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ASSESSING PORT SERVICE QUALITY DIMENSIONS WITH FERMATEAN FUZZY AHP METHOD

LİMAN HİZMET KALİTESİ BOYUTLARININ FERMATEAN BULANIK AHP YÖNTEMİ İLE DEĞERLENDİRİLMESİ

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Abstract

Assessing the quality of businesses and improving them accordingly is critical for sustainable competitive advantage. This study focuses on evaluating the dimensions affecting the service quality of sea ports, which contribute significantly to the development of global trade. Therefore, this paper aims to determine the importance weights of the dimensions of the ROPMIS model presented by Thai (2008). In today's world, Fermatean fuzzy sets (FFSs) are a useful tool in many decision-making problems due to the possibility of better capturing human uncertainty and subjectivity. The weights of dimensions of the ROPMIS model are determined with AHP method under the Fermatean fuzzy environment. The suggested approach is an effective means of managing the ambiguities and errors in the data pertaining to the dimensions' weights. In order to provide a tool for assessing and ranking port global quality dimensions that may have an impact on sustainable port service quality, this study serves as a benchmark for subsequent research.

Keywords: Analytical hierarchy process, fermatean fuzzy set, multi-criteria decision, port service quality, sustainability.

Öz

İşletmelerin kalitesinin değerlendirilmesi ve buna bağlı olarak geliştirilmesi sürdürülebilir rekabet avantajı açısından kritik öneme sahiptir. Bu çalışma, küresel ticaretin gelişmesine önemli katkı sağlayan deniz limanlarının hizmet kalitesine etki eden boyutların değerlendirilmesine odaklanmaktadır. Bu nedenle bu makale Thai (2008) tarafından sunulan ROPMIS modelinin boyutlarının önem ağırlıklarını belirlemeyi amaçlamaktadır. Günümüz dünyasında Fermatean bulanık kümeler (FFSs), insan belirsizliğini ve öznelliğini daha iyi yakalama olasılığı nedeniyle birçok karar verme probleminde yararlı bir araçtır. ROPMIS modelinin boyutlarının ağırlıkları Fermatean bulanık ortamında AHP yöntemiyle belirlenir. Önerilen yaklaşım, boyutların ağırlıklarına ilişkin verilerdeki belirsizliklerin ve hataların yönetilmesinde etkili bir yöntemdir. Sürdürülebilir liman hizmet kalitesi üzerinde etkisi olabilecek küresel liman kalite boyutlarını değerlendirmek ve sıralamak için bir araç sağlamak amacıyla bu çalışma, daha sonraki araştırmalar için bir referans noktası görevi görmektedir.

Anahtar Kelimeler: Analitik hiyerarşi süreci, fermatean bulanık küme, çok kriterli karar verme, liman hizmet kalitesi, sürdürülebilirlik.

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1. INTRODUCTION

Because customers perception of the services they receive—that is, service quality—affects important outcomes including customer loyalty, word-of-mouth, firm revenue, and long-term sustainability, businesses need to continuously monitor customer perception of their services. (Ladhari, 2009; Guo et al., 2023). Both a company's operations and the country's economy strategically depend on the quality of products and services. Service Quality is the examination of how well a service is delivered to customer expectations. Ports play the role of nodes apart from their traditional roles in logistics processes, that in international supply chains and also make significant contributions to national economies. Any failure or unreliability of port services can greatly influence the smooth movement of these flows in the next stage of the supply chain and make port customers – shipping lines and cargo owners – unhappy (Thai, 2016). Parasuraman et al. (1985) state service quality factors affect customer satisfaction. It is important for ports to improve customer satisfaction in order to obtain sustainable competitive advantage. A port's competitive standing is mostly determined by the quality of its services, not by more conventional considerations like price and amenities (Cho et al., 2010). In times of intense competition and uncertainty, it is crucial that port operators and relevant government agencies identify key success factors that will enable them to improve the quality and competitiveness of port services (Hsu et al., 2023). The demand for port service is a derived demand and ports must follow service quality trends otherwise they will be left behind (Ugboma et al., 2007). There are several providers that offer port services (Talley et al., 2014, Talley, 2019): (1) the port operator; (2) shipper agent; (3) shipping line agents; (4) harbor pilots; (5) tugboat operator; and (6) government customs. The higher the value of the quality of service offered to port users, the higher the competitiveness of the port (Song & Yeo, 2004).

Evaluation of service quality criteria is a type of MCDM problem and requires MCDM approaches to strengthen the decision making process. Evaluation of service quality criteria often involves imprecise and uncertain judgment. The Fuzzy set concept, introduced by Zadeh (1965), is an important tool to evaluate the uncertainty of subjective decision of experts in decision-making problems. Fuzzy set theory has difficulty dealing with the complex uncertainty problems inherent in realistic problems. Later, as an extension of fuzzy sets, which relate each element to both membership and non-membership degrees, Atanassov (1986) developed intuitionistic fuzzy sets (IFS). IFS the condition $0 \leq \mu(x) + \nu(x) \leq 1$ where $\mu(x)$ and $\nu(x)$ denote the membership degree and non-membership degree of the object x, respectively. Smarandache (1998) was introduced the concept of neutrosophic information by introducing neutrosophic sets (NSs), in which, along with the truth and falsity values, the factor of indeterminacy. In 2010, hesitant fuzzy sets (HFSs) were introduced by Torra (2010). The conception of Pythagorean fuzzy set (PFS) was pioneered via Yager (2013). PFSs satisfy the condition $\mu(x)^2 + \nu(x)^2 \leq 1$. Spherical fuzzy set (SFS) introduced by Kutlu Gündoğdu ve Kahraman, (2019), modeled the vagueness of the problem is in a three-dimensional spherical geometry (Menekşe and Akdağ, 2023). Fermatean fuzzy set (FFS) (Senapati and Yager, 2020) is one of the effective generalizations of the Fuzzy set theory (Zadeh, 1965), which is formulated $0 \leq \mu(x)^3 + \nu(x)^3 \leq 1$. Because they are all confined within the space of FFSs, FFSs are more powerful than FSs, IFSs, and PFSs (Mishra et al., 2023). Figure 1 presents some extensions of ordinary fuzzy sets that have been defined differently in the literature in order to define membership functions.

