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Research Article

A multi-criteria fuzzy analytic network process analysis to supplier selection in fishery of halal supply chain

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Abstract

This research aims to determine a crab's supplier related to product quality standards and halal perspectives. Location research was conducted at a crab processing company located in Bangkalan Regency, East Java Province, Indonesia. The selection of suppliers was evaluated using the multicriteria decision method, particularly the fuzzy analytical network process, which contains 10 criteria and 47 sub-criteria. The criteria involve quality, cost, services, delivery, supplier profile, environmental issues, food safety, social responsibility, work, health and safety, and halal perception. The results show that quality, cost, services, and delivery are the crucial criteria to evaluate a supplier's performance. Applying sanitation procedures, supply chain transparency, and quality products are the key to determining a supplier for quality criteria because it has strong relationships with halal practices. Offering a lower price could not provide a better indication. However, considering total ownership is crucial to prevent product rejection due to low standards in the future. Meanwhile, the capability to fulfill uncertainty of purchasing orders or demand quality products is also a crucial indicator in service criteria for maintaining business competition in the VUCA era. Delivery criteria, including delivery time, transparency, and delivery speed, are crucial to facing the growing demand for halal products.

Keywords:
Fuzzy ANP;
Fishery;
Halal Supply Chain;
Supplier selection.

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1. Introduction

The fisheries sector is critical to global food security, providing millions worldwide with a significant source of protein and essential nutrients. It plays an important role in many people's diets, especially in developing countries where fish is often the main source of animal protein (Paramor & Frid, 2015; White, 2024; Ye, 2015). This sector supports the livelihoods of millions of people, contributing to economic stability and poverty alleviation (Mehanna, 2021; Sampantamit et al., 2020; White, 2024). Despite challenges such as overfishing and environmental concerns, fisheries remain integral to achieving sustainable food systems and meeting the nutritional needs of a growing global population (Reinert, 2022; Thilsted et al., 2016; White, 2024).

The global Muslim population is expected to reach 26% by 2030, driving increased demand for halal products (Ahmadiyah et al., 2022). This demand is particularly significant in countries such as Indonesia, which has the largest Muslim population globally and represents a substantial market opportunity for halal food manufacturers (Ahmadiyah et al., 2022; Herianingrum et al., 2024). The halal industry, including halal fishery products, is growing rapidly due to the religious obligation of Muslims to consume halal products, which are considered safer and ethical (Farouk, 2023; Rahman & Ali, 2024). In addition, economic growth and increased purchasing power in Muslim-majority regions are further fueling demand (Bashir et al., 2019; Kabir, 2015).

Halal supply chain issues risk contamination at various stages, including hatcheries, livestock, slaughter, storage, handling, and transportation (Busyra & Ardi, 2020; Supian, 2018). Overcoming halal product problems can be solved by implementing a halal assurance system, paying attention to halal critical points, and adopting technology to maintain halal compliance at every stage of the process (Kamaruddin et al., 2012; Saeed, 2023; Yaacob et al., 2023). In addition, developing comprehensive halal supply chain guidelines and policy frameworks is required to address the lack of unified regulations and ensure halal integrity at every stage of the supply chain (Khan et al., 2022; Saleh et al., 2016). Implementing good practices in the halal food supply chain, including avoiding direct contact with haram products, is essential to build consumer trust and ensure consumer perception (Mohamed et al., 2024; Tieman, 2011). Moreover, The Halal Supply Chain Model can be a critical instrument for designing and managing halal food supply chains in extending halal integrity from source to the point of consumer purchase, emphasizing the importance of environmentally friendly, socially responsible, and ethically governed practices in Halal Supply Chain (Ghalih & Chang, 2024; Tieman et al., 2012)

It is necessary to evaluate suppliers to ensure that the entire process of managing fishery products carried out by suppliers meets halal standards because the criteria of halal certification was a critical criterion for supplier selection after quality criteria (Putri et al., 2024). The complexity of the problem involves various factors such as quality, sustainability, legality, and compliance with halal standards. Each factor demands strict standards and monitoring systems. Various assessment methods and the existence of a quality assurance system strongly influence the quality of fishery products (Ismail et al., 2024; Suseno & Suadi, 2021). Sustainability is linked to sustainable fishing practices and certification from agencies (Hazen et al., 2016; Hopkins et al., 2024; Kaiser & Edwards-Jones, 2006). Legality aspects include compliance with national and international regulations and the presence of tracking systems to prevent illegal fishing (Hopkins et al., 2024; Parkes et al., 2010). For Muslim consumers, fishery products must meet halal standards, which include the type of fish and processing and handling methods that involve no non-halal substances being used in the production process (Chowdhury et al., 2023). Halal standards have implications for suppliers managing fishery products, requiring high hygiene standards, strict quality control, and certification from reputable halal certification bodies. Key considerations for suppliers in managing fishery products to meet halal standards include collaboration, knowledge sharing, risk management, and establishing a comprehensive documentation and traceability system.

The globalization of fish trade creates challenges in ensuring the safety and quality of fishery products, especially with additional requirements from major importers that demand the development of effective national seafood control systems for domestic and export needs. Long distribution and handling processes in the supply chain often jeopardize product safety if not properly controlled, while developing countries face difficulties complying with international standards (Al-Busaidi et al., 2016; Dey et al., 2005). To ensure product halalness, halal food supply chains must implement high hygiene and sanitation standards, involve halal compliance critical control point (HCCCP) analysis, and obtain certification from trusted halal institutions with oversight by relevant authorities (Dey et al., 2005; Kamaruddin et al., 2012; Osman, 2023). In addition, the role of suppliers is very important, so it is necessary to work together to set common goals, share knowledge, and overcome challenges in the halal supply chain, comprehensive documentation, and traceability systems to maintain the concept of Halalan Toyyiban (Busyra & Ardi, 2020; Saeed, 2023). Based on this, it is necessary to conduct research on supplier selection in the fishing industry.

