0.4,0.6,0.3)	(0.7,0.3,0.2)	(0.5,0.4,0.4)	(0.1,0.9,0)
C8	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.5,0.4,0.4)

Table 8. Spherical fuzzy evaluation matrix of criteria for DM1

DM2	C1	C2	C3	C4	C5	C6	C7	C8
C1	(0.5,0.4,0.4)	(0.6,0.4,0.3)	(0.2,0.8,0.1)	(0.4,0.6,0.3)	(0.3,0.7,0.2)	(0.7,0.3,0.2)	(0.6,0.4,0.3)	(0.4,0.6,0.3)
C2	(0.4,0.6,0.3)	(0.5,0.4,0.4)	(0.8,0.2,0.1)	(0.4,0.6,0.3)	(0.3,0.7,0.2)	(0.7,0.3,0.2)	(0.6,0.4,0.3)	(0.2,0.8,0.1)
C3	(0.8,0.2,0.1)	(0.2,0.8,0.1)	(0.5,0.4,0.4)	(0.4,0.6,0.3)	(0.3,0.7,0.2)	(0.7,0.3,0.2)	(0.3,0.7,0.2)	(0.2,0.8,0.1)
C4	(0.6,0.4,0.3)	(0.6,0.4,0.3)	(0.6,0.4,0.3)	(0.5,0.4,0.4)	(0.6,0.4,0.3)	(0.6,0.4,0.3)	(0.4,0.6,0.3)	(0.2,0.8,0.1)
C5	(0.7,0.3,0.2)	(0.7,0.3,0.2)	(0.7,0.3,0.2)	(0.4,0.6,0.3)	(0.5,0.4,0.4)	(0.6,0.4,0.3)	(0.7,0.3,0.2)	(0.2,0.8,0.1)
C6	(0.3,0.7,0.2)	(0.3,0.7,0.2)	(0.3,0.7,0.2)	(0.4,0.6,0.3)	(0.4,0.6,0.3)	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.3,0.7,0.2)
C7	(0.4,0.6,0.3)	(0.4,0.6,0.3)	(0.7,0.3,0.2)	(0.6,0.4,0.3)	(0.3,0.7,0.2)	(0.8,0.2,0.1)	(0.5,0.4,0.4)	(0.2,0.8,0.1)
C8	(0.6,0.4,0.3)	(0.8,0.2,0.1)	(0.8,0.2,0.1)	(0.8,0.2,0.1)	(0.8,0.2,0.1)	(0.7,0.3,0.2)	(0.8,0.2,0.1)	(0.5,0.4,0.4)

Table 9. Spherical fuzzy evaluation matrix of criteria for DM2

DM3	C1	C2	C3	C4	C5	C6	C7	C8
C1	(0.5,0.4,0.4)	(0.1,0.9,0)	(0.1,0.9,0)	(0.1,0.9,0)	(0.1,0.9,0)	(0.4,0.6,0.3)	(0.2,0.8,0.1)	(0.1,0.9,0)
C2	(0.9,0.1,0)	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.1,0.9,0)	(0.3,0.7,0.2)	(0.3,0.7,0.2)	(0.1,0.9,0)	(0.1,0.9,0)
C3	(0.9,0.1,0)	(0.8,0.2,0.1)	(0.5,0.4,0.4)	(0.1,0.9,0)	(0.2,0.8,0.1)	(0.3,0.7,0.2)	(0.1,0.9,0)	(0.1,0.9,0)
C4	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.5,0.4,0.4)	(0.3,0.7,0.2)	(0.3,0.7,0.2)	(0.1,0.9,0)	(0.1,0.9,0)
C5	(0.9,0.1,0)	(0.7,0.3,0.2)	(0.8,0.2,0.1)	(0.7,0.3,0.2)	(0.5,0.4,0.4)	(0.3,0.7,0.2)	(0.1,0.9,0)	(0.1,0.9,0)
C6	(0.6,0.4,0.3)	(0.7,0.3,0.2)	(0.7,0.3,0.2)	(0.7,0.3,0.2)	(0.7,0.3,0.2)	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.1,0.9,0)
C7	(0.8,0.2,0.1)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.8,0.2,0.1)	(0.5,0.4,0.4)	(0.1,0.9,0)
C8	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.5,0.4,0.4)

Table 10. Spherical fuzzy evaluation matrix of criteria for DM3

DM4	C1	C2	C3	C4	C5	C6	C7	C8
C1	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.2,0.8,0.1)	(0.2,0.8,0.1)	(0.2,0.8,0.1)	(0.1,0.9,0)	(0.2,0.8,0.1)	(0.1,0.9,0)
C2	(0.8,0.2,0.1)	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.1,0.9,0)	(0.1,0.9,0)	(0.2,0.8,0.1)	(0.1,0.9,0)	(0.1,0.9,0)
C3	(0.8,0.2,0.1)	(0.8,0.2,0.1)	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.3,0.7,0.2)	(0.2,0.8,0.1)	(0.1,0.9,0)	(0.1,0.9,0)
C4	(0.8,0.2,0.1)	(0.9,0.1,0)	(0.8,0.2,0.1)	(0.5,0.4,0.4)	(0.1,0.9,0)	(0.2,0.8,0.1)	(0.1,0.9,0)	(0.1,0.9,0)
C5	(0.8,0.2,0.1)	(0.9,0.1,0)	(0.7,0.3,0.2)	(0.9,0.1,0)	(0.5,0.4,0.4)	(0.2,0.8,0.1)	(0.1,0.9,0)	(0.1,0.9,0)
C6	(0.9,0.1,0)	(0.8,0.2,0.1)	(0.8,0.2,0.1)	(0.8,0.2,0.1)	(0.8,0.2,0.1)	(0.5,0.4,0.4)	(0.1,0.9,0)	(0.1,0.9,0)
C7	(0.8,0.2,0.1)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.5,0.4,0.4)	(0.1,0.9,0)
C8	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.9,0.1,0)	(0.5,0.4,0.4)