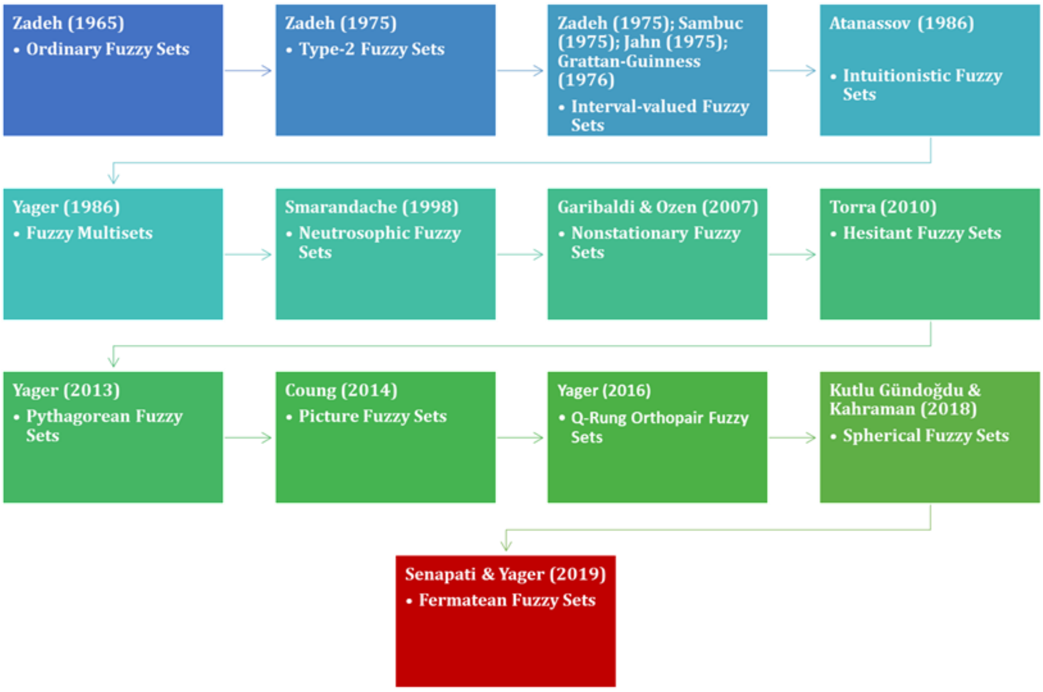

Figure 1. Extension of Fuzzy Sets (Alkan & Kahraman, 2023)

Thomas L. Saaty developed AHP (Analytic Hierarchy Process) multi-criteria evaluation approach to represent multi-criteria decisions in the year 1970s (Saaty, 1977). AHP is an MCDM method that measures the consistency of the decisions taken and reduces the bias prejudice the decision by structuring the problem (Kumar and Pant, 2023). AHP is based on pairwise comparison based on expert judgments that contain uncertainties. To mitigate the uncertainties in the traditional AHP, fuzzy versions have been developed. Different fuzzy set extension AHP applications have been used in MCDM problems. Fuzzy AHP Abdullah et al., (2023); Interval type-2 fuzzy AHP Celik and Akyuz (2018); Intuitionistic fuzzy AHP Sun et al., (2023); Neutrosophic AHP Karasan et al., (2022); Pythagorean fuzzy AHP Ilbahar et al., (2018); Picture fuzzy AHP Kutlu Gündoğdu et al., (2021); Spherical fuzzy AHP Liu et al., (2023); Fermatean Fuzzy AHP Alkan and Kahraman (2023).

In this paper adopts Fermatean fuzzy AHP to identify the importance of factors which may influence port service quality. The purpose of this paper is to evaluate the port service quality factors including uncertainty and ambiguity for sustainable port development by using the advantages of the Fermatean fuzzy sets. As a result, it will direct the stakeholders involved in the port sector regarding the significance of the elements affecting service quality and customer satisfaction.

2. LITERATURE REVIEW

2.1. Maritime Transportation

The maritime industry is vital to the international economy and social well-being (Narasimha et al., 2021). The United Nations Conference on Trade and Development (UNCTAD) reported that total seaborne trade to grow by 2.4 per cent in 2023 (UNCTAD, 2023). The maritime transport system has an major role in linking the global supply chain and contributing to the development of the world's economy (Hu & Zhu, 2009; Liu et al.,2024). Maritime transportation is the guiding transportation model in overseas trade, as it efficiently transports approximately 80% of large volumes of commodities in global trade (Li et al., 2023). Sea ports and waterways are nodes and links that enable the transportation of cargo in maritime transportation, respectively (Talley, 2013). The maritime logistics industry has an important role in the global transportation system. Sea ports are also an important part of maritime logistics (Zhou et al.,2021).

Maritime ports contribute to economic development as a gateways for export trade (Jiang et al., 2023). Ports are a sub-system of the total transportation network and the intersection point of other transportation modes. In this context, it is an economic infrastructure that serves the handling of domestic and international cargoes (Park & De, 2004). Ports provide services rather than producing physical products (Talley & Ng, 2016).

Ports provide two different services: to cargo and to vessel. The basic function of ports is to provide shelter to ships in different sizes, allowing the transfer of cargo to different transportation modes (Roa et al., 2013). There are two different operations in ports: maritime operations and terminal operations. Maritime operations correspond to the processes that begin with the docking of a vessel, and end with the cargo transfer. Terminal operations to correspond the processes from the end of a vessel's cargo transfer to the storage of the cargo at the shipyard (Agüero-Tobar et al., 2023).

2.2. Service Quality (SQ)

SQ is considered a major factor for the success of an organization, especially in the service-based industry, as it is strongly associated with customer satisfaction (Ding et al., 2020). The service is complex in nature and must have functional quality (Grönroos, 1982). Parasuraman et al. (1985, 1988) proposed the SERVQUAL model, which consists of the dimensions "tangibles", "reliability", "responsiveness", "assurance" and "empathy" to evaluate service quality. Cronin and Taylor (1992, 1994) suggested the SERVPERF model, which includes the relationships between service quality, customer satisfaction and purchasing intentions. The Gaps Model of SQ, which evaluates quality by considering the factors that contribute to determining the quality between the quality expected by the customers and the quality offered by the companies was proposed by Parasuramanet et al. (1985, 1988) and Zeithaml et al. (1993). The ROPMIS model, which consists of resources, outcomes, processes, management, image and social responsibility dimensions, was introduced by Tai (2008) to measure service quality in maritime transportation.

Bhattacharya et al. (2023) applied the AHP-SERVQUAL approach for perception-satisfaction-based quality assessment of tourism and accommodation services in the Himalayan region. Tumsekcali et al. (2023) adapted the SERVQUAL model for public transportation services and provided a fuzzy MCDM technique using IVIF-AHP integrated IVIF-WASPAS. In order to assess service quality across employment-related government agencies, Ocampo et al. (2019) developed an integrated SERVQUAL model and AHP&TOPSIS. A balanced scorecard-based SERVQUAL was presented by Dinçer et al. (2019) to rank rivals in the banking industry with hesitant fuzzy information. Liu et al. (2015) used the modified fuzzy SERVQUAL method to evaluate service quality in the certification and inspection industry. Awasthi et al. (2011) suggested an integrated model based on SERVQUAL and fuzzy TOPSIS to evaluate the service quality of urban transportation systems. Shu et al. (2023) used the SERVPERF scale, AHP, and the 2-tuple linguistic model to evaluate the overall customer satisfaction of hotels. Lupo (2015) applied the fuzzy ServPerf model combined with ELECTRE III to assess service quality at airports.

2.3. Service Quality in Maritime Industry

Thai (2008) introduced the ROPMIS model to evaluate service quality in maritime transportation. The relationship between service quality and customer satisfaction at the Port of Singapore examined by Thai (2016) using the ROPMIS model. Yeo et al. (2015) investigated port service quality (PSQ) concept and its impact on customer satisfaction at Korean container ports. Hemalatha et al. (2018) applied TOPSIS and GRP methods to evaluate the service quality of twelve container terminal operators in India. Ugboma et al. (2007) determined the service quality offered by two ports in Nigeria using the SERVQUAL model. Miremadi et al. (2011) used the SERVQUAL model at Shahid Rajaie Port (SRP) in Bandar Abbas to determine service quality in the port industry. Viet (2015) analyzed the relationship between service quality factors and customer satisfaction level in six ports belonging to a company. Chen et al. (2009) tested the service quality gap between the service provider and the customer using the SERVQUAL model in the shipping industry. Ha (2003) identified seven factors that can have a direct or indirect impact on port service quality: Ready information availability of port-related activities, port location, port turnaround time, facilities available, port management, port costs and customer convenience. Cho et al. (2010) proposed three dimensions for the relationship between port service quality and customer satisfaction, namely endogenous quality, exogenous quality and relational quality. Phan et al. (2021) aimed to investigate the impact of the concept of port service quality (PSQ) on customer satisfaction in the container port industry in Vietnam.

