A Multi-Criteria Decision Framework for Sustainable Supplier Selection in the Blue Swimming Crab Supply Chain

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Abstract

Supplier selection for perishable seafood commodities such as blue swimming crab involves multiple conflicting and interdependent criteria. This study aims to develop an integrated multi-criteria decision framework for sustainable supplier selection in the Indonesian blue swimming crab supply chain by combining DEMATEL, Fuzzy ANP, and Fuzzy TOPSIS. DEMATEL maps causal relationships among criteria, Fuzzy ANP determines priority weights while accounting for interdependencies, and Fuzzy TOPSIS ranks the alternatives while preserving the vagueness of linguistic judgments. Eleven experts at PT XYZ in Gresik evaluated five suppliers. On-time delivery (weight = 0.1186) and competitive price (weight = 0.0994) are the most critical sub-criteria. Rembang ranks first (closeness coefficient = 0.7530), followed by Tuban, Madura, Pasuruan, and Cirebon. Sensitivity analysis confirms the robustness to ±20% weight variation, and rank correlation with 2023-2025 performance data supports the ranking, demonstrating the applicability of the proposed framework for sustainable supplier selection.

Keywords: decision-making, sustainable supplier selection, DEMATEL, fuzzy ANP, fuzzy TOPSIS

1. Introduction

The Indonesian blue swimming crab (Portunus pelagicus) processing industry is a major non-oil export sector, with export volume reaching 29,177 tons in 2022 and a total value of USD 484.23 million [1]. The United States accounts for approximately 80% of Indonesian crab exports, while Indonesia accounts for 44.43% of the global pasteurized crab market [1]. However, the industry faces severe sustainability challenges caused by overfishing, with exploitation rates reaching 0.70-0.76 and the spawning potential ratio (SPR) dropping below 20% across several fishing grounds [2]. These conditions threaten raw material availability, making supplier selection a key decision that goes beyond traditional cost and volume considerations to encompass sustainability, traceability, and regulatory compliance [3].

This supply-chain structure also differs structurally from the seafood chains most often studied. In integrated aquaculture chains, the supplier is a single production unit whose process is documented and controllable. Blue swimming crab is wild-caught by dispersed small-scale fishers and reaches the processor through successive layers of village collectors and mini-plants, so that, in practice, a supplier is a regional aggregation of many independent boats. No single counterparty can fully control either volume or grade; most determinants of final quality are established before the processor takes possession, and several decisive attributes are determined through the judgment of the receiving staff. Because no vertical integration exists, purchasing decisions are the main channel through which a plant passes quality and sustainability requirements upstream [4].

Supplier selection in the perishable seafood industry is inherently complex, and that complexity violates assumptions on which conventional decision models rest. Raw material quality—measured by freshness (capture-to-delivery time < 24 hours), carapace size consistency (12-15 cm), and meat yield (> 20%)—directly affects final product quality and export rejection rates

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[5]. This complexity creates three methodological challenges. First, because grade decays with elapsed time, delivery reliability, freshness, and realized price are causally linked rather than separate dimensions; thus, methods that assume criterion independence, such as AHP, are not designed to model such coupling. Second, supply originates from capture rather than controlled production, so capacity, flexibility, quality, and price interact in both directions, requiring a feedback-based network rather than a hierarchy [6]. Third, several attributes are observable only through linguistic judgment, which a crisp scale cannot represent without discarding its intrinsic imprecision [7].

Multi-criteria decision making (MCDM) methods are widely used in supplier selection research. Haryono et al. [8] report that 68% of studies use hybrid approaches, with DEMATEL-ANP-TOPSIS the most common at 42%, while seafood-specific applications account for less than 5% of research on food supplier selection. To further substantiate this research gap, a structured search was conducted in Scopus and Google Scholar on 10 August 2026 using (“supplier selection” OR “vendor selection”) AND (“seafood” OR “fish” OR “crab” OR “fisheries”) AND (“Indonesia”) for 2015-2026. It returned 14 records, of which 6 were retained after screening [9]; none applied an integrated DEMATEL-Fuzzy ANP-Fuzzy TOPSIS framework to blue swimming crab suppliers.