Table 11. Spherical fuzzy evaluation matrix of criteria for DM4

DM5	C1	C2	C3	C4	C5	C6	C7	C8
C1	(0.5,0.4,0.4)	(0.6,0.4,0.3)	(0.3,0.7,0.2)	(0.6,0.4,0.3)	(0.3,0.7,0.2)	(0.4,0.6,0.3)	(0.6,0.4,0.3)	(0.2,0.8,0.1)
C2	(0.4,0.6,0.3)	(0.5,0.4,0.4)	(0.7,0.3,0.2)	(0.6,0.4,0.3)	(0.3,0.7,0.2)	(0.6,0.4,0.3)	(0.6,0.4,0.3)	(0.3,0.7,0.2)
C3	(0.7,0.3,0.2)	(0.3,0.7,0.2)	(0.5,0.4,0.4)	(0.4,0.6,0.3)	(0.3,0.7,0.2)	(0.7,0.3,0.2)	(0.4,0.6,0.3)	(0.3,0.7,0.2)
C4	(0.4,0.6,0.3)	(0.4,0.6,0.3)	(0.6,0.4,0.3)	(0.5,0.4,0.4)	(0.4,0.6,0.3)	(0.6,0.4,0.3)	(0.4,0.6,0.3)	(0.2,0.8,0.1)
C5	(0.7,0.3,0.2)	(0.7,0.3,0.2)	(0.7,0.3,0.2)	(0.6,0.4,0.3)	(0.5,0.4,0.4)	(0.6,0.4,0.3)	(0.7,0.3,0.2)	(0.3,0.7,0.2)
C6	(0.6,0.4,0.3)	(0.4,0.6,0.3)	(0.3,0.7,0.2)	(0.4,0.6,0.3)	(0.4,0.6,0.3)	(0.5,0.4,0.4)	(0.3,0.7,0.2)	(0.2,0.8,0.1)
C7	(0.4,0.6,0.3)	(0.4,0.6,0.3)	(0.6,0.4,0.3)	(0.6,0.4,0.3)	(0.3,0.7,0.2)	(0.7,0.3,0.2)	(0.5,0.4,0.4)	(0.2,0.8,0.1)
C8	(0.8,0.2,0.1)	(0.7,0.3,0.2)	(0.7,0.3,0.2)	(0.8,0.2,0.1)	(0.7,0.3,0.2)	(0.8,0.2,0.1)	(0.8,0.2,0.1)	(0.5,0.4,0.4)

Table 12. Spherical fuzzy evaluation matrix of criteria for DM5

Then SWAM is applied to obtain spherical fuzzy weights of criteria. Computations related to spherical fuzzy weights of criteria for DM1 are seen as below $\left(w = \frac{1}{8} = 0.125\right)$:

$$\tilde{w}_1^{DM1} = \left\{ \begin{array}{c} \sqrt{1-\begin{bmatrix}(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.2^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.2^2)^{0.125}* \\ (1-0.6^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}}, \\ [(0.4)^{0.125}*(0.4)^{0.125}*(0.8)^{0.125}*(0.4)^{0.125}*(0.8)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.9)^{0.125}], \\ \sqrt{\begin{array}{c}\begin{bmatrix}(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.2^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.2^2)^{0.125}* \\ (1-0.6^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}- \\ \begin{bmatrix}(1-0.5^2-0.4^2)^{0.125}*(1-0.5^2-0.4^2)^{0.125}*(1-0.2^2-0.1^2)^{0.125}* \\ (1-0.5^2-0.4^2)^{0.125}*(1-0.2^2-0.1^2)^{0.125}*(1-0.6^2-0.3^2)^{0.125} \\ (1-0.5^2-0.4^2)^{0.125}*(1-0.1^2-0^2)^{0.125}\end{bmatrix}\end{array}} \end{array} \right\}$$

$$\tilde{w}_1^{DM1} = \{0.436,0.526,0.326\}$$

$$\tilde{w}_2^{DM1} = \left\{ \begin{array}{c} \sqrt{1-\begin{bmatrix}(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.8^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.2^2)^{0.125}* \\ (1-0.6^2)^{0.125}*(1-0.6^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}}, \\ [(0.4)^{0.125}*(0.4)^{0.125}*(0.2)^{0.125}*(0.4)^{0.125}*(0.8)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.9)^{0.125}], \\ \sqrt{\begin{array}{c}\begin{bmatrix}(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.8^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.2^2)^{0.125}* \\ (1-0.6^2)^{0.125}*(1-0.6^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}- \\ \begin{bmatrix}(1-0.5^2-0.4^2)^{0.125}*(1-0.5^2-0.4^2)^{0.125}*(1-0.8^2-0.1^2)^{0.125}* \\ (1-0.5^2-0.4^2)^{0.125}*(1-0.2^2-0.1^2)^{0.125}*(1-0.6^2-0.3^2)^{0.125} \\ (1-0.6^2-0.3^2)^{0.125}*(1-0.1^2-0^2)^{0.125}\end{bmatrix}\end{array}} \end{array} \right\}$$