One of the fishery product processing companies is a crab (*Portunus pelagicus*) processing company. This company produces crab and converts it into crab meat for export. To meet consumer demand, the company cooperates with suppliers. The main raw materials are obtained from Bangkalan Regency and Pasuruan Regency, East Java Province, Indonesia. In Bangkalan Regency, three main suppliers have cooperated with the company to ensure smooth supply. Suppliers from Pasuruan Regency, East Java Province, Indonesia, meet the shortage of crab supply. The company sets strict raw material specifications, such as size, meat quality, and freshness of the crab, to ensure that the final product meets high-quality standards. Good quality crab is characterized by thick meat, pure white, and free from pungent fishy odor. The processing process combines modern technology and strict quality control, producing market-ready crab meat for domestic and export markets. Supplier selection is a critical component of supply chain management, which involves identifying, evaluating, and contracting suppliers to optimize cost, quality, and reliability. Various research methods have been developed to overcome the complexity of the supplier selection process in the supply chain, such as the Analytic Hierarchy Process (AHP), PROMETHEE, Analytic Network Process (ANP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Data Envelopment Analysis (DEA), Multi-Criteria Decision Making (MCDM), Best-Worst Method (BWM), Fuzzy Logic, Integrated and Hybrid Models (Abdulla & Baryannis, 2024; Akburak, 2022; Alkahtani et al., 2019; Andreji, 2015; Bekkaoui et al., 2022; Dewayana et al., 2023; Erdinç et al., 2024; Haryono et al., 2024; Karsak & Dursun, 2016; Rezaei et al., 2016; Rozi & Herowati, 2018; Sharma & Tripathy, 2023; Taherdoost & Brard, 2019; Tang & Day, 2014).

Fuzzy ANP (FANP) is an appropriate method for supplier selection, addressing the complexity and uncertainty inherent in multi-criteria decision-making (MCDM) problems. Unlike traditional methods such as AHP, FANP incorporates feedback loops, allowing for more dynamic and realistic modeling of decision criteria (L.-Z. Lin & Hsu, 2008; J. Ren et al., 2016). FANP is widely used for supplier selection based on the uncertainty of criteria (Ayağ & Samanlioglu, 2016; Pang, 2009; Sennaroglu & Akıcı, 2020)In addition, Fuzzy AHP also uses quantitative and qualitative criteria evaluation to determine suppliers (Ayağ & Samanlioglu, 2016; X. Chen & Hu, 2010; Pang, 2009; A. Ren et al., 2023; Wang et al., 2021). FANP allows the evaluation of quantitative and qualitative criteria, considering the interdependence and feedback between them. Qualitative criteria are cost, quality, lead time, and reliability (Rezaei et al., 2016; Taherdoost & Brard, 2019). While the qualitative criteria are environmental impact, sustainability, and supplier reputation (Agrawal, 2022; Rezaei et al., 2016). FANP is used to select suppliers in the automotive sector, electronic industry, chemical industry, and product supply chain (Sennaroglu & Akıcı, 2020; Vinodh et al., 2011; Yücenur et al., 2011) The advantages of the FANP method are that it can improve decision-making through a structured approach, flexibility for various industries, and comprehensive evaluation by considering priorities and feedback between criteria, resulting in more reliable supplier selection decisions (X. Chen & Hu, 2010; Otay & Kahraman, 2019).

This research aims to fill the research gap regarding the selection of fishery product suppliers, especially crab suppliers who not only meet quality standards but also meet halal requirements comprehensively. Furthermore, research on simultaneous consideration of green, sustainable, and resilient criteria in a fuzzy environment is limited (Fallahpour et al., 2021) and underexplored for supplier selection purposes (Alamroshan et al., 2022). By developing an integrated Fuzzy ANP model, this research is expected to improve the quality and consumer confidence in halal fishery products in Indonesia and support the development of a sustainable fisheries industry. This research makes a significant contribution to the development of the halal fisheries industry in Indonesia by integrating the halal perspective and sustainable criteria for supplier evaluation to face challenges in global demand. Maflahah et al. (2024) stated that one of the obstacles to fishery products expanding the market reach is having no halal certification even though they have good quality products. This research is expected to increase efficiency, transparency, and accountability in the halal fishery product supply chain by providing a supplier selection model based on data and quantitative analysis.

2. Literature Review

2.1. Supplier selection in the fishery products supply chain

Supplier selection in fishery product supply chains is an important aspect of supply chain management, impacting cost, quality, and sustainability. Key factors in supplier selection for fishery product supply chains include raw material quality, purchasing risk reduction, and supply capability and risk control (Chattopadhyay et al., 2022; Hsu et al., 2016; Junior et al., 2013; Kowang et al., 2017; Mohanty & Gahan, 2011; A. Ren et al., 2023; Tang & Day, 2014). Quality, consistent pricing, environmental, economic, and social sustainability aspects are considerations for supplier selection (A. Ren et al., 2023)(A. Ren et al., 2024). Delivery reliability is critical in many industries, but it has less effect on product distribution (Kowang et al., 2017; A. Ren et al., 2023). Challenges in supplier selection include risks affecting logistics performance and decision-making complexity (Gia et al., 2021; Wang et al., 2022). An emerging trend involves the integration of remote sensing technologies (satellite imagery and blockchain technology) and using metaheuristic algorithms to address challenges in the fish supply chain, improve supply chain resilience, and contribute to revenue generation opportunities from economically disadvantaged suppliers in developing countries (Sengupta et al., 2022; Yang et al., 2023). Supplier selection affects supply, market, and operational risks, directly impacting the logistics performance of companies in the fisheries supply chain (Gia et al., 2021). In addition, supplier selection directly affects organizational performance, product quality, and other factors related to the production process (Junior et al., 2013). Effective supplier selection requires strong integration and collaboration across the supply chain with modern information systems in the food industry, including fisheries (Vodenicharova, 2020).

2.2. Halal in the fishing industry

The concept of halal is a guideline that means it is permissible according to Islamic law. Components of products that must be halal-certified are medicines, cosmetics, and other products. The halal market continues to grow along with the increasing population. The increasing number of halal products is increasing demand from Muslim and non-Muslim consumers who associate halal products with quality and safety (Maulidia, 2022; Nazim & Yusof, 2023; Sujibto & Fakhruddin, 2023). This is a significant opportunity for the growth of the halal fisheries industry. Ensuring that products and production processes meet halal standards in the fisheries industry is essential to serve the rapidly growing Muslim consumer market (Jubaedah et al., 2023; Maulidia, 2022;

Mustapha et al., 2024; Nazim & Yusof, 2023; Sujibto & Fakhruddin, 2023). Price, sensory attributes, freshness, origin, production method, and halal certification and labeling influence consumer preferences for fishery products. Consumers are willing to pay more for halal-certified fishery products (Mitra et al., 2024; Mustapha et al., 2024). Fish is a halal product. However, processed fishery products are still in doubt due to the presence of additional ingredients. Therefore, fishery products require halal certification.