3. METHODOLOGY

3.1. Fermatean Fuzzy Sets (FFSs)

This section provides some basic concepts and the mathematical operations based on Fermatean fuzzy sets (FFSs). Senapati and Yager (2019) introduced FFSs, which have more flexible processing capabilities in multi-attribute decision-making problems and are a novel extension of intuitionistic fuzzy sets (IFSs) and Pythagorean fuzzy sets (PFSs). which requires that the cubic sum of membership and non-membership should not exceed one. Compared to IFS and PFS, FFS can accommodate a wider range of evaluation information and provides greater ability to identify uncertain information. Fig. 2 shows the difference between IFS, PFS and FFS in graphical representation.

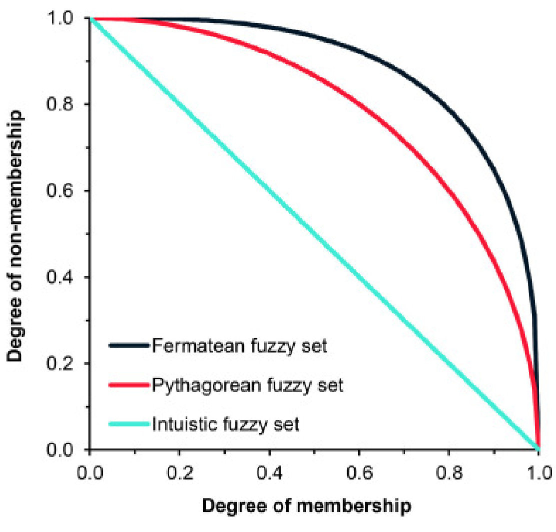

Figure 2. The Differences Between IFS, PFS and FFS (Simić et al., 2022)

Definition 1. Assume that $\mathrm{P} = (\mu_{\mathrm{P}}, v_{\mathrm{P}})$, $\mathrm{P}_1 = (\mu_{\mathrm{P}_1}, v_{\mathrm{P}_1})$ and $\mathrm{P}_2 = (\mu_{\mathrm{P}_2}, v_{\mathrm{P}_2})$ are three FFSs and $\omega > 0$, then some FFSs operators are presented as follows (Senapati & Yager, 2019; 2020):

$$\mathrm{P}_1 \cap \mathrm{P}_2 = \left(min\{\mu_{\mathrm{P}_1}, \mu_{\mathrm{P}_2}\}, max\{v_{\mathrm{P}_1}, v_{\mathrm{P}_2}\}\right) \quad (1)$$

$$P_1 \cup P_2 = \left(max\{\mu_{P_1}, \mu_{P_2}\}, min\{v_{P_1}, v_{P_2}\}\right) \quad (2)$$

$$P^c = (v_P, \mu_P) \quad (3)$$

$$P_1 \oplus P_2 = \left(\sqrt[3]{\mu_{P_1}^3 + \mu_{P_2}^3 - \mu_{P_1}^3\mu_{P_2}^3}, v_{P_1}v_{P_2}\right) \quad (4)$$

$$P_1 \otimes P_2 = \left(\mu_{P_1}\mu_{P_2}, \sqrt[3]{v_{P_1}^3 + v_{P_2}^3 - v_{P_1}^3 v_{P_2}^3}\right) \quad (5)$$

$$\omega P = \left(\sqrt[3]{1 - (1 - \mu_P^3)^\omega}, v_P^\omega\right) \quad (6)$$

$$P^\omega = \left(\mu_P^\omega, \sqrt[3]{1 - (1 - v_P^3)^\omega}\right) \quad (7)$$

Definition 2. The score function SF and the accuracy function AF are defined as follows (Keshavarz-Ghorabaee et al., 2020):

$$SF = \mu_{\mathrm{P}}^3 - v_{\mathrm{P}}^3 \quad (8)$$

$$AF = \mu_{\mathrm{P}}^3 + v_{\mathrm{P}}^3 \quad (9)$$

Let $\mathrm{P}_1 = (\mu_{\mathrm{P}_1}, v_{\mathrm{P}_1})$ and $\mathrm{P}_2 = (\mu_{\mathrm{P}_2}, v_{\mathrm{P}_2})$ be two FFSs. To compare two FFS, the score and accuracy functions are deployed as below (Senapati & Yager 2019):

If $SF_1 < SF_2, then\ F_1 < F_2$

If $SF_1 > SF_2, then\ F_1 > F_2$

If $SF_1 = SF_2, then$

If $AF_1 < AF_2, then\ F_1 < F_2$

If $AF_1 > AF_2, then\ F_1 > F_2$

If $AF_1 = AF_2, then\ F_1 = F_2$

Definition 3. Assume that $\mathrm{P}_i = (\mu_{\mathrm{P}_i}, v_{\mathrm{P}_i})$ (i=1,2,3,…,n) is a number of Fermatean fuzzy numbers (FFNs) and $w = (w_1, w_2, w_3, \ldots, w_n)^{\mathrm{P}}$ is weight vector of P_i. ($\sum_{i=1}^n w_i = 1$) (Senapati & Yager, 2019; Biswas et al., 2021):

Fermatean fuzzy weighted average (FFWA) operator is:

$$FFWA(\mathrm{P}_1, \mathrm{P}_2, \mathrm{P}_3, \ldots, \mathrm{P}_n) = \left(\sum_{i=1}^n w_i\mu_{\mathrm{P}_i}, \sum_{i=1}^n w_i v_{\mathrm{P}_i}\right) \quad (10)$$

Fermatean fuzzy weighted geometric (FFWG) operator is:

$$FFWG(\mathrm{P}_1, \mathrm{P}_2, \mathrm{P}_3, \dots, \mathrm{P}_n) = \left(\prod_{i=1}^{n} \mu_{\mathrm{P}_i}{}^{w_i}, \prod_{i=1}^{n} v_{\mathrm{P}_i}{}^{w_i}\right) \quad (11)$$

The Fermatean fuzzy weighted power average (FFWPA) operator is:

$$FFWPA(\mathrm{P}_1, \mathrm{P}_2, \mathrm{P}_3, \dots, \mathrm{P}_n) = \left(\sqrt[3]{\sum_{i=1}^{n} w_i \mu_{\mathrm{P}_i}^3}, \sqrt[3]{\sum_{i=1}^{n} w_i v_{\mathrm{P}_i}^3}\right) \quad (12)$$

The Fermatean fuzzy weighted power geometric (FFWPG) operator is:

$$FFWPG(\mathrm{P}_1, \mathrm{P}_2, \mathrm{P}_3, \dots, \mathrm{P}_n) = \left(\sqrt[3]{1 - \prod_{i=1}^{n}\left(1 - \mu_{\mathrm{P}_i}^3\right)^{w_i}}, \sqrt[3]{1 - \prod_{i=1}^{n}\left(1 - v_{\mathrm{P}_i}^3\right)^{w_i}}\right). \quad (13)$$

3.2. Fermatean Fuzzy Analytic Hierarchy Process Method (FF-AHP)

Analytical Hierarchy Process (AHP) is a multi-criteria decision making (MCDM) method that is widely used to prioritize criteria by pairwise comparison and determining the importance weights of the criteria with simple operations. (Saaty, 1980). Despite the easy calculation steps of classical AHP, it is not sufficient to express the judgments of decision makers under uncertainty. Therefore, in the studies applied in the literature, AHP is applied to solve MCDM problems with different fuzzy set extensions to overcome the uncertainties in pairwise comparisons. Recently, in many studies, AHP has been extended and applied in the Fermatean fuzzy sets environment such as supplier selection problem (Camci et al., 2022), and prioritizing digital supply chain transformation strategies (Alkan & Kahraman, 2023). The fermatean fuzzy AHP (FF-AHP) method's steps are given as follows (Camci et al., 2022; Alkan & Kahraman, 2023):

Step 1: Construct the hierarchical structure
Identify the problem which consists of criteria and sub-criteria, and alternatives.