$$\tilde{w}_2^{DM1} = \{0.545,0.442,0.295\}$$

$$\tilde{w}_3^{DM1} = \left\{ \begin{array}{c} \sqrt{1-\begin{bmatrix}(1-0.8^2)^{0.125}*(1-0.2^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.2^2)^{0.125}* \\ (1-0.6^2)^{0.125}*(1-0.4^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}}, \\ [(0.2)^{0.125}*(0.8)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.8)^{0.125}*(0.4)^{0.125}*(0.6)^{0.125}*(0.9)^{0.125}], \\ \sqrt{\begin{array}{c}\begin{bmatrix}(1-0.8^2)^{0.125}*(1-0.2^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.2^2)^{0.125}* \\ (1-0.6^2)^{0.125}*(1-0.4^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}- \\ \begin{bmatrix}(1-0.8^2-0.1^2)^{0.125}*(1-0.2^2-0.1^2)^{0.125}*(1-0.5^2-0.4^2)^{0.125}* \\ (1-0.5^2-0.4^2)^{0.125}*(1-0.2^2-0.1^2)^{0.125}*(1-0.6^2-0.3^2)^{0.125} \\ (1-0.4^2-0.3^2)^{0.125}*(1-0.1^2-0^2)^{0.125}\end{bmatrix}\end{array}} \end{array} \right\}$$

$$\tilde{w}_3^{DM1} = \{0.500,0.507,0.266\}$$

$$\tilde{w}_4^{DM1} = \left\{ \begin{array}{c} \sqrt{1-\begin{bmatrix}(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}* \\ (1-0.6^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}}, \\ [(0.4)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.9)^{0.125}], \\ \sqrt{\begin{array}{c}\begin{bmatrix}(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}* \\ (1-0.6^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}- \\ \begin{bmatrix}(1-0.5^2-0.4^2)^{0.125}*(1-0.5^2-0.4^2)^{0.125}*(1-0.5^2-0.4^2)^{0.125}* \\ (1-0.5^2-0.4^2)^{0.125}*(1-0.5^2-0.4^2)^{0.125}*(1-0.6^2-0.3^2)^{0.125} \\ (1-0.5^2-0.4^2)^{0.125}*(1-0.1^2-0^2)^{0.125}\end{bmatrix}\end{array}} \end{array} \right\}$$

$$\tilde{w}_4^{DM1} = \{0.488,0.442,0.370\}$$

$$\tilde{w}_5^{DM1} = \left\{ \begin{array}{c} \sqrt{1-\begin{bmatrix}(1-0.8^2)^{0.125}*(1-0.8^2)^{0.125}*(1-0.8^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*\\ (1-0.6^2)^{0.125}*(1-0.6^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}}, \\ \left[(0.2)^{0.125}*(0.2)^{0.125}*(0.2)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.9)^{0.125}\right], \\ \sqrt{\begin{array}{c}\begin{bmatrix}(1-0.8^2)^{0.125}*(1-0.8^2)^{0.125}*(1-0.8^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.5^2)^{0.125}*\\ (1-0.6^2)^{0.125}*(1-0.6^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix} - \\ \begin{bmatrix}(1-0.8^2-0.1^2)^{0.125}*(1-0.8^2-0.1^2)^{0.125}*(1-0.8^2-0.1^2)^{0.125}*\\ (1-0.5^2-0.4^2)^{0.125}*(1-0.5^2-0.4^2)^{0.125}*(1-0.6^2-0.3^2)^{0.125}\\ (1-0.6^2-0.3^2)^{0.125}*(1-0.1^2-0^2)^{0.125}\end{bmatrix}\end{array}} \end{array} \right\}$$

$$\tilde{w}_5^{DM1} = \{0.658, 0.341, 0.241\}$$

$$\tilde{w}_6^{DM1} = \left\{ \begin{array}{c} \sqrt{1-\begin{bmatrix}(1-0.4^2)^{0.125}*(1-0.4^2)^{0.125}*(1-0.4^2)^{0.125}*(1-0.4^2)^{0.125}*(1-0.4^2)^{0.125}*\\ (1-0.5^2)^{0.125}*(1-0.3^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}}, \\ \left[(0.6)^{0.125}*(0.6)^{0.125}*(0.6)^{0.125}*(0.6)^{0.125}*(0.6)^{0.125}*(0.4)^{0.125}*(0.7)^{0.125}*(0.9)^{0.125}\right], \\ \sqrt{\begin{array}{c}\begin{bmatrix}(1-0.4^2)^{0.125}*(1-0.4^2)^{0.125}*(1-0.4^2)^{0.125}*(1-0.4^2)^{0.125}*(1-0.4^2)^{0.125}*\\ (1-0.5^2)^{0.125}*(1-0.3^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix} - \\ \begin{bmatrix}(1-0.4^2-0.3^2)^{0.125}*(1-0.4^2-0.3^2)^{0.125}*(1-0.4^2-0.3^2)^{0.125}*\\ (1-0.4^2-0.3^2)^{0.125}*(1-0.4^2-0.3^2)^{0.125}*(1-0.5^2-0.4^2)^{0.125}\\ (1-0.3^2-0.2^2)^{0.125}*(1-0.1^2-0^2)^{0.125}\end{bmatrix}\end{array}} \end{array} \right\}$$