Halal standards in the fishing industry cover various aspects, including raw materials, processing methods, packaging, and distribution. These standards ensure that products are not only allowed but also hygienic and safe for consumption (Nirwana et al., 2024; Suseno & Suadi, 2021). In the product production process, raw material components are the main concern determining the product's halalness. For fishery products, the main concern is the source of fish and ensuringensure it is free from contamination by non-halal substances. In addition, the type of feed used in cultivation must also be halal (Boti et al., 2024; Suseno & Suadi, 2021). Fish processing involves several steps, such as stunning, bleeding, gutting, and filleting. Each step must adhere to halal guidelines, ensuring there is no cross-contamination with non-halal products (Ghaly et al., 2013; Liu et al., 2022). Many fishery product processing technologies using high-pressure processes, modified atmosphere packaging, and the use of natural preservatives can help extend the shelf life of fish products while maintaining their halal status. These technologies also contribute to sustainable fisheries management (Karim, 2023; Liu et al., 2022). Fishery products produce by-products that have high added value. Even these by-products must meet the criteria of halal products (Irianto et al., 2014; Liu et al., 2022; Vidanarachchi et al., 2014). The process of halal fishery products impacts the business's economic performance, namely being able to produce safe and quality products (Brown et al., 2022; Bujas et al., 2023; Miret-Pastor et al., 2014; Zoli et al., 2024). The stages of the packaging and distribution process determine the halalness of the product. Packaging materials must be halal certified, and the distribution process must prevent contamination with non-halal products (Nirwana et al., 2024; Suseno & Suadi, 2021).

Entrepreneurs experience obstacles in conducting halal certification, including ignorance of knowledge, legal constraints, and procedures for obtaining certification (Muneeza & Mustapha, 2021). To assure halal products, producers must be more aware of and educated on halal standards, including training on proper handling and processing techniques to ensure compliance (Shoid et al., 2022; Suseno & Suadi, 2021). Certification programs are needed as a promotional tool for sustainable fishing (Miret-Pastor et al., 2014).

One of the significant challenges in the global halal industry is the lack of integrated halal standards. Different countries have varying halal certification requirements, which can complicate international trade. Ensuring halal compliance in the fishing industry involves a comprehensive approach that includes proper sourcing, processing, packaging, and distribution. By adhering to halal standards, the fishing industry can meet Muslim consumers' demands and attract a wider market that values quality and safety.

2.3. Fuzzy Analytic Network Process (FANP) in supply chain research

Fuzzy ANP (FANP) analysis is widely used in various aspects of supply chain management to solve complex problems. FANP is widely used for supplier selection by identifying the criteria of suppliers who most quickly and accurately fulfill orders (R.-H. Lin, 2012; Vinodh et al., 2011). Supplier performance evaluation based on environmental criteria to improve overall supply chain sustainability using the FANP approach (Chuang et al., 2018; Malviya et al., 2018) (Zhang et al., 2023). In addition, FANP can also be used to develop a performance evaluation index system for supply chains, overcoming the complexity and uncertainty of evaluating various performance factors (Baozhu, 2009). FANP has been applied to measure supply chain resilience by identifying key resilience capabilities and criteria using fuzzy sets to handle ambiguous pairwise comparisons (Wicher et al., 2016). FANP is used for strategic decision-making on implementing green supply chain management practices based on prioritizing the five big data (value, volume, velocity, variety, and correctness) in the context of supply chain finance (Alidrisi, 2021). FANP can be used to compare traditional supply chain management with blockchain-based supply chain management, highlighting the benefits of blockchain in terms of data security, decentralization, and overall efficiency (Yadav & Singh, 2020). This method can also be combined with other methods, such as fuzzy TOPSIS, interpretive structural modeling (ISM), and fuzzy DEMATEL, for more comprehensive decision-making (Alidrisi, 2021)(Y. Chen et al., 2018; Tseng & Geng, 2013).

3. Methods

This research was conducted at a crab processing company located in Bangkalan Regency, East Java Province, Indonesia.

Determining suppliers of crab raw materials using the Fuzzy ANP (FANP) approach. FANP uses the principle of Analytic Network Process (ANP), which is a system analysis with influence and feedback. The ANP network consists of a control layer and a network layer. The control layer contains independent goals and principles or only one goal. The network layer consists of groups of elements that interact with each other. The stages of using the FANP method are as follows:

1. Identification of Criteria and sub-criteria.
   Based on literature and interviews with fishery product processing industry experts, identification of supplier selection criteria.
2. ANP Modeling
   Preparation of an ANP network structure consisting of the main cluster (supplier selection criteria) and nodes (sub-criteria).
3. Determine the relationship weight between criteria.
   The stage of determining the relationship between criteria reflects the interdependence between these factors. This stage is done by distributing questionnaires. The

questionnaire was given to experts or decision-makers on selecting suppliers of crab raw materials in the company. The number of respondents was 3 respondents. Respondents provide appropriate weights for each criterion using the FANP method. To determine the relationship between the degree of interdependence, the ANP technique, which is an extension of the AHP (Analytical Hierarchy Process), is used to determine the relative importance of criteria. ANP was developed to generate priorities for decisions without making assumptions about unidirectional hierarchical relationships between decision levels. The determination of the level of importance of each criterion and sub-criteria refers to Saaty's pairwise comparison scale of 1 to 9 (Saaty, 2008). The value and definition of qualitative opinions from Saaty's comparison scale are 1 (equally important), 3 (more important), 5(important), 7 (Very important), and 9 (Absolutely important).