Step 2: Construct the pairwise comparison matrix
The pairwise comparison matrix can be constructed using fermatean fuzzy linguistic terms as shown in for every expert.

$$Q = \left[Q_{ij}\right]_{mxm} = \begin{bmatrix} 1 & \mathrm{q}_{12} & \cdots & \mathrm{q}_{1\mathrm{m}} \\ \mathrm{q}_{21} & 1 & \cdots & \mathrm{q}_{2\mathrm{m}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{q}_{\mathrm{m}1} & \mathrm{q}_{\mathrm{m}2} & \cdots & 1 \end{bmatrix} \quad (14)$$

Where *i, j*=1,2,…,*m*.

Table 1. Linguistic Term for Pairwise Comparisons

SI	Meaning	FFN	SI	FFN
9	Absolutely more importance (AMI)	(0,970, 0,233)	8	(0,929, 0,121)
7	Very high importance (VHI)	(0,900, 0,307)	6	(0,844, 0,107)
5	High importance (HI)	(0,794, 0,083)	4	(0,737, 0,068)
3	Slightly high importance (SHI)	(0,670, 0,091)	2	(0,585, 0,059)
1	Equal importance (EI)	(0,465, 0,082)	1/2	(0,369, 0,062)
1/3	Slightly low importance (SLI)	(0,322, 0,038)	1/4	(0,293, 0,054)
1/5	Low importance (LI)	(0,272, 0,050)	1/6	(0,256, 0,048)
1/7	Very low importance (VLI)	(0,243, 0,040)	1/8	(0,233, 0,053)
1/9	Absolutely low importance (ALI)	(0,224, 0,050)		

Step 3: Measure the consistency of pairwise comparison matrices
To calculate the consistency, Saaty's classical consistency steps is applied.

Step 4: Computing aggregated pairwise comparison matrix
Pairwise comparison matrices established by each expert are aggregated by using Fermatean fuzzy weighted geometric mean (FFWG) operator, and in a single matrix.

Step 5: Evaluate the criteria FFN weights
The local weights (w) of each criterion are calculated by using FFWG operator (Eq.11).

$W = (w_1, \ldots, w_n)$, $\sum_{i=1}^{n} w_i = 1$, where W is the weight of the criteria.

3.3. ROPMIS Model

ROPMIS is a conceptual model introduced and tested by Thai (2008) to measure port service quality. This model consists of 6 dimensions (resources, outcomes, process, management, images and social responsibility) and sub-criteria related to these dimensions. This model investigates the impact of service quality on customer satisfaction in the port industry.

Yeo et al. (2015) revised the ROPMIS model developed by Thai (2008). Since there is a relationship between the social responsibility profile of businesses and their perceived image, the image and social responsibility dimensions are combined in the revised model, as shown in Figure 3.

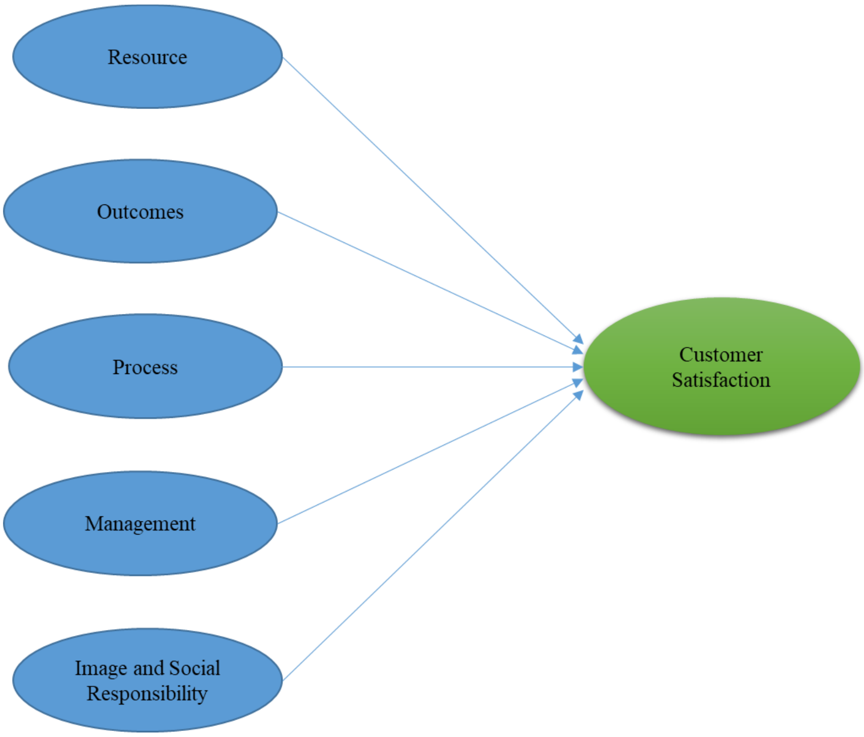

Figure 3. Conceptual Framework of ROPMIS Model (Yeo et al., 2015)

3.4. The Proposed Methodology

This study employs a hybrid technique that based on the ROPMIS model and combining Fermatean fuzzy AHP to prioritize criteria affecting the level of service provided by the port sector. As a result of a detailed literature survey and experts' opinions, the dimensions and evaluation criteria of the model are determined. A criteria hierarchy is constructed based on the ROPMIS model in order to evaluate customer satisfaction. AHP is applied to obtain the weights of the PSQ dimensions under the fermatean fuzzy environment. The inner levels of the suggested combined methodology are shown in Figure 4.