$$\tilde{w}_6^{DM1} = \{0.382, 0.611, 0.293\}$$

$$\tilde{w}_7^{DM1} = \left\{ \begin{array}{c} \sqrt{1-\begin{bmatrix}(1-0.5^2)^{0.125}*(1-0.4^2)^{0.125}*(1-0.6^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.4^2)^{0.125}*\\ (1-0.7^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix}}, \\ \left[(0.4)^{0.125}*(0.6)^{0.125}*(0.4)^{0.125}*(0.4)^{0.125}*(0.6)^{0.125}*(0.3)^{0.125}*(0.4)^{0.125}*(0.9)^{0.125}\right], \\ \sqrt{\begin{array}{c}\begin{bmatrix}(1-0.5^2)^{0.125}*(1-0.4^2)^{0.125}*(1-0.6^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.4^2)^{0.125}*\\ (1-0.7^2)^{0.125}*(1-0.5^2)^{0.125}*(1-0.1^2)^{0.125}\end{bmatrix} - \\ \begin{bmatrix}(1-0.5^2-0.4^2)^{0.125}*(1-0.4^2-0.3^2)^{0.125}*(1-0.6^2-0.3^2)^{0.125}*\\ (1-0.5^2-0.4^2)^{0.125}*(1-0.4^2-0.3^2)^{0.125}*(1-0.7^2-0.2^2)^{0.125}\\ (1-0.5^2-0.4^2)^{0.125}*(1-0.1^2-0^2)^{0.125}\end{bmatrix}\end{array}} \end{array} \right\}$$

$$\tilde{w}_7^{DM1} = \{0.503, 0.472, 0.319\}$$

$$\tilde{w}_8^{DM1} = \left\{ \begin{array}{c} \sqrt{1-\begin{bmatrix}(1-0.9^2)^{0.125}*(1-0.9^2)^{0.125}*(1-0.9^2)^{0.125}*(1-0.9^2)^{0.125}*(1-0.9^2)^{0.125}*\\ (1-0.9^2)^{0.125}*(1-0.9^2)^{0.125}*(1-0.5^2)^{0.125}\end{bmatrix}}, \\ \left[(0.1)^{0.125}*(0.1)^{0.125}*(0.1)^{0.125}*(0.1)^{0.125}*(0.1)^{0.125}*(0.1)^{0.125}*(0.1)^{0.125}*(0.4)^{0.125}\right], \\ \sqrt{\begin{array}{c}\begin{bmatrix}(1-0.9^2)^{0.125}*(1-0.9^2)^{0.125}*(1-0.9^2)^{0.125}*(1-0.9^2)^{0.125}*(1-0.9^2)^{0.125}*\\ (1-0.9^2)^{0.125}*(1-0.9^2)^{0.125}*(1-0.5^2)^{0.125}\end{bmatrix} - \\ \begin{bmatrix}(1-0.9^2-0^2)^{0.125}*(1-0.9^2-0^2)^{0.125}*(1-0.9^2-0^2)^{0.125}*\\ (1-0.9^2-0^2)^{0.125}*(1-0.9^2-0^2)^{0.125}*(1-0.9^2-0^2)^{0.125}\\ (1-0.9^2-0^2)^{0.125}*(1-0.5^2-0.4^2)^{0.125}\end{bmatrix}\end{array}} \end{array} \right\}$$

$$\tilde{w}_8^{DM1} = \{0.880, 0.118, 0.081\}$$

Spherical fuzzy weights of criteria for DM2,DM3,DM4 and DM5 are given in Tables 13,14,15, and 16 respectively.

Criteria	$\widetilde{w}_j^{DM2}$
C1	{0.503,0.499,0.282}
C2	{0.552,0.457,0.254}
C3	{0.511,0.509,0.226}
C4	{0.538,0.458,0.304}
C5	{0.604,0.397,0.251}
C6	{0.351,0.638,0.262}
C7	{0.552,0.457,0.254}
C8	{0.746,0.250,0.180}

Table 13. Spherical fuzzy weights of criteria for DM2

Criteria	$\widetilde{w}_j^{DM3}$
C1	{0.258,0.761,0.203}
C2	{0.491,0.571,0.177}
C3	{0.569,0.488,0.163}
C4	{0.704,0.335,0.142}
C5	{0.652,0.377,0.182}
C6	{0.593,0.418,0.237}
C7	{0.821,0.186,0.108}
C8	{0.880,0.118,0.081}

Table 14. Spherical fuzzy weights of criteria for DM3

Criteria	$\widetilde{w}_j^{DM4}$
C1	{0.248,0.755,0.183}
C2	{0.404,0.654,0.172}
C3	{0.520,0.525,0.179}
C4	{0.631,0.418,0.150}
C5	{0.699,0.334,0.150}
C6	{0.728,0.291,0.142}
C7	{0.836,0.170,0.099}
C8	{0.880,0.118,0.081}

Table 15. Spherical fuzzy weights of criteria for DM4

Criteria	$\widetilde{w}_j^{DM5}$
C1	{0.473,0.527,0.288}
C2	{0.532,0.466,0.287}
C3	{0.496,0.508,0.262}
C4	{0.461,0.534,0.305}
C5	{0.625,0.371,0.256}
C6	{0.411,0.584,0.286}
C7	{0.503,0.499,0.282}
C8	{0.741,0.253,0.179}