4. Pairwise Comparison Matrix Creation
   The pairwise comparison matrix describes the influence of each element on each criterion. Decision-makers make comparisons by assessing the level of importance of a criterion. The scale of 1 to 9 used for pairwise comparisons measures the relative importance of one criterion to another.
5. Determining Consistency
   Consistency testing of the pairwise comparison matrix is an important step to ensure the judgments' reliability. The Consistency Ratio (CR) is used as an indicator to assess the extent to which consistency is achieved. Generally, the matrix is considered consistent if the CR value is ≤ 0.1.
6. Intiating supermatrix
   The matrix calculation is based on the supermatrix created by Saaty. However, using ANP allows for the explicit consideration of interactions in the process. Respondents were asked to evaluate all proposed criteria and sub-criteria in pairs. Using fuzzy sets is more compatible with linguistic terms and ambiguities associated with humans. So, using fuzzy numbers to perform long-term predictions and make decisions in real-world situations is better. The geometric mean accurately represents the consensus of experts and is the most widely used in practical applications (Dargi et al., 2014). This study uses the geometric mean as a model for triangular fuzzy numbers. Each number in the pairwise comparison matrix represents the personal views of the decision-makers and is an ambiguous concept. Using fuzzy numbers is the best approach to unify the divided expert comments. The following equations is used to solve FANP according to Dargi et al., (2014) and Galankashi et al., (2015).

$$M_{ij} = (I_{ij}, m_{ij}, u_{ij}) \quad (1)$$

$$I_{ij} = min(B_{ijk}) \quad (2)$$

$$m_{ij} = \sqrt[n]{\prod_{k=1}^{n} B_{ijk}} \quad (3)$$

$$u_{ij} = max(B_{ijk}) \quad (4)$$

where B_{ijk} is denoted by the k-th expert score for comparative importance between two criteria $C_i - C_j$. The algebraic operation of two triangular fuzzy numbers, M_1 and M_2, can be expressed as Equation (5) – (7)

$$M_1 + M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (5)$$

$$M_1 * M_2 = (l_1 * l_2, m_1 * m_2, u_1 * u_2) \quad (6)$$

$$M_1^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right), M_2^{-1} = \left(\frac{1}{u_2}, \frac{1}{m_2}, \frac{1}{l_2}\right) \quad (7)$$

Note that the multiplication of two triangular fuzzy numbers or a convex triangular fuzzy number is no longer a triangular fuzzy number. The equation only represents the approximate real multiplication of two triangular fuzzy numbers and the convex multiplication of one triangular fuzzy number. In the Extent analysis method, the following equation is used for each column of the pairwise matrix, S_k which is a triangular number itself. The fuzzy composite value for the i-th entity is defined in Equation (8).

$$S_k = \sum_{j=1}^{n} M_{kj} * \left[\sum_{i=1}^{m}\sum_{j=1}^{n} M_{ij}\right]^{-1} \quad (8)$$

After the value S_k is calculated, the degree of probability for every two S_k must be determined. Furthermore, if M_1 and M_2 are two triangular fuzzy numbers, the degree of probability for M_1 over M_2 is calculated as below (also written as $M_1 \geq M_2$):

$$\begin{Bmatrix} v(M \geq M) = 1 & if\ M \geq M \\ v(M \geq M) = 0 & if\ L \geq U \\ v(M \geq M) = hgt\ (M \cap M) & otherwise \end{Bmatrix} \quad (9)$$

$$hgt(M_1 \cap M_2) = \frac{u_1 - l_2}{(u_1 - l_2) + (m_2 - m_1)} \quad (10)$$

In this study, we face the large scale of a triangular number from the remaining k number of the triangular number, which is obtained from equation (9):

$$v(M_1 \geq M_2 \ldots . M_i) = v(M_1 \geq M_2), \ldots ., v(M_1 \geq M_i) \quad (11)$$

To calculate the weight index in the pairwise matrix, the formula is as follows

$$W(x_i) = Min\{V(S_i \geq S_k)\} \quad (12)$$
$$k = 1,2,3, \ldots, n \quad k \neq i$$

Therefore, the weight vector is defined as:

$$w(X_i) = [W(C_1), W(C_2), W(C_n)]^T \quad (13)$$

Which is the same value as the non-normal coefficient of fuzzy AHP. Equation (12) produces the normal value of the result of equation (11) and is denoted by W.

$$W_i = \frac{w_i}{\sum w_i} \quad (14)$$

Next, the correlation effect among the criteria is determined. Group members apply pairwise comparisons to measure the mutual impact of criteria on each other. A pairwise comparison matrix is provided for each criterion. The provided pairwise comparison matrix requires the relative impact of the interdependent relationship of criteria. This matrix's main specific normal vector is considered as the column array in matrix B regarding the weight correlation. In matrix B, a zero value for the weights indicates a specific vector, which means the criteria do not correlate with the corresponding others. To combine the previous two steps, we apply equation (16) to calculate the comparative correlation of criteria. The combination in this process means applying the coefficient interdependence weight matrix over the results of the fuzzy AHP process.

$$W_c = B.W \quad (15)$$

7. Selection of the best alternative, after getting the value of each element in the limit matrix, then calculate the value of the element according to the ANP model created. The alternative with the highest global priority is the best.

4. Results and Discussion

Proper supplier selection is a crucial aspect of supply chain management, as it directly impacts final product quality, operational efficiency, and customer satisfaction. The table presented outlines the various criteria and sub-criteria that can be used as a reference in the supplier evaluation and selection process. Network creation will establish criteria and sub-criteria to determine raw materials suppliers for crab processing. To determine the criteria and sub-criteria obtained from interviews and literature studies. The criteria and sub-criteria used for supplier selection are shown in **Table 1.**