The choice of this combination warrants justification, given that more recent ranking techniques are available. The three methods address different questions and are complementary rather than interchangeable: DEMATEL identifies which criteria influence others and provides the network structure; Fuzzy ANP converts that structure into weights that account for feedback and interdependence; and Fuzzy TOPSIS ranks the alternatives while retaining the vagueness of the expert ratings. Techniques such as MAIRCA, CODAS, CRADIS, and CoCoSo belong to the third stage alone: each takes a given weight vector, and none derives interdependence, so substituting one would leave the first two stages untouched. They are, moreover, defined on crisp data and would require the fuzzy matrix to be defuzzified before being ranked, thereby discarding the uncertainty the framework carries. Fuzzy TOPSIS was retained because its distance-to-ideal logic extends directly to triangular fuzzy numbers [10], and compensatory distance-based methods with identical weights produce closely correlated orderings [11].

To address this gap, this study develops a decision framework that (1) identifies and validates relevant criteria for crab supplier selection, (2) maps causal relationships among criteria using DEMATEL, (3) computes global priority weights with Fuzzy ANP while accounting for interdependencies, (4) ranks alternative suppliers using Fuzzy TOPSIS, and (5) evaluates robustness through sensitivity analysis and validation against three years of realized supplier performance. The framework is implemented at a crab-processing company in Gresik, Indonesia, to assess five active suppliers.

This study contributes in three ways. Methodologically, it applies an integrated DEMATEL-Fuzzy ANP-Fuzzy TOPSIS framework to a wild-capture seafood chain. The results show that the causal position of a criterion and its weight carry different managerial meanings: a criterion may drive the behavior of others while weakly discriminating among the available alternatives. Empirically, it provides a set of criteria adapted to a perishable capture chain, combining Triple Bottom Line dimensions with perishability-specific attributes. For validation, the ranking is tested against weight perturbation and against three years of operating records rather than reported as a single result. The remainder of the paper is structured as follows: Section 2 describes the framework and methods, Section 3 presents the results and discussion, and Section 4 concludes.

2. Materials and Methods

2.1 Research framework

The research follows a sequential three-phase approach. Phase 1 employs DEMATEL to construct an impact-relation map and identify cause-effect relationships among five main criteria; its output is the outer-dependence structure of the network, not a weight vector. Phase 2 uses Fuzzy ANP to compute global priority weights on that structure. Phase 3 applies Fuzzy TOPSIS to rank the five supplier alternatives using the weights obtained from Phase 2. All weights entering Phase 3 originate from the limit supermatrix of the Fuzzy ANP alone, and no combination or averaging of two weight vectors takes place. A sensitivity analysis is then conducted to test the robustness of the ranking results. Fig. 1 shows the sequential integration of the three methods, followed by sensitivity analysis and validation.

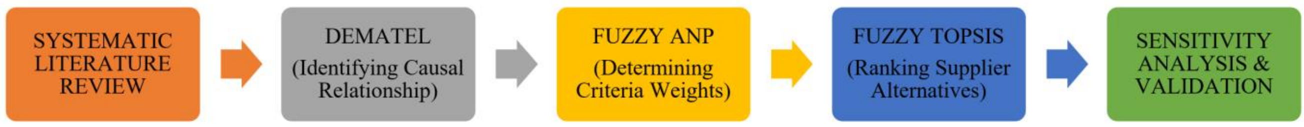

Fig. 1 Research framework of the integrated DEMATEL-Fuzzy ANP-Fuzzy TOPSIS model

2.2 Criteria and sub-criteria

Based on a systematic literature review [7, 8, 12, 13] and expert validation, five main criteria and fifteen sub-criteria were established, as presented in Table 1. They encompass quality (freshness, size consistency, meat yield), price (competitive price, price stability, transportation cost), delivery (on-time delivery, flexibility, supply capacity), service (responsiveness, communication, complaint handling), and sustainability (traceability, certification, responsible fishing practices), reflecting the triple bottom line dimensions [14].