Table 16. Spherical fuzzy weights of criteria for DM5

After obtaining spherical fuzzy weights of criteria for all DMs, their judgments are aggregated by using geometric mean. Computations related to aggregating the judgments of DMs for C1 are seen as below:

$$\tilde{w}_1^s = \left\{ \begin{array}{c} [(0.436)^{0.2} * (0.503)^{0.2} * (0.258)^{0.2} * (0.248)^{0.2} * (0.473)^{0.2}], \\ \sqrt{1 - \left[\begin{array}{c} (1-(0.526)^2)^{0.2} * (1-(0.499)^2)^{0.2} * (1-(0.761)^2)^{0.2} * (1-(0.755)^2)^{0.2} * \\ (1-(0.527)^2)^{0.2} \end{array} \right]}, \\ \hline \sqrt{\left[\begin{array}{c} (1-(0.526)^2)^{0.2} * (1-(0.499)^2)^{0.2} * (1-(0.761)^2)^{0.2} * (1-(0.755)^2)^{0.2} * \\ (1-(0.527)^2)^{0.2} \end{array} \right] - \left[\begin{array}{c} (1-(0.526)^2-(0.326)^2)^{0.2} * (1-(0.499)^2-(0.282)^2)^{0.2} * (1-(0.761)^2-(0.203)^2)^{0.2} * \\ (1-(0.755)^2-(0.183)^2)^{0.2} * (1-(0.527)^2-(0.288)^2)^{0.2} \end{array} \right]} \end{array} \right\}$$

$$\tilde{w}_1^s = \{0.367, 0.641, 0.254\}$$

After aggregating the judgments of DMs for other criteria, obtained spherical fuzzy weights of criteria $(\tilde{w}_j^s)$ can be seen as Table 17.

Criteria	$\tilde{w}_j^s$
C1	{0.367,0.641,0.254}
C2	{0.502,0.530,0.238}
C3	{0.519,0.508,0.224}
C4	{0.557,0.444,0.277}
C5	{0.647,0.365,0.221}
C6	{0.474,0.535,0.260}
C7	{0.626,0.393,0.243}
C8	{0.822,0.184,0.132}

Table 17. Spherical fuzzy weights of criteria after aggregation

Then score function is applied for defuzzifying the criteria weights. Computations related to C1 are given as below:

$$S(\tilde{w}_1^s) = \sqrt{\left|100 * \left[\left(3 * 0.367 - \frac{0.254}{2}\right)^2 - \left(0.254 - \frac{0.641}{2}\right)^2\right]\right|} = 9.727$$

Following to defuzzification phase, normalization is applied for obtaining final criteria weights $(\bar{w}_j^s)$. Defuzzified, normalized criteria weights and their ranking are given in Table 18.

Criteria	$S(\tilde{w}_j^s)$	$\bar{w}_j^s$	**Rank**
C1	9.727229	0.077086	8
C2	13.8639	0.109869	6
C3	14.45049	0.114517	5
C4	15.33523	0.121529	4
C5	18.3026	0.145045	2
C6	12.91998	0.102388	7
C7	17.5628	0.139182	3
C8	24.0238	0.190384	1

Table 18. Defuzzified, normalized criteria weights and their ranking

According to the Table 18 while cooperation with service providers (C8) was found as the most important criterion with the value of 0.190384, managing change (C1) was acquired as the least important one having the value of 0.077086. Ranking of other criteria can be written as C5 > C7 > C4 > C3 > C2 > C6 respectively.

5. Comparison Analysis

In this section the results of Spherical fuzzy AHP are compared with other fuzzy extensions (type 2 fuzzy sets, intuitionistic fuzzy sets, pythagorean fuzzy sets, neutrosophic fuzzy sets and fermatean fuzzy sets) based AHP in order to show the robustness. Ranking results of other fuzzy extensions are shown in Table 19.

Criteria	Type 2 fuzzy AHP	Intuitionistic fuzzy AHP	Pythagorean fuzzy AHP	Neutrosophic AHP	Fermatean fuzzy AHP
C1	8	8	8	8	8
C2	6	6	7	7	7
C3	7	7	5	6	5
C4	4	4	4	4	4
C5	2	3	2	3	2
C6	5	5	6	5	6
C7	3	2	3	2	3
C8	1	1	1	1	1

Table 19. Ranking results of other fuzzy extensions

According to the Table 19, ranking of Spherical fuzzy AHP is more similar to Pythagorean and Fermatean fuzzy AHP rather than others having with the correlation value of 0.976. In general, all methods give same ranking results for C1 (8th), C4 (4th) and C8 (1st). Differences in ranking are caused from computational steps and considered aggregation operators. Spearman correlation matrix for ranking results is given in Table 20.

	Spherical fuzzy AHP	Type 2 fuzzy AHP	Intuitionistic fuzzy AHP	Pythagorean fuzzy AHP	Neutrosophic AHP	Fermatean fuzzy AHP
Spherical fuzzy AHP	1					
Type 2 fuzzy AHP	0,905	1				
Intuitionistic fuzzy AHP	0,881	0,976	1			
Pythagorean fuzzy AHP	0,976	0,929	0,905	1		
Neutrosophic AHP	0,905	0,952	0,976	0,952	1	
Fermatean fuzzy AHP	0,976	0,929	0,905	1	0,952	1

Table 20. Spearman correlation matrix for ranking results

As can be seen from Table 20, ranking results of Spherical fuzzy AHP have high correlation with other fuzzy extensions apart from intuitionistic fuzzy AHP.

6. Conclusion, Managerial Implications, Limitations and Future Research

In this study, we rank the critical success factors for agile logistic applications using a spherical fuzzy sets-based AHP approach. These factors were determined through an in-depth literature review process. The choice for spherical fuzzy sets over crisp, fuzzy, intuitionistic, pythagorean, and neutrosophic sets was based on their ability to account for the hesitancy of DMs separately from membership and non-membership degrees. Determining and weighting critical success factors is considered a real-world decision-making problem suitable for multi-criteria decision-making techniques under spherical fuzzy sets. These techniques applied here set businesses on a good path to respond to market needs and customer demands (Haq & Boddu, 2015), and being able to identify and rank the most effective factors that determine agility should help increase competitiveness in the changing market conditions.