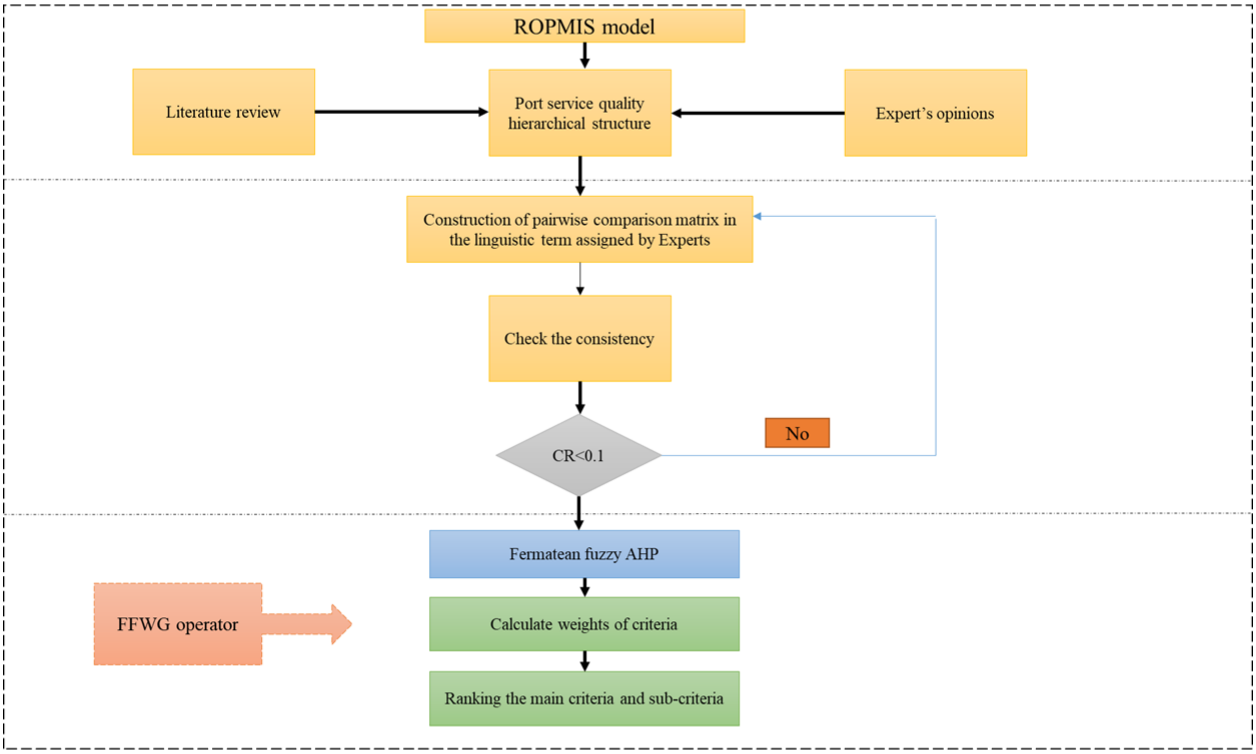

Figure 4. The Proposed Methodology

4. APPLICATION

Considering the increasing competition in global trade, the quality of services offered by port operators is an important criterion for port users to choose the port (Ha, 2003). In order to regularly assessment of service quality in the port sector, effective criteria must be determined and their importance weight must be calculated well. In this section, the service quality dimensions of the ROPMIS model, presented by Thai (2008) to evaluate customer satisfaction in port operations, are prioritized using FF-AHP. To evaluate the criteria, a decision-making team consisting of three experienced experts who work in the sector or related field, follow current developments and can evaluate port operations is formed. Experts are abbreviated as E1, E2 and E3. As a result of expert opinions and evaluation of studies in the literature, five main criteria and twenty sub-criteria have been determined within the scope of port service quality affecting customer satisfaction, based on the ROPMIS model. The hierarchical structure shown in Fig. 5. The consistency ratios (CR) for the first level and second level criteria given in Table 2 are calculated according to the scale presented in Table 1. According to Saaty (2008), If $CR \leq 0.1$, consistency is acceptable in pairwise comparisons else return to construction of pairwise comparison matrix. The local weights are calculated using Eq.11. This process is performed for each comparison matrix.. Sub-criteria are ranked locally according to the obtained score function values.. The global weights and rankings of the sub-criteria are calculated after the normalization process. FF-AHP results are presented in Table 5.

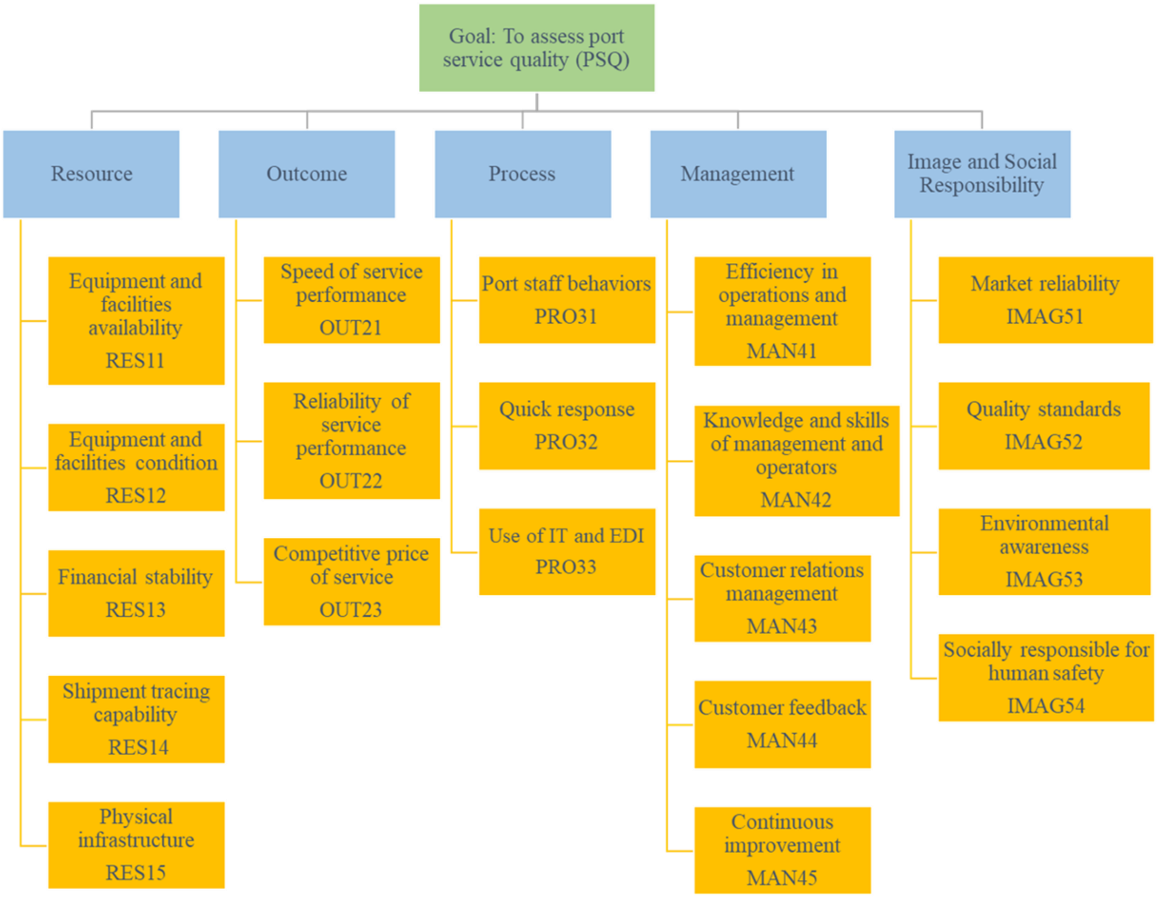

Figure 5. Hierarchical Structure of PSQ Criteria

Table 2. Descriptions of The Criteria for PSQ

Main Criteria (Dimensions)	**Sub-Criteria**	**Code**	**References**
Resource (RES)	Technical equipment and facilities of the port used	RES11	Adapted from Thai (2008) and Yeo et al. (2015)
	Proper functioning functionality of port equipment and facilities	RES12	
	Financially strong and stable position of the port	RES13	
	The port's shipment tracking and trace capacity	RES14	
	Physical infrastructure of the port (berths, yards, warehouses, and logistics connection)	RES15	
Outcome (OUT)	Performance speed of port services	OUT21	Adapted from Thai (2008) and Yeo et al. (2015)
	The port provides reliable and damage-free service	OUT22	
	The port offers competitive service prices compared to other companies	OUT23	
Process (PRO)	Port staff attitudes and behaviors	PRO31	Adapted from Thai (2008) and Yeo et al. (2015)
	The ability of port staff to quickly respond and resolve customer requirements	PRO32	
	The port's use of ICT applications (IT and EDI) in customer services	PRO33	
Management (MAN)	Effective use of ICT applications by the port administration	MAN41	Adapted from Thai (2008) and
	Port management's ability and knowledge to manage operations	MAN42	