Table 1 Criteria and sub-criteria for supplier selection

Criterion	Code	Sub-Criteria	Definition	Type	Data source
Quality (C1)	C1.1	Freshness	Capture-to-delivery <24 h; cold-chain integrity	Benefit	Goods-receipt records
	C1.2	Size/Consistency	Carapace width 12-15 cm; weight uniformity	Benefit	Incoming inspection log
	C1.3	Meat Yield	Meat percentage >20% of total weight	Benefit	Production record
Price (C2)	C2.1	Competitive Price	Net purchase price per kg relative to market	Cost	Purchase-order records
	C2.2	Price Stability	Price fluctuation within ±10% over 3 months	Benefit	Purchase-order records
	C2.3	Transport Cost	Total logistics cost per kg incl. cooling	Cost	Logistics records
Delivery (C3)	C3.1	On-Time Delivery	Delivery timeliness ≥90%	Benefit	Goods-receipt records
	C3.2	Flexibility	Ability to adjust volume ±20% within 24h	Benefit	Purchase-order records
	C3.3	Supply Capacity	Consistent contract volume fulfillment	Benefit	Purchase-order records
Service (C4)	C4.1	Responsiveness	Response time to queries/complaints < 4 h	Benefit	Correspondence log
	C4.2	Communication	Clarity of documents and information openness	Benefit	Goods-receipt records
	C4.3	Complaint Handling	Problem resolution within 24-48 h	Benefit	Complaint log
Sustainability (C5)	C5.1	Traceability	Product tracking from catch to plant	Benefit	Catch documentation
	C5.2	Certification	MSC/ASC/HACCP or relevant certifications	Benefit	Supplier file
	C5.3	Sustainable Fishing	Compliance with size limits, berried crab ban, and eco-friendly gear	Benefit	Audit record

Table 1 also states the type of each sub-criterion: thirteen are benefit-oriented and two—competitive price (C2.1) and transportation cost (C2.3)—are cost-oriented. For the sub-criteria requiring qualitative assessment, measurable proxies are provided: flexibility is the share of ±20% volume-adjustment requests met within 24 hours, and communication is the share of deliveries with complete documentation.

The qualitative sub-criteria are scored through a periodic supplier audit rather than a single elicitation. The underlying counts are extracted from purchase-order and goods-receipt records for a defined review period, expressed as ratios, and mapped onto the same five-point scale using fixed bands, with 0.90 or above corresponding to Very Good and below 0.50 to Very Poor. This makes the ratings auditable and repeatable without reconvening the panel.

2.3 Expert panel

A purposive sample of 11 experts from PT. XYZ participated. The panel is a complete enumeration of the staff who hold decision-making responsibility for supplier evaluation and possess working knowledge of all five candidate supply regions. Three inclusion criteria were applied: direct operational involvement in supplier evaluation or in the acceptance and processing of incoming raw material; a minimum of one year of service; and functional coverage of all five evaluated dimensions, so that each is represented by respondents whose daily work concerns it. The panel comprised the Plant Manager, Production Manager, Quality Control Manager, Finance and Accounting Manager, Production and QC Supervisors, Document Controller, and Lab Administrator, with each person's functional area, years of experience, and decision domain recorded.

Several safeguards were applied against bias. The instruments were completed individually and without group discussion, and identical written definitions of every criterion accompanied the questionnaire. Every pairwise matrix was accepted only when CR < 0.10, and judgments were aggregated using the geometric mean, reducing the influence of disproportionately high or low judgments. All participants are internal employees with no financial interest in any evaluated supplier; the absence of academic, regulatory, and supplier perspectives is stated as a limitation in Section 4 [15].

2.4 DEMATEL method

DEMATEL was used to analyze direct and indirect influences among the five main criteria. Experts evaluated pairwise influences on a 0-4 scale, and the geometric mean was used to aggregate the individual assessments into the direct-relation matrix Z. The normalized matrix D was computed as $D = Z / s$, where s is the maximum of the row and column totals, and the total-relation matrix T was derived, as expressed by:

$$T = D\left(I - D\right)^{-1} \tag{1}$$

where I is the identity matrix; from T, the row sums (R) and column sums (C) were calculated. Prominence ($R + C$) indicates the overall importance of a criterion, while relation ($R - C$) assigns it to the cause group ($R - C > 0$) or the effect group ($R - C < 0$) [16]. A threshold of $\alpha = 0.5027$, the average of all elements in T, was used to identify the significant relationships that define the ANP network structure.

2.5 Fuzzy ANP

Fuzzy ANP extends the analytic network process with triangular fuzzy numbers (TFNs) to handle uncertainty in pairwise comparisons [17]. Experts used a five-term linguistic scale converted to TFNs: Equal Importance (1, 1, 1), Weakly More Important (1, 3, 5), Fairly More Important (3, 5, 7), Strongly More Important (5, 7, 9), and Absolutely More Important (7, 9, 9). The network was constructed from the significant relationships identified by DEMATEL, with matrices built at three levels: among main criteria, among sub-criteria within each cluster, and for outer dependencies between clusters—the geometric mean was used to aggregate judgments, as the standard operator for reciprocal matrices; no Delphi-type iteration was conducted. Consistency ratios were verified for all matrices, with CR < 0.10 deemed acceptable [18]. The local weights formed the supermatrix, which was normalized and raised to powers until convergence.