Table 1
Criteria and Sub criteria for Supplier Selection

Criteria	Sub criteria	Criteria	Sub criteria
Quality (A)	A1: Product quality compliance with specifications	Environmental Issues (F)	F1: Recycling
	A2: Quality management system document		F2: Energy consumption
Cost (B)	B1: Product unit price		F3: Waste management
	B2: Price stability		F4: Green logistics
	B3: Efforts to increase prices		F5: Green packaging
Service (C)	C1: Compliance with product change requests		F6: Environmental management system certificate
	C2: Compliance with change order requests	Food safety (G)	G1: Food safety team
	C3: Compliance with payment terms change requests		G2: Traceability system
	C4: Provide information and products to deal with emergencies		G3: Food safety management system certificate
	C5: Ease of communication and transparency	Social Responsibility(H)	H1: Child labor
	C6: Warranty policy		H2: Collective bargaining agreement, trade union organization rights
	C7: Bilateral agreements/contracts		H3: Discrimination
Delivery (D)	D1: Compliance with delivery volumes		H4: Working hours
	D2: Adherence to delivery schedule		H5: Wages
	D3: Delivery speed		*H6: Disciplinary practices*
	D4: Delivery vehicle reception		H7: Forced labor
	D5: Compliance with delivery requirement change requests		H8: Social responsibility certificate
Supplier General Perception (E)	E1: Reliability	Occupational Health and Safety (I)	I1: Occupational health and safety team
	E2: Industry Experience		I2: Occupational health and safety management system certificate
	E3: Geographic location		J1: Halal Certification
	E4: Reference		J2: Compliance with Halal Procedures
	E5: Financial capability	Halal perceptive (J)	J3: Supply Chain Transparency
	E6: Number/adequacy of delivery vehicles		J4: Reputation and Trust
	E7: Supplier management system in place		

The relationship between criteria and sub-criteria is shown in **Figure 1** and FANP can effectively manage interdependent relationships among criteria and sub-criteria, which is crucial for accurate decision-making in complex systems (Huang, 2012; Kumru & Kumru, 2015).

After designing criteria and sub-criteria, questionnaires are distributed to experts to assess all criteria and make pairwise comparisons. The linkage of criteria and sub-criteria are the input for the ANP network. **Table 2** is an instance response of pairwise comparison between criteria, and **Table 3** represents the expert's response for pairwise comparison in delivery sub-criteria.

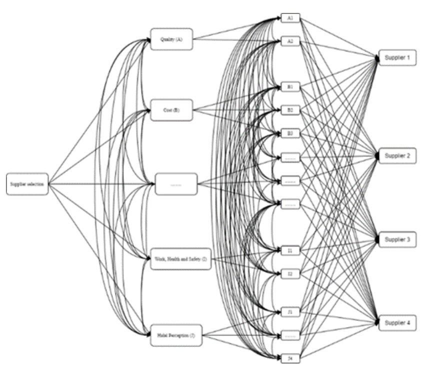

Fig. 1. Illustration of relationship between criteria and sub-criteria for selecting crab suppliers

Table 2
Pairwise comparison matrix between criteria

Criteria	A	B	C	D	E	F	G	H	I	J

A	1	3	3	3	3	3	2	2	2	5
B	0.33	1	3	2	2	2	3	2	2	4
C	0.33	0.33	1	3	2	2	3	2	3	3
D	0.33	0.50	0.33	1	3	2	3	2	3	4
E	0.33	0.50	0.50	0.33	1	3	2	2	2	3
F	0.33	0.50	0.50	0.50	0.33	1	2	2	2	3
G	0.50	0.33	0.33	0.33	0.50	0.50	1	3	3	2
H	0.50	0.50	0.50	0.50	0.50	0.50	0.33	1	3	3
I	0.50	0.50	0.33	0.33	0.50	0.50	0.33	0.33	1	2
J	0.20	0.25	0.33	0.25	0.33	0.33	0.50	0.33	0.50	1

Table 3
Pairwise comparison matrix between delivery sub-criteria in supplier selection

	C1	C2	C3	C4	C5	C6	C7
C1	1	3	3	5	5	3	7
C2	0.33	1	3	3	4	7	7
C3	0.33	0.33	1	2	3	5	5
C4	0.20	0.33	0.50	1	3	3	3
C5	0.20	0.25	0.33	0.33	1	4	4
C6	0.33	0.14	0.20	0.33	0.25	1	3
C7	0.14	0.14	0.20	0.33	0.25	0.33	1

Table 4.
Triangular Fuzzy Number (TFN) for supplier selection Criteria

Criteria	Triangular Fuzzy Number (l, m, u)									
	A	B	C	D	E	F	G	H	I	J
A	(1,1,1)	(1,3,5)	(1,3,5)	(1,3,5)	(1,3,5)	(1,3,5)	(1,2,4)	(1,2,4)	(1,2,4)	(3,5,7)
B	(0.20,0.33,1)	(1,1,1)	(1,3,5)	(1,2,4)	(1,2,4)	(1,2,4)	(1,3,5)	(1,2,4)	(1,2,4)	(2,4,6)
C	(0.20,0.33,1)	(0.20,0.33,1)	(1,1,1)	(1,3,5)	(1,2,4)	(1,2,4)	(1,3,5)	(1,2,4)	(1,3,5)	(1,3,5)
D	(0.20,0.33,1)	(0.25, 0.50, 1)	(0.20,0.33,1)	(1,1,1)	(1,3,5)	(1,2,4)	(1,3,5)	(1,2,4)	(1,3,5)	(2,4,6)
E	(0.20,0.33,1)	(0.25, 0.50, 1)	(0.25,0.5,1)	(0.20, 0.33,1)	(1,1,1)	(1,3,5)	(1,2,4)	(1,2,4)	(1,2,4)	(1,3,5)
F	(0.20,0.33,1)	(0.25, 0.50, 1)	(0.25,0.5,1)	(0.25, 0.5,1)	(0.20, 0.50,1)	(1,1,1)	(1,3,5)	(1,2,4)	(1,2,4)	(1,3,5)
G	(0.25,0.50,1)	(0.20,0.33,1)	(0.20,0.33,1)	(0.20,0.33,1)	(0.25,0.50,1)	(0.20,0.50,1)	(1,1,1)	(1,3,5)	(1,3,5)	(1,2,4)
H	(0.25,0.50,1)	(0.25,0.5,1)	(0.25,0.50,1)	(0.25,0.50,1)	(0.25,0.50,1)	(0.25,0.50,1)	(0.20,0.33,1)	(1,1,1)	(1,3,5)	(1,3,5)
I	(0.25,0.50,1)	(0.25,0.5,1)	(0.20,0.33,1)	(0.20,0.33,1)	(0.25,0.50,1)	(0.25,0.50,1)	(0.20,0.33,1)	(0.20,0.33,1)	(1,1,1)	(1,2,4)
J	(0.14,0.20,0.33)	(0.17,0.25,0.50)	(0.20,0.33,1)	(0.17,0.25,0.5)	(0.20,0.33,1)	(0.20,0.33,1)	(0.25,0.50,1)	(0.20,0.50,1)	(0.25,0.50,1)	(1,1,1)