	Port management's ability to understand customer needs and requirements well	MAN43	Yeo et al. (2015)
	Collecting feedback about customer services and producing solutions	MAN44	
	Efforts to continuously improve the port's customer-centered operation and processes of management	MAN45	
Image and Social Responsibility (IMAGE)	Market reliability of the port	IMAG51	Adapted from Thai (2008) and Yeo et al. (2015)
	Implementation of international quality standards in the port (ISO 14001, OHSAS 18001 etc.)	IMAG52	
	Environmental awareness in port operations (green port)	IMAG53	
	Corporate social responsibility behaviors about human safety	IMAG54	

Table 3. A Matrix of Pairwise Comparisons for The Main Criteria

	E1					E2					E3				
	RES	OUT	PRO	MAN	IMAGE	RES	OUT	PRO	MAN	IMAGE	RES	OUT	PRO	MAN	IMAGE
RES	EI	LI	VLI	ALI	SLI	EI	SLI	VLI	ALI	SLI	EI	SLI	LI	VLI	SLI
OUT	HI	EI	SLI	VLI	SHI	SHI	EI	SLI	VLI	SHI	SHI	EI	SLI	LI	SHI
PRO	VHI	SHI	EI	SLI	SHI	VHI	SHI	EI	SLI	SHI	HI	SHI	EI	SLI	SHI
MAN	AMI	VHI	SHI	EI	HI	AMI	VHI	SHI	EI	VHI	VHI	HI	SHI	EI	VHI
IMAGE	SHI	SLI	SLI	LI	EI	SHI	SLI	SLI	VLI	EI	SHI	SLI	SLI	VLI	EI
CR	0.071					CR 0.057					CR 0.061				

Table 4. Aggregated FFSs for Main Criteria

	RES		OUT		PRO		MAN		IMAGE	
RES	0,465	0,082	0,304	0,042	0,252	0,043	0,230	0,046	0,322	0,038
OUT	0,709	0,088	0,465	0,082	0,322	0,038	0,252	0,043	0,670	0,091
PRO	0,863	0,199	0,670	0,091	0,465	0,082	0,322	0,038	0,670	0,091
MAN	0,946	0,255	0,863	0,199	0,670	0,091	0,465	0,082	0,863	0,199
IMAGE	0,670	0,091	0,322	0,038	0,322	0,038	0,252	0,043	0,465	0,082

Table 5. FF Local and Global Weights of Criteria and SF Values

Main criteria (Dimensions)	Sub-criteria	Local weights		Global weights		SF	Local ranking	w	Global ranking
Resource		0,305	0,048						
	RES11	0,352	0,059	0,107	0,068	0,001	4	0,057	19
	RES12	0,556	0,089	0,170	0,093	0,004	2	0,224	14
	RES13	0,288	0,048	0,088	0,060	0,000	5	0,031	20
	RES14	0,540	0,091	0,165	0,095	0,004	3	0,205	16
	RES15	0,719	0,132	0,219	0,134	0,008	1	0,483	11
Outcome		0,448	0,064						
	OUT21	0,456	0,068	0,204	0,083	0,008	2	0,228	12
	OUT22	0,658	0,113	0,294	0,119	0,024	1	0,682	5
	OUT23	0,336	0,051	0,150	0,073	0,003	3	0,091	17
Process		0,566	0,087						
	PRO31	0,333	0,052	0,188	0,093	0,006	3	0,097	13
	PRO32	0,504	0,074	0,285	0,102	0,022	2	0,337	7
	PRO33	0,600	0,100	0,340	0,119	0,037	1	0,567	3
Management		0,738	0,150						
	MAN41	0,401	0,057	0,296	0,152	0,022	4	0,091	6
	MAN42	0,323	0,047	0,238	0,151	0,010	5	0,047	9

	MAN43	0,425	0,062	0,314	0,153	0,027	3	0,107	4
	MAN44	0,550	0,074	0,406	0,155	0,063	2	0,234	2
	MAN45	0,719	0,130	0,531	0,177	0,144	1	0,521	1
Image & Soc. Resp.		0,382	0,054						
	IMAGE51	0,686	0,113	0,262	0,117	0,016	1	0,550	8
	IMAGE52	0,418	0,060	0,160	0,072	0,004	3	0,125	15
	IMAGE53	0,548	0,097	0,209	0,102	0,008	2	0,280	10
	IMAGE54	0,298	0,050	0,114	0,066	0,001	4	0,045	18

5. DISCUSSION ON RESULTS

The aim of this paper is to identify and prioritize the main criteria and sub-criteria for port service quality in fuzzy environment. Based on the review of the research literature, the main criteria and sub-criteria of service quality have been identified based on the ROPMIS model and prioritized based on the Fermatean fuzzy AHP method. Although the criteria used in this study are all important, the results of the study show; Management (0,738, 0,150) is the most important main criteria, and respectively, Process (0,566, 0,087), Outcome (0,448, 0,064), Image and Social Responsibility (0,382, 0,054), and Resource (0,305, 0,048) are important. The finding that the management main criterion has the highest importance weight in terms of port service quality is compatible with the results of Thai (2008) and Yeo et al. (2015), who found that this factor is perceived as the most important factor in delivering service quality in maritime transportation.

Moreover, it is seen that the image and social responsibility (0,382, 0,054) has a significant weight, and indicating that it is an important service quality criterion in terms of corporate sustainability of ports. Emission values resulting from port activities affect air quality, and therefore may have negative consequences on the health of employees and human around the port (Prati et al., 2015; Botana et al., 2023). In terms of sustainability and social responsibility, ports implement their operations according to "green port" dimensions. The environmental activities of ports have consequences on the image and development of ports (Acciaro, 2015).

The findings suggest that port sector professionals and practitioners should apply the necessary tactical and strategic methods, according to the importance weights of the criteria, to implement sustainability considering port operations.

6. CONCLUSION

This study is presented as a guide for port sector managers and practitioners to contribute to customer satisfaction by investigating the importance of PSQ criteria. In this context, the importance weights and rankings of the defined dimensions of the ROPMIS model introduced by Thai (2008) are calculated. FF-AHP methodology is used to calculate the local and global weights of the dimensions.

According to Table 5, the final main dimensions ranking is MAN > PRO > OUT > IMAGE > RES. Considering all the main dimensions, management is determined to be the most important one. When it comes to the global ranking of each service quality criterion, MAN44 and MAN45 are ranked as the most important and second most important drivers of port service quality, respectively. The contribution of factors arising from management-based operations in ports to increasing customer satisfaction shows that the results of this study are compatible with existing studies (Yeo et al., 2015; Phan et al., 2021).

The study's findings have significant managerial implications for managers in the port industry. Through the current study of the validated port service quality model, port managers could first comprehend the dimensions and issues of port service quality according to customers' requests and suggestions. Second, in order to improve the port's reputation and, consequently, the perceived level of service quality in the eyes of its clients, port management ought to focus more on corporate social responsibility initiatives in addition to standards like infrastructure, resources, and transportation links. Green port practices should be specifically encouraged in port operations and associated activities. These are necessary for sustainable maritime activities and reducing greenhouse gas emissions. In order to achieve sustainable success, ports need to develop operational processes as well as a strategic coordination center and benchmarking system. (Othman et al.,2023).

However, the study's conclusions have significant theoretical and managerial implications, its limitations should be taken into account since it generalizes port service quality dimensions. Therefore, these criteria could be developed for different port types for future research.