Our analysis found that cooperation with service providers, owing to its weight score, was the most important factor for the two cities (Ordu and Giresun) considered in the study. Obtained results support the studies of Erdal and Korucuk (2016), Wen et al. (2019), Zhang et al. (2021) and Xu et al. (2022). Because efficient cooperation with service providers provide implementing business processes in qualified and desired dimension. At the same time supply chain management integration is being executed by enabling internal and external customer satisfaction. Therefore obtained results emphasize the importance of cooperation with service providers in terms of users.

Additionally information technologies was found as the second critical success factor with a high score. Results support the studies of Korucuk (2019), Chege et al. (2020) and, Olimov and Mamurova (2022). Usage of information technologies with desired level for all units is considered as one of the effective parameter in modelling business processes and achieving desired quality level. Efficient management of information technologies increases business performance, productivity and efficiency. Besides constant training and adoption of related technologis by employees have importance in providing efficient usage of information technologies, and these lead to additional costs for companies.

Finally, our analysis showed that managing indeterminacy was considered as the third critical success factor. The studies of Şanal (2020) and Surkova et al. (2022) coincide with these results. Managing indeterminacy enables reducing risks and evaluating risky processes with more realistic for businesses. Well operated indeterminacy based roadmap provide substantial advantages in sustainability and demand forecasting for businesses. Managing indeterminacy effectively by businesses in today's risky environment positively affects in forming long term strategies.

It is worth noting that our study's application is limited to Ordu province. Therefore, future research should expand the scope to logistic companies operating in a more extensive geographical area to contribute to the literature. More critical success factors in agile logistics could be included and the results compared using different multi-criteria decision-making methods. We also propose the inclusion of various critical success factors for different logistic-based applications.

References

Arslan, A. (2011). The applicability of agile manufacturing management system on apparel: Regional Development Agency Level 2 TR72 (Kayseri, Sivas and Yozgat) example. Unpublished Master Thesis, Gazi University, Ankara.

Ashraf, S., & Abdullah, S. (2019). Spherical aggregation operators and their application in multiattribute group decision-making. Int J Intell Syst, 34(3),493–523. https://doi.org/10.1002/int.22062.

Atanacković, A. (2019). The Implementation of Agile Project Management in the Fast Fashion Industry. European Project Management Journal, 9(1), 42-51. https://doi.org/10.18485/epmj.2019.9.1.6

Baki, B. (2003). 21. Yüzyılın Üretim Paradigması: Çevik Üretim, Atatürk Üniversitesi İktisadi ve İdari Bilimler Dergisi, 17(1-2), 291-305.

Barahona, F., Ettl, M., Petrik, M., & Rimshnick, P. M. (2013). Agile Logistics Simulation and Optimization for Managing Disaster Responses. Proceedings of the 2013 Winter Simulation Conference (WSC), Washington, DC, USA (pp. 3341-3351). https://doi.org/ 10.1109/WSC.2013.6721698.

Büyükçetin, Y. (2003). Lojistik görüş. TÜGİAD Elegans Magazine, Sayı:59, Haber:30, Retreived from http://www.elegans.com.tr/arsiv/59/haber030.html. Accessing date: 22.03.2019.

Candan, G., & Cengiz Toklu, M. (2022). Sustainable industrialization performance evaluation of European Union countries: an integrated spherical fuzzy analytic hierarchy process and grey relational analysis approach. International Journal of Sustainable Development & World Ecology, 29(5), 387-400. https://doi.org/10.1080/13504509.2022.2027293.

Chege, S.M., Wang, D., & Suntu, S.L. (2020) Impact of information technology innovation on firm performance in Kenya. Information Technology for Development, 26(2), 316-345. https://doi.org/10.1080/02681102.2019.1573717.

Christopher, M., & Towill, D.R. (2000). Supply chain migration from lean and functional to agile and customised. Suppy Chain Management:An International Journal,5(4),206-213. https://doi.org/10.1108/13598540010347334

Çancı, M. & Erdal, M. (2003). Lojistik yönetimi. İstanbul:UTİKAD Yayınları.

Damen, J. (2001). Service-controlled agile logistics. Logistics Information Management, 14(3), 185-195. https://doi.org/10.1108/09576050110390211

Erdal, H. & Korucuk, S. (2016). Toplam Kalite Yönetimine Askeri Bakış Açısı: Toplam Kalite Liderliği. Karabük Üniversitesi Sosyal Bilimler Enstitüsü Dergisi , 6 (2) , 465-484.

Galankashi, M. R., Helmi, S. A., Rahim, A. R., & Rafiei, F. M. (2019). Agility assessment in manufacturing companies. Benchmarking: An International Journal, 26(7), 2081-2104. https://doi.org/10.1108/BIJ-10-2018-0328

Ghobakhloo, M., & Azar, A. (2018). Business excellence via advanced manufacturing technology and lean-agile manufacturing. Journal of Manufacturing Technology Management, 29(1), 2-24. https://doi.org/10.1108/JMTM-03-2017-0049

Gunasekaran, A. (1999). Agile manufacturing: A framework for research and development. International Journal of Production Economics, 62(1-2), 87-105. https://doi.org/10.1016/S0925-5273(98)00222-9

Haq, A. N., & Boddu, V. (2015). Analysis of agile supply chain enablers for Indian food processing industries using analytical hierarchy process. International Journal of Manufacturing Technology and Management, 29(1-2), 30-47. https://doi.org/10.1504/IJMTM.2015.066780

İlhan, Ö.Ö. (2007). Agile manufacturing, the effects of environmental factors on agile manufacturing and the point of view of Turkish companies about agile manufacturing. Unpublished Master Thesis, Gebze Technical University, Kocaeli.