The weighting results obtained are transformed into a Triangular Fuzzy Number (TFN). The TFN transformation results of the three respondents on the criteria are illustrated in **Table 4,** and an example of the TFN scale in the delivery sub-criteria is presented in **Table 5.**

Table 5.
Triangular Fuzzy Number (TFN) for delivery subcriteria in supplier selection

Subcriteria	Triangular Fuzzy Number (l, m, u)						
	C1	C2	C3	C4	C5	C6	C7
C1	(1,1,1)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)
C2	(0.20,0.33,1)	(1,1,1)	(1,3,5)	(1,3,5)	(2,4,6)	(5,7,9)	(5,7,9)
C3	(0.20,0.33,1)	(0.20,0.33,1)	(1,1,1)	(1,2,4)	(1,3,5)	(3,5,7)	(3,5,7)
C4	(0.14,0.20,0.33)	(0.20,0.33,1)	(0.25,0.50,1)	(1,1,1)	(1,3,5)	(1,3,5)	(1,3,5)
C5	(0.14,0.20,0.33)	(0.17, 0.25, 0.50)	(0.20,0.33,1)	(0.20, 0.33,1)	(1,1,1)	(1,2,4)	(2,4,6)
C6	(0.20,0.33,1)	(0.11,0.14,0.20)	(0.14,0.20,0.33)	(0.20,0.33,1)	(0.17,0.25,0.5)	(1,1,1)	(1,3,5)
C7	(0.11,0.14,0.20)	(0.11,0.14,0.20)	(0.14,0.20,0.33)	(0.20,0.33,1)	(0.17,0.25,0.5)	(0.20,0.33,1)	(1,1,1)

The defuzzification process is carried out to convert the TFN scale into real or firm (crisp) numbers. Defuzzification calculations are carried out for all criteria, sub-criteria, and alternative suppliers available. The results of the criteria defuzzification calculation is presented in **Table** 6 and an instance of the defuzzification calculation of shipping sub-criteria can be seen in **Table 7**.

Table 6
Defuzzification Criteria

Criteria	A	B	C	D	E	F	G	H	I	J
A	1	3	3	3	3	3	2	2	2	5
B	0.42	1	3	2	2	2	3	2	2	4
C	0.42	0.42	1	3	2	2	3	2	3	3
D	0.42	0.54	0.42	1	3	2	3	2	3	4
E	0.42	0.54	0.54	0.42	1	3	2	2	2	3
F	0.42	0.54	0.54	0.54	0.42	1	3	2	2	3
G	0.54	0.42	0.42	0.42	0.54	0.53	1	3	3	2
H	0.54	0.54	0.54	0.54	0.54	0.54	0.42	1	3	3
I	0.54	0.54	0.42	0.42	0.54	0.54	0.42	0.42	1	2
J	0.21	0.28	0.42	0.28	0.42	0.42	0.54	0.42	0.54	1

Table 7
Defuzzification of delivery Sub Criteria

	C1	C2	C3	C4	C5	C6	C7
C1	1	3	3	5	5	3	7
C2	0.42	1	3	3	4	7	7
C3	0.42	0.42	1	2	3	5	5
C4	0.21	0.42	0.54	1	3	3	3
C5	0.21	0.28	0.42	0.42	1	4	4
C6	0.42	0.15	0.21	0.42	0.28	1	3
C7	0.15	0.15	0.21	0.42	0.28	0.42	1

After defuzzification, the matrix is normalized by dividing each element by the total number of its columns, resulting in a matrix ready for eigenvector calculation. The eigenvector is calculated by summing the values in each row of the normalized matrix and dividing it by the number of elements, resulting in a local priority weight for each element. The results of the eigenvector calculation on the criteria can be seen in **Table 8**.

Consistency Ratio (CR) is used to assess the consistency of judgments in a pairwise comparison matrix. CR is calculated by dividing the Consistency Index (CI) by the Random Index (IR), where CI is obtained by calculating the matrix eigenvalues. The matrix is considered consistent if the CR value is ≤ 0.1; if CR > 0.1, the assessment needs to be reviewed to improve consistency. The results of the consistency ratio calculation are shown in **Table 9.**

Table 8
Eigenvector calculation on criteria

Criteria	Eigenvector
A	0.179
B	0.145
C	0.133
D	0.129
E	0.101
F	0.090
G	0.079
H	0.070
I	0.046
J	0.030

Table 9
Consistency value ratio of criteria and sub-criteria.

Name	CR
Criteria	0.090
Sub Criterion A	0.000
Sub Criterion B	0.071
Sub Criterion C	0.094
Sub Criterion D	0.096
Sub Criterion E	0.077
Sub Criterion F	0.081
Sub Criterion G	0.063
Sub Criterion H	0.074
Sub Criterion I	0.000
Sub Criterion J	0.071

In the process of supplier evaluation and selection using the Analytical Network Process (ANP) method, it is important to ensure consistency in the assessment of pairwise comparisons between criteria and sub-criteria. The Consistency Ratio (CR) value obtained indicates the assessment's consistency level. Based on **Table 9** presented, the CR value for the main criterion is 0.09047, which is below the threshold of 0.1, indicating an acceptable level of consistency. The CR values on the sub-criteria quality (0.000), cost (0.071), service (0.094), delivery (0.096), general perception of suppliers (0.077), environmental issues (0.081), social responsibility (0.063), food safety (0.074), and occupational safety (0.000), and halal perspective (0.071) show less than 0.1 so that the opinions of respondents are considered consistent.

An equally important stage is the preparation of the supermatrix. The stages of preparing the supermatrix are (1) Unweighted supermatrix, which is a matrix containing local priority vectors obtained from pairwise comparisons between elements in the system; (2) Weighted Supermatrix, obtained by multiplying each element in the unweighted supermatrix by the corresponding cluster weight, so that each column has a total of one; (3) Limit Supermatrix, produced by iteratively scaling the weighted supermatrix until the values in each column converge and stabilize, reflecting global priorities in a complex system. This step enables a comprehensive analysis of the interactions and dependencies between elements in the FANP, thus supporting more accurate decision-making in complex and uncertain situations.