REFERENCES

Abdullah, A. G., Shafii, M. A., Pramuditya, S., Setiadipura, T. & Anzhar, K. (2023). Multi-criteria decision making for nuclear power plant selection using fuzzy AHP: Evidence from Indonesia. *Energy and AI*, 14, 100263.

Acciaro, M. (2015). Corporate responsibility and value creation in the port sector. *International Journal of Logistics Research and Applications*, 18(3), 291-311.

Agüero-Tobar, M. A., González-Araya, M. C. & González-Ramírez, R. G. (2023). Assessment of maritime operations efficiency and its economic impact based on data envelopment analysis: A case study of Chilean ports. *Research in Transportation Business & Management*, *46*, 100821.

Alkan, N. & Kahraman, C. (2023). Prioritization of supply chain digital transformation strategies using multi-expert Fermatean fuzzy analytic hierarchy process. *Informatica*, 34(1), 1-33.

Atanassov, K.T. (1986). Intuitionistic Fuzzy Sets. *Fuzzy Sets and Systems*, 20(1), 87-96.

Awasthi, A., Chauhan, S. S., Omrani, H. & Panahi, A. (2011). A hybrid approach based on SERVQUAL and fuzzy TOPSIS for evaluating transportation service quality. *Computers & Industrial Engineering,* 61(3), 637-646.

Bhattacharya, P., Mukhopadhyay, A., Saha, J., Samanta, B., Mondal, M., Bhattacharya, S. & Paul, S. (2023). Perception-satisfaction based quality assessment of tourism and hospitality services in the Himalayan region: An application of AHP-SERVQUAL approach on Sandakphu Trail, West Bengal, India. *International Journal of Geoheritage and Parks*, 11(2), 259-275.

Biswas, S., Pamucar, D., Kar, S. & Sana, S. S. (2021). A new integrated FUCOM–CODAS framework with fermatean fuzzy information for multi-criteria group decision-making. *Symmetry*, 13(12), 2430.

Botana, C., Fernández, E. & Feijoo, G. (2023). Towards a Green Port strategy: The decarbonisation of the Port of Vigo (NW Spain). *Science of the Total Environment*, *856*, 159198.

Camci, A., Ertürk, M.E. & Gül, S. (2022). A novel Fermatean fuzzy analytic hierarchy process proposition and ıts usage for supplier selection problem in ındustry 4.0 transition. Garg, H. (eds) q-Rung Orthopair Fuzzy Sets. *Springer*, Singapore.

Celik, E. & Akyuz, E. (2018). An interval type-2 fuzzy AHP and TOPSIS methods for decision-making problems in maritime transportation engineering: The case of ship loader. *Ocean Engineering,* 155, 371-381.

Chen, K. K., Chang, C. T. & Lai, C.S. (2009). Service quality gaps of business customers in the shipping industry. *Transportation Research Part E: Logistics and Transportation Review*, 45(1), 222-237.

Cho, C. H., Kim, B. I. & Hyun, J. H. (2010). A comparative analysis of the ports of Incheon and Shanghai: The cognitive service quality of ports, customer satisfaction, and post-behaviour. *Total Quality Management*, 21(9), 919-930.

Cronin, J. J. & Taylor, S. A. (1994). SERVPERF versus SERVQUAL: reconciling performance-based and perceptions-minus-expectations measurement of service quality. *Journal of Marketing*, 58(1), 125-131.

Cronin, J.J. & Taylor, S.A. (1992). Measuring service quality: A re-examination and extension. *Journal of Marketing*, 56(3), 55–68.

Dinçer, H., Yüksel, S. & Martínez, L. (2019). Analysis of balanced scorecard-based SERVQUAL criteria based on hesitant decision-making approaches. *Computers & Industrial Engineering*, 131, 1-12.

Ding, K., Choo, W.C., Ng, K.Y. & Ng, S.I. (2020). Employing structural topic modelling to explore perceived service quality attributes in Airbnb accommodation. *International Journal of Hospitality Management*, 91, 102676.

Grönroos, C. (1982). An applied service marketing theory. *European journal of Marketing*, 16(7), 30-41.

Guo, Y., Li, Y., Liu, D. & Xu, SX. (2023). Measuring service quality based on customer emotion: An explainable AI approach. *Decision Support Systems,* 114051, In Press.

Ha, M.S. (2003). A comparison of service quality at major container ports: Implications for Korean ports. *Journal of Transport Geography*, 11(2), 131-137.

Hemalatha, S., Dumpala, L. & Balakrishna, B. (2018). Service quality evaluation and ranking of container terminal operators through hybrid multi-criteria decision making methods. *The Asian Journal of Shipping and Logistics*, 34(2), 137-144.

Hsu, C. T., Chou, M. T. & Ding, J. F. (2023). Key factors for the success of smart ports during the post-pandemic era. *Ocean & Coastal Management*, 233, 106455.

Hu, Y. & Zhu, D. (2009). Empirical analysis of the worldwide maritime transportation network. *Physica A: Statistical Mechanics and its Applications*, *388*(10), 2061-2071.

Ilbahar, E., Karaşan, A., Cebi, S. & Kahraman, C. (2018). A novel approach to risk assessment for occupational health and safety using Pythagorean fuzzy AHP & fuzzy inference system. *Safety Science*, 103, 124-136.

Jiang, M., Zhao, S. & Jia, P. (2023). The spatial spillover effect of seaport capacity on export trade: Evidence from China pilot free trade zones. *Ocean & Coastal Management*, *245*, 106879.

Karasan, A., Ilbahar, E., Cebi, S. & Kahraman, C. (2022). Customer-oriented product design using an integrated neutrosophic AHP & DEMATEL & QFD methodology. *Applied Soft Computing*, 118, 108445.

Keshavarz-Ghorabaee, M., Amiri, M., Hashemi-Tabatabaei, M., Zavadskas, E. K. & Kaklauskas, A. (2020). A new decision-making approach based on Fermatean fuzzy sets and WASPAS for green construction supplier evaluation. *Mathematics*, 8(12), 2202.

Kumar, A. & Pant, S. (2023). Analytical hierarchy process for sustainable agriculture: An overview. *MethodsX*, 10, 101954.

Kutlu Gündoğdu, F. & Kahraman, C. (2019). Spherical fuzzy sets and spherical fuzzy TOPSIS method. *Journal of Intelligent & Fuzzy Systems*, 36(1), 337-352.

Kutlu Gündoğdu, F., Duleba, S., Moslem, S., & Aydın, S. (2021). Evaluating public transport service quality using picture fuzzy analytic hierarchy process and linear assignment model. *Applied Soft Computing*, 100, 106920.

Ladhari, R. (2009). A review of twenty years of SERVQUAL research. *International Journal Of Quality and Service Sciences*, 1(2), 172-198.

Li, D., Jiao, J., Wang, S. & Zhou, G. (2023). Supply Chain Resilience from the Maritime Transportation Perspective: A bibliometric analysis and research directions. *Fundamental Research*.

Liu, Y., Ma, X., Qiao, W., Ma, L. & Han, B. (2024). A novel methodology to model disruption propagation for resilient maritime transportation systems–a case study of the Arctic maritime transportation system. *Reliability Engineering & System Safety*, *241*, 109620.

Liu, Q., Chen, J., Yang, K., Liu, D., He, L., Qin, Q. & Wang, Y. (2023). An integrating spherical fuzzy AHP and axiomatic design approach and its application in human–machine interface design evaluation. *Engineering Applications of Artificial Intelligence*, 125, 106746.