Kahraman, C., & Kaya, İ. (2010). Supplier Selection in Agile Manufacturing Using Fuzzy Analytic Hierarchy Process. In: L. Wang, S. L. Koh (eds), Enterprise Networks and Logistics for Agile Manufacturing (pp. 155-190). Springer, London. https://doi.org/10.1007/978-1-84996-244-5_8

Kalkan, M. B., & Aydın, K. (2020). The role of 4PL provider as a mediation and supply chain agility. Modern Supply Chain Research and Applications, 2(2), 99-111. https://doi.org/10.1108/MSCRA-09-2019-0019

Kasap, G. C., & Peker, D. (2009). Çevik Üretim: Otomotiv Ana Sanayinde Faaliyet Gösteren Bir İşletmenin Çevikliğinin Ortaya Konmasına Yönelik Bir Araştırma. Electronic Journal of Social Sciences, 8(27), 57-78.

Kisperska-Moroń, D. (2003). Potential for SMEs Partnership in Agile Supply Chains. DSI & APDSI (pp. 1-2). Shanghai:China.

Korucuk, S. (2018). Lojistik Strateji Seçenekleri, 3. Bölüm, Editör, Erdal, H. Lojistik Stratejiler (Yalın, Çevik ve İşbirlikli), Ekin Yayınları: Bursa.

Korucuk, S. (2019). Üretim işletmelerinde verimliliğin önündeki engellerin ve verim artırıcı tekniklerin bütünleşik ahp-topsıs ile sıralanması: Erzurum ili örneği , Verimlilik Dergisi, 1, 219-241.

Kutlu Gündoğdu, F. & Kahraman, C. (2019a) Spherical fuzzy sets and spherical fuzzy TOPSIS method. Journal of Intelligent & Fuzzy Systems, 36(1), 337-352. https://doi.org/ 10.3233/JIFS-181401

Kutlu Gündoğdu, F. & Kahraman, C. (2019b) Extension of WASPAS with spherical fuzzy sets. Informatica, 30(2), 269-292.

Kutlu Gündoğdu, F. & Kahraman, C. (2019c) A novel VIKOR method using spherical fuzzy sets and its application to warehouse site selection. Journal of Intelligent & Fuzzy Systems, 37(1),1197-1211. https://doi.org/ 10.3233/JIFS-182651

Kutlu Gündoğdu, F. & Kahraman, C. (2019d) A novel fuzzy TOPSIS method using emerging interval-valued spherical fuzzy sets. Engineering Applications of Artificial Intelligence,85, 307-323. https://doi.org/10.1016/j.engappai.2019.06.003

Kutlu Gündoğdu, F. & Kahraman, C. (2020a). A novel spherical fuzzy analytic hierarchy process and its renewable energy application. Soft Computing, 24, 4607-4621. https://doi.org/10.1007/s00500-019-04222-w

Kutlu Gündoğdu, F. & Kahraman, C. (2020b). Spherical Fuzzy Analytic Hierarchy Process (AHP) and Its Application to Industrial Robot Selection. In: C. Kahraman, S. Cebi, S. Cevik Onar, B. Oztaysi, A. Tolga, I. Sari (eds) Intelligent and Fuzzy Techniques in Big Data Analytics and Decision Making. INFUS 2019. Advances in Intelligent Systems and Computing, vol 1029 (pp.988-996). Springer, Cham. https://doi.org/10.1007/978-3-030-23756-1_117

Lubinski, P., Doliwa, D., & Stachowiak, A. (2016). Agile Logistics Strategy as the Determinant of Supply Chain Management – the Textile Industry Case Study. 3rd International Conference on Social Science (ICSS 2016), (pp. 958-963).

Maskell, B. (2001). The age of agile manufacturing. Supply Chain Management, 6(1), 5-11. https://doi.org/10.1108/13598540110380868

Malakouti, M., Rezaei, S., & Shahijan, M. K. (2017). Agile supply chain management (ASCM): a management decision-making approach. Asia Pacific Journal of Marketing and Logistics, 29(1), 171-182. https://doi.org/10.1108/APJML-02-2016-0031

Mishra, N., Kumar, V., & Chan, F. (2010). A Multi-agent Framework for Agile Outsourced Supply Chains. In: L. Wang, & S. L. Koh (eds), Enterprise Networks and Logistics for Agile Manufacturing. (pp.207-226). Springer, London. https://doi.org/10.1007/978-1-84996-244-5_10

Olimov, S.S. & Mamurova, D.I. (2022). Information Technology in Education. Pioneer : Journal of Advanced Research and Scientific Progress, 1(1), 17–22. Retrieved from https://innosci.org/jarsp/article/view/11.

Özparlak, H.M.(2003). Differences between lean manufacturing-agile manufacturing and the management of transition to agile enterprise. Unpublished Master Thesis, İstanbul Techical University, İstanbul.

Pool, J. K., Jamkhaneh, H. B., Tabaeeian, R. A., & Shahin, A. (2018). The effect of business intelligence adoption on agile supply chain performance. International Journal of Productivity and Quality Management, 23(3), 289-306. https://doi.org/10.1504/IJPQM.2018.089802

Rahman, A. R., Ab. Rashid, S., & Hamid, N. R. (2018). Agility and Digitalization Competency in Logistics 4.0 in Military Setting: The Challenge, Risks and Opportunities. Asian Journal of Social Science Research, 1(2), 1-29.