This supermatrix produce local and global weight values. In the FANP, the local weight value reflects the priority of elements in one group of criteria. In contrast, the global weight value describes the overall priority of elements by considering the interrelationships between criteria in a complex network. The benefit of applying FANP is that it can derive local and global weights simultaneously, streamlining the evaluation process and reducing the complexity of calculations (Huang, 2012). Local and global weights are calculated based on criteria, sub-criteria, and supplier alternatives, as seen in **Table 10.**

Table 10.
Local weights, global weights of criteria, subcriteria

Criteria	Criteria Local Weight	Sub criteria	Local Weight Sub Criteria	Global Weight	Criteria	Criteria Local Weight	Sub criteria	Local Weight Sub Criteria	Global Weight
Alternative	0.04	Supplier 1	0.561	0.224	F	0.079	F1	0.412	0.007
		Supplier 2	0.252	0.101			F2	0.242	0.004
		Supplier 3	0.137	0.055			F3	0.159	0.003
		Supplier 4	0.050	0.020			F4	0.098	0.002
A	0.218	A1	0.833	0.036			F5	0.060	0.001
		A2	0.167	0.007			F6	0.029	0.000
B	0.155	B1	0.614	0.019	G	0.068	G1	0.627	0.009
		B2	0.268	0.008			G2	0.280	0.004
		B3	0.117	0.004			G3	0.094	0.001
C	0.134	C1	0.354	0.010	H	0.063	H1	0.334	0.004
		C2	0.249	0.007			H2	0.223	0.003
		C3	0.148	0.004			H3	0.162	0.002
		C4	0.100	0.003			H4	0.106	0.001
		C5	0.076	0.002			H5	0.074	0.001
		C6	0.047	0.001			H6	0.047	0.001
		C7	0.027	0.001			H7	0.035	0.000
D	0.118	D1	0.469	0.011			H8	0.020	0.000
		D2	0.273	0.006	I	0.045	I1	0.800	0.007
		D3	0.176	0.004			I2	0.200	0.002
		D4	0.049	0.001	J	0.028	J1	0.533	0.003
		D5	0.033	0.001			J2	0.291	0.002
E	0.091	E1	0.339	0.006			J3	0.126	0.001
		E2	0.224	0.004			J4	0.050	0.000
		E3	0.149	0.003					
		E4	0.132	0.002					
		E5	0.072	0.001					
		E6	0.051	0.001					
		E7	0.033	0.001					

The local weight and global weight values for each criterion, sub-criteria, and supplier alternative are used to rank them in order of priority. This process helps identify the most significant elements of decision-making. To determine the priority order based on the global weight value, from highest to lowest. This order indicates the relative priority of each element in the context of the overall decision. By ranking based on local and global weights, decision-makers can objectively determine the priority of criteria, sub-criteria, and suppliers, thereby supporting the selection of optimal suppliers by the needs and objectives of the organization. The results of ranking criteria, sub-criteria, and supplier alternatives in selecting crab suppliers are shown in Table 11.

Table 11
Supplier selection criteria prioritization

Criteria	Global Weight	Priority
Quality	0.087	1
Cost	0.062	2
Services	0.054	3
Shipping	0.047	4
General perception of suppliers	0.036	5
Environmental issues	0.032	6
Food safety	0.027	7
Social responsibility	0.025	8
Work safety	0.018	9
Halal perspective	0.011	10

Table 11 shows that the global weight shows how much influence each criterion has on the final decision based on the relative evaluation between criteria. Quality Criteria (0.087) has the highest global weight. Product quality is the main pillar in supplier selection to maintain the halalness of a product. This criterion covers the product's physical aspects and includes a clean and transparent production process. Companies guarantee consumer satisfaction and maintain brand reputation by ensuring high product quality. Choosing the right supplier based on product quality will help companies build a strong halal supply chain, minimize the risk of contamination, and increase consumer confidence in the products produced. Product quality criteria can affect the entire business process, company reputation, and customer satisfaction (Ismail et al., 2024; Suseno & Suadi, 2021).

The cost criterion is the second priority, with a global weight value of 0.062. Cost correlates with the importance of cost efficiency in business decisions. Cost is a fundamental aspect of almost every economic decision, especially in the context of supplier selection or resource allocation. Competitive raw material prices directly impact a company's profit margin. However, it is important to remember that the lowest price is not always the best indicator. Companies need to consider the total cost of ownership (TCO), which includes purchasing, shipping, storage, and quality costs that may arise if the products received are not up to standard. By considering TCO, companies can make wiser decisions in the long run. In addition to price, other factors such as purchase discounts, payment terms, and transportation costs also need to be considered to optimize procurement costs (Rezaei et al., 2016; Taherdoost & Brard, 2019).

Service criteria are a crucial factor in choosing the right supplier. Service is the third priority, with a global weight value of 0.054. In addition to product quality and competitive prices, the supplier's ability to fulfill change requests, provide timely information, and have a clear warranty policy will greatly affect the continuity of cooperation. By choosing suppliers with excellent service, companies can build long-term mutually beneficial relationships, improve operational efficiency, and ultimately increase customer satisfaction. Factors such as ease of communication, transparency in business, and flexibility in dealing with changes are also important considerations in evaluating the quality of a supplier's service (Cahyono et al., 2023; Sutanto et al., 2023).

Delivery criteria are important in choosing suppliers that can ensure the company's smooth operation. Timeliness of delivery, volume following orders, and speed of delivery are key factors in maintaining the availability of goods and meeting customer needs. In addition, suppliers' flexibility in adjusting delivery requirements and adequate vehicle-receiving facilities will support the efficiency of the logistics process. By thoroughly evaluating delivery performance, companies can select suppliers who can provide reliable and quality delivery services, thereby increasing customer satisfaction and business competitiveness (Martins et al., 2019; Mikusova et al., 2018).