Liu, R., Cui, L., Zeng, G., Wu, H., Wang, C., Yan, S. & Yan, B. (2015). Applying the fuzzy SERVQUAL method to measure the service quality in certification & inspection industry. *Applied Soft Computing*, 26, 508-512.

Lupo, T. (2015). Fuzzy ServPerf model combined with ELECTRE III to comparatively evaluate service quality of international airports in Sicily. *Journal of Air Transport Management*, 42, 249-259.

Menekşe, A. & Akdağ, H. C. (2023). Medical waste disposal planning for healthcare units using spherical fuzzy CRITIC-WASPAS. *Applied Soft Computing*, 144, 110480.

Miremadi, A., Ghalamkari, S. & Sadeh, F. (2011). Customer satisfaction in port industry (A case study of Iranian shipping). *International Conference on Sociality and Economics Development*, 10, 58-62.

Mishra, A. R., Rani, P., Deveci, M., Gokasar, I., Pamucar, D. & Govindan, K. (2023). Interval-valued Fermatean fuzzy heronian mean operator-based decision-making method for urban climate change policy for transportation activities. *Engineering Applications of Artificial Intelligence*, 124, 106603.

Narasimha, P. T., Jena, P. R. & Majhi, R. (2021). Impact of COVID-19 on the Indian seaport transportation and maritime supply chain. *Transport Policy*, 110, 191-203.

Ocampo, L., Alinsub, J., Casul, R. A., Enquig, G., Luar, M., Panuncillon, N., ... & Ocampo, C. O. (2019). Public service quality evaluation with SERVQUAL and AHP-TOPSIS: A case of Philippine government agencies. *Socio-Economic Planning Sciences*, 68, 100604.

Othman, M. K., Rahman, N.S.F.A., Ismail, A., Osnin, N.A. & Hanafiah, R. M. (2023). Revisiting Malaysia’s port classification system in a complex operational environment to streamline the coordination and management of maritime ports. *Case Studies on Transport Policy*, *13*, 101062.

Parasuraman, A., Zeithaml, V. A. & Berry, L. L. (1985). A conceptual model of service quality and its implications for future research. *Journal of Marketing*, 49(4), 41-50.

Parasuraman, A., Zeithaml, V. A. & Berry, L. L. (1988). SERVQUAL: A multiple item scale for measuring consumer perceptions of service quality. *Journal of Retailing*, 64(1), 12-40.

Park, R.K. & De, P. (2004). An alternative approach to efficiency measurement of seaports. *Maritime Economics & Logistics*, 6, 53-69.

Phan, T. M., Thai, V. V. & Vu, T. P. (2021). Port service quality (PSQ) and customer satisfaction: An exploratory study of container ports in Vietnam. *Maritime Business Review*, 6(1), 72-94.

Prati, M. V., Costagliola, M. A., Quaranta, F. & Murena, F. (2015). Assessment of ambient air quality in the port of Naples. *Journal of the Air & Waste Management Association*, 65(8), 970-979.

Roa, I., Peña, Y., Amante, B. & Goretti, M. (2013). Ports: Definition and study of types, sizes and business models. *Journal of Industrial Engineering and Management (JIEM)*, 6(4), 1055-1064.

Saaty, T.L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15(3), 234-281.

Saaty, T.L. (1980). The analytic process: planning, priority setting, resources allocation. *McGraw*, New York.

Saaty, T.L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83-98.

Senapati, T. & Yager, R. R. (2019). Fermatean fuzzy weighted averaging/geometric operators and its application in multi-criteria decision-making methods. *Engineering Applications of Artificial Intelligence*, 85, 112-121.

Senapati, T. & Yager, R. R. (2020). Fermatean fuzzy sets. *Journal of Ambient Intelligence and Humanized Computing*, 11, 663-674.

Shu, Z., Torralba, M. H., Carrasco, R. A. & López, M.F.B. (2023). Assessing customer satisfaction of London luxury hotels with the AHP method and the SERVPERF scale: A case study of customer reviews on TripAdvisor. *Procedia Computer Science,* 221, 73-80.

Simić, V., Ivanović, I., Đorić, V. & Torkayesh, A.E. (2022). Adapting urban transport planning to the COVID-19 pandemic: An integrated fermatean fuzzy model. *Sustainable Cities and Society*, 79, 103669.

Smarandache, F. (1998). Neutrosophy: neutrosophic probability, set, and logic: Analytic synthesis & synthetic analysis. *Amer. Res. Press.*

Song, D. W. & Yeo, K.T. (2004). A competitive analysis of Chinese container ports using the analytic hierarchy process. *Maritime Economics & Logistics*, 6, 34-52.

Sun, Y., Zhou, X., Yang, C. & Huang, T. (2023). A visual analytics approach for multi-attribute decision making based on intuitionistic fuzzy AHP and UMAP. *Information Fusion*, 96, 269-280.

Talley, W.K. (2013). Maritime transportation research: topics and methodologies. *Maritime Policy & Management*, *40*(7), 709-725.

Talley, W. K., Ng, M. & Marsillac, E. (2014). Port service chains and port performance evaluation. *Transportation Research Part E: Logistics and Transportation Review*, 69, 236-247.

Talley, W.K. & Ng, M. (2016). Port economic cost functions: A service perspective. *Transportation Research Part E: Logistics and Transportation Review*, 88, 1-10.

Talley, W.K. (2019). Note: Determinants of cargo port choices by cargo port service providers. *Transportation Research Part E: Logistics and Transportation Review*, 132, 48-50.

Thai, V.V. (2008). Service quality in maritime transport: Conceptual model and empirical evidence. *Asia Pacific Journal of Marketing and Logistics*, 20(4), 493-518.

Thai, V.V. (2016). The impact of port service quality on customer satisfaction: The case of Singapore. *Maritime Economics & Logistics*, 18, 458-475.

Torra, V. (2010). Hesitant fuzzy sets. *International Journal of Intelligent Systems*, 25(6), 529–539.

Tumsekcali, E., Ayyildiz, E. & Taskin, A. (2021). Interval valued intuitionistic fuzzy AHP-WASPAS based public transportation service quality evaluation by a new extension of SERVQUAL Model: P-SERVQUAL 4.0. *Expert Systems with Applications*, 186, 115757.

Ugboma, C., Ogwude, I. C., Ugboma, O. & Nnadi, K. (2007). Service quality and satisfaction measurements in Nigerian ports: An exploration. *Maritime Policy & Management*, 34(4), 331-346.

UNCTAD, (2023). *Review of Maritime Transport 2023*. Retrieved October 13, 2023 from https://unctad.org/system/files/official-document/rmt2023_en.pdf.

Viet, N.H. (2015). Service quality at the seaport system of saigon newport corporation. *Int. J. Mark. Stud*, 7(6), 145-154.

Yager, R., (2013). *Pythagorean fuzzy subsets*. Joint IFSA World Congress and NAFIPS Annual Meeting, (IFSA/NAFIPS) (2013), 57-61.

Yeo, G. T., Thai, V. V. & Roh, S.Y. (2015). An analysis of port service quality and customer satisfaction: The case of Korean container ports. *The Asian Journal of Shipping and Logistics*, 31(4), 437-447.

Zeithaml, V. A., Berry, L. L. & Parasuraman, A. (1993). The nature and determinants of customer expectations of service. *Journal of The Academy of Marketing Science*, 21, 1-12.

Zhou, C., Ma, N., Cao, X., Lee, L. H. & Chew, E.P. (2021). Classification and literature review on the integration of simulation and optimization in maritime logistics studies. *IISE Transactions*, 53(10), 1157-1176.