Saaty, T.L. (1980). The analytic hierarchy process: planning, priority setting, resource allocation. McGraw-Hill, New York.

Saaty, T.L. (2008). Decision making with the analytic hierarchy process. International Journal of Services Sciences, 1(1),83–98. https://doi.org/10.1504/IJSSci.2008.01759

Sambamurthy, V., Bharadwaj, A., & Grover, V. (2003). Shaping Agility through Digital Options: Reconceptualizing the Role of Information Technology in Contemporary Firms. MIS quarterly, 27(2), 237-263. https://doi.org/10.2307/30036530

Selvakumar, G., & Jayashree, L.S. (2020). Agile Supply Chain Management Enabled by the Internet of Things and Microservices. In: L. Kumar, L. Jayashree, R. Manimegalai (eds) Proceedings of International Conference on Artificial Intelligence, Smart Grid and Smart City Applications,AISGSC 2019 (pp. 449-456). Springer, Cham. https://doi.org/10.1007/978-3-030-24051-6_43

Shahriaria, M., & Pilevarib, N. (2017). Agile Supplier Selection in Sanitation Supply Chain Using Fuzzy VIKOR Method. Journal of Optimization in Industrial Engineering, 10(21), 19-28. https://doi.org/10.22094/JOIE.2016.257

Sharaf, I.M. (2021). Global Supplier Selection with Spherical Fuzzy Analytic Hierarchy Process. In: C. Kahraman, F. Kutlu Gündoğdu (eds) Decision Making with Spherical Fuzzy Sets. Studies in Fuzziness and Soft Computing, vol 392. Springer, Cham. https://doi.org/10.1007/978-3-030-45461-6_14

Sharifi, H., & Zhang, Z. (1999). A methodology for achieving agility in manufacturing organisations: An introduction. International Journal of Production Economics, 62(1-2), 7-22. https://doi.org/10.1016/S0925-5273(98)00217-5

Surkova, E.V., & Mazhaiskii, Y.A. (2022). Management of Business Processes. Russ. Engin. Res. 42, 292–294. https://doi.org/10.3103/S1068798X22030248

Swafford P.M., Ghosh S., & Murthy N. (2008). Achieving supply chain agility through IT integration and flexibility. International Journal of Production Economics,116(2),288-297. https://doi.org/10.1016/j.ijpe.2008.09.002

Şanal, M. (2020). Yönetimde Sinerji için Kuantum Bakış Açısı . Avrasya Sosyal ve Ekonomi Araştırmaları Dergisi , 7 (1) , 42-50 .

Taghizadeh, H., Valyani, A., & Bazrkar, A. (2015). Analysis and Prioritization of Effective Strategies for Agile Supply Chain Case Study: Pharmaceutical Industry in Iran. Mediterranean Journal of Social Sciences, 6(6), 376-383. https://doi.org/10.5901/mjss.2015.v6n6s2p376

Tao, J., Li, Y., & Yao, M. (2009). Reconstruction Model of Agile Logistics Based on Decision-Making Method of Gray Relational Grade. International Conference on Artificial Intelligence and Computational Intelligence, Shanghai, China (pp. 518-522). https://doi.org/10.1109/AICI.2019.18

Wen, Z., Liao, H., Zavadskas., E. K., & Al-Barakati, A. (2019) Selection third-party logistics service providers in supply chain finance by a hesitant fuzzy linguistic combined compromise solution method, Economic Research-Ekonomska Istraživanja, 32(1), 4033-4058. https://doi.org/10.1080/1331677X.2019.1678502

Xu, H. (2010). Agile Manufacturing in Complex Supply Networks. In: L. Wang, L. S. Koh (eds) Enterprise Networks and Logistics for Agile Manufacturing (pp. 39-65). Springer, London. https://doi.org/10.1007/978-1-84996-244-5_3

Xu, N.R., Liu, J.B., Li, D.X., & Wang, J. (2016). Research on Evolutionary Mechanism of Agile Supply Chain Network via Complex Network Theory. Mathematical Problems in Engineering, 4346580. https://doi.org/10.1155/2016/4346580

Xu,Z., Cao, J., Xu, Y., Sun, Y., & Zhang, X., (2022). Decision-Making Mechanism of Cooperative Innovation between Clients and Service Providers Based on Evolutionary Game Theory. Discrete Dynamics in Nature and Society, 8774462. https://doi.org/10.1155/2022/8774462

Xu, Z. & Liao, H. (2014). Intuitionistic Fuzzy Analytic Hierarchy Process. IEEE Transactions on Fuzzy Systems, 22(4),749–761. https://doi.org/10.1109/TFUZZ.2013.2272585

Yarmohammadi, Y., Maleki, R., Khanbabaie, K., Yasini, A., & Mafi, K. (2014). Identifying the Most Agile Supply Chain in Iran Auto Industry: ANP Approach. INTERNATIONAL JOURNAL of ACADEMIC RESEARCH, 6(5), 55-63. https://doi.org/10.7813/2075-4124.2014/6-5/A.9

Zerenler, M.(2007). Information Technology and Business Performance in Agile Manufacturing: An Empirical Study in Textile Industy. 4th International Conference on Information Technology (ITNG'07), Las Vegas, Nevada, USA (pp.543-549). https://doi.org/10.1109/ITNG.2007.111

Zhang, X., Liu, Y., & Dan, B. (2021). Cooperation strategy for an online travel platform with value-added service provision under demand uncertainty, International Transactions in Operational Research, 28(6),3416-3436. https://doi.org/10.1111/itor.12977.