The general perception criteria of suppliers are important factors that are often an initial consideration when choosing a business partner. In addition to technical aspects such as product quality and on-time delivery, the supplier's reputation in the industry, experience, and financial capability are also crucial considerations. Factors such as geographical location, number of delivery vehicles, and the existence of a good supplier management system also affect the market's perception of the supplier's ability to meet customer needs. By considering these criteria, companies can build trust in suppliers and minimize the risks associated with inappropriate partner selection (Martins et al., 2019; Song & Zhuang, 2017).

Environmental criteria are becoming an important consideration in selecting suppliers in an era of increasing concern for sustainability. In addition to product quality and competitive pricing, companies today also consider suppliers' commitment to the environment. Factors such as recycling, energy efficiency, waste management, green logistics, eco-friendly packaging, and environmental management system certification indicate suppliers' seriousness in reducing negative environmental impacts. By choosing environmentally oriented suppliers, companies contribute to the preservation of nature, enhance brand reputation, and attract environmentally conscious consumers (Eslamipoor, 2023).

Food safety is crucial in selecting suppliers, especially for the food and beverage industry. The existence of a competent food safety team, a good traceability system, and food safety management system certifications such as ISO 22000 or HACCP are proof of the supplier's commitment to maintaining product quality and safety. By ensuring that suppliers have implemented good food safety practices, companies can protect consumers from health risks, maintain brand reputation, and meet applicable regulatory requirements. By carefully evaluating these food safety criteria, companies can build safe and reliable supply chains (Almelaih Alfzari & Omain, 2022; Ito et al., 2012; Susilawati et al., 2023).

Social responsibility criteria are important indicators in selecting suppliers that are committed to ethical business practices. In addition to product quality and competitive pricing, companies today also consider how suppliers treat their workers. Factors such as the prohibition of child labor, the existence of fair labor agreements, the cessation of discrimination, reasonable working hours, living wages, and humane disciplinary practices are key considerations. Social responsibility certifications such as SA8000 or SEDEX are tangible proof that suppliers have met international standards regarding workers' rights. By choosing socially responsible suppliers, companies build a good reputation and contribute to improving social conditions in the supply chain (Adawiyyah et al., 2021; Sumarliah et al., 2023).

Occupational health and safety (OHS) criteria are important in selecting suppliers. The presence of a competent OHS team and OHS management system certifications such as ISO 45001 demonstrate the supplier's commitment to creating a safe and healthy working environment for its workers. By choosing suppliers that prioritize OHS, companies not only protect supplier workers from the risk of workplace accidents but also increase productivity and meet applicable legal requirements. In addition, companies can also avoid the risk of poor reputation due to the occurrence of OHS incidents (Schalkwyk et al., n.d.; Türkeş et al., 2024) .

Halal perception criteria are important in selecting suppliers, especially for the food and beverage industry that targets Muslim consumers. The existence of valid halal certification, compliance with documented halal procedures, and transparency in the supply chain are evidence of suppliers' commitment to halal principles. In addition, the reputation and trust that suppliers have built is also an important consideration. By choosing suppliers that meet the criteria for halal perception, companies not only meet the needs of Muslim consumers but also strengthen their brand image and avoid the risk of a bad reputation due to violations of halal principles (Kharrazi et al., 2024; Mabkhot, 2023; Riska Alifia et al., 2023; Santoso & Rachman, 2023). Moreover, applying halal certification for fishery products provides an opportunity for a country to gain socioeconomic benefits (Muneeza & Mustapha, 2021)

The results of the analysis of the ten criteria can be classified. Namely, the criteria of quality, cost, service, and delivery are the basic criteria that are often used in supplier selection. High product quality, competitive costs, good service, and timely delivery are key to business success. General supplier perception criteria are criteria that can measure the supplier's reputation in the market. A good reputation can assure quality and reliability. Environmental issues, food safety, and social responsibility are criteria that reflect the company's concern for sustainability and business ethics. Meanwhile, work safety criteria and halal perspectives are more specific criteria, especially for certain industries. Occupational safety is important to ensure a safe working environment, while the halal perspective is very relevant for the food and beverage industry that targets Muslim consumers.

Table 12 shows the priority of selecting suppliers of crab raw materials based on the criteria and sub-criteria obtained.

Table 12
Supplier alternative prioritization

Alternative	Local weight	Global weight	Priority
Supplier 1	0.561	0.224	1
Supplier 2	0.252	0.101	2
Supplier 3	0.137	0.055	3
Supplier 4	0.049	0.019	4

Based on Table 10 and Table 12, Supplier 1 is the best choice based on the evaluation that has been done. Supplier 1 has the highest global weight, indicating that this supplier best meets the predetermined criteria, such as quality, cost, service, etc. The results of this evaluation can be used as a basis for making decisions in selecting suppliers, but keep in mind that the final decision must also consider other qualitative factors and the broader business context. The results of this evaluation provide a strong foundation for the company to build a long-term partnership with Supplier 1.

The results of this evaluation have significant implications for the procurement strategy of crab raw materials. The company must focus its negotiation efforts and relationship development with Supplier 1. In addition, the company should also diversify risks by maintaining good relationships with other suppliers, albeit with lower priority. Periodic evaluation of the performance of all suppliers is necessary to ensure that the decisions taken remain relevant. In addition, companies should also consider sustainability factors, such as environmentally friendly fishing practices and fishermen's welfare, in selecting and working with suppliers. By doing so, companies can not only fulfill their production needs but also contribute to the sustainability of the fishing industry

5. Conclusion

Priority criteria for selecting suppliers of raw crab materials in the crab processing industry based on global weight values using Fuzzy Analytic Network Process Analysis (FANP) is product quality (0.087), which is the most dominant factor in selecting suppliers of raw crab materials. Furthermore, cost (0.062), service (0.054), and delivery (0.047) criteria also have significant weights. These factors indicate that the company not only focuses on quality but also considers aspects of efficiency, customer satisfaction, and smooth operations. The criteria of environmental issues (0.032), general perception of suppliers (0.036), food safety (0.027), social responsibility (0.025), and occupational safety (0.018) have low weights but should still be considered. This shows that the company is committed to sustainability and business ethics. The halal perspective (0.011) as a specific criterion for the food and beverage industry is also a consideration but with a relatively smaller weight.

Supplier 1, with a weight value of 0.224, is prioritized and recommended for procuring crab raw materials.

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