2.6 Fuzzy TOPSIS

Fuzzy TOPSIS was used to rank the five supplier alternatives across the 15 sub-criteria [19]. Experts rated each supplier on a five-level linguistic scale converted to TFNs: VP = (0, 0, 2.5), P = (0, 2.5, 5), F = (2.5, 5, 7.5), G = (5, 7.5, 10), VG = (7.5, 10, 10) [20]. Ratings were aggregated by the arithmetic mean of the fuzzy components, since reciprocity does not apply to performance judgments. The decision matrix was then separately normalized for the benefit and cost criteria. For the two cost sub-criteria, the fuzzy positive ideal solution is the element-wise minimum, and the fuzzy negative ideal solution is the element-wise maximum, of the weighted values, preserving the direction of preference expressed on the rating scale.

For benefit criteria, the normalized value is calculated as:

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+} \right) \tag{2}$$

where $u_j^+ = max_i\, u_{ij}$.

For cost criteria, the normalized value is calculated as:

$$\tilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}} \right) \tag{3}$$

where $l_j^- = min_i\, l_{ij}$.

Each normalized value was multiplied by its corresponding global weight from Fuzzy ANP to obtain the weighted normalized matrix, from which the fuzzy positive ideal solution (FPIS, A+) and fuzzy negative ideal solution (FNIS, A−) were determined for each sub-criterion.

The Euclidean distance between two triangular fuzzy numbers $\tilde{A} = (l_1, m_1, u_1)$ and $\tilde{B} = (l_2, m_2, u_2)$ can be calculated as:

$$d(\tilde{A}, \tilde{B}) = \sqrt{\frac{1}{3}\left[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2 \right]} \tag{4}$$

The distances to A+ and A− were obtained by summing across all sub-criteria, and the closeness coefficient (CC) was then computed by:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{5}$$

where a higher *CC* value indicates better overall supplier performance.

2.7 Sensitivity analysis

To test robustness, a sensitivity analysis was conducted by varying the weights of the main criteria by ±20% from the baseline, a magnitude conventionally used in such analyses [21]. Six scenarios were tested: three criteria (Quality, Price, Delivery) × two directions. As reported in Section 3.2, these three clusters jointly carry 96.4% of the aggregate sub-criteria weight, so a ±20% perturbation of any one redistributes 5.1 to 7.8 percentage points of total weight. In contrast, the same perturbation of the two remaining clusters, which together carry 3.6%, would redistribute at most 0.5 percentage points. Perturbing the three dominant clusters is therefore the strongest test this weight structure admits. For each scenario, the calculations were repeated and the rankings compared against the baseline.

2.8 Validation

The model results were validated against historical supplier performance data from PT. XYZ for the period 2023-2025, comprising the on-time delivery rate, the rejection rate, and the supply contribution percentage, to assess whether the model ranking corresponds to realized operational performance [22]. The Spearman rank correlation coefficient quantifies agreement. Because only five alternatives were compared, exact p-values were obtained by enumerating all 120 permutations of the null distribution rather than relying on asymptotic approximations, which may be unreliable at this sample size. The historical records contain incomplete entries for some suppliers and seasonal variation in fishing conditions, and these limitations should be considered when interpreting the validation results.

3. Results and Discussion

3.1 DEMATEL Analysis

The aggregated direct-relation matrix Z and the normalized matrix D were computed as described in Section 2.4. The cause-effect analysis (Table 2) assigns three criteria to the cause group: Quality (C1, R − C = +0.3137), Service (C4, +1.2802), and Sustainability (C5, +0.5268)—while Price (C2, −0.5587) and Delivery (C3, −1.5621) are effect criteria, indicating that decisions on quality, service, and sustainability drive price and delivery performance rather than the reverse.

Table 2 Cause-effect analysis results

Criterion	*R*	*C*	*R*+*C* (Prominence)	*R*-*C* (Relation)	Role
Quality (C1)	3.1146	2.8008	5.9154	+0.3137	Cause
Price (C2)	2.7316	3.2903	6.0218	-0.5587	Effect
Delivery (C3)	1.3452	2.9073	4.2525	-1.5621	Effect
Service (C4)	2.5347	1.2545	3.7892	+1.2802	Cause
Sustainability (C5)	2.8422	2.3154	5.1576	+0.5268	Cause

Service (C4) exhibits the highest relation value (+1.2802), identifying it as the strongest causal driver. This finding may appear counter-intuitive if the criteria are read as independent performance dimensions. Because raw material can lose commercial grade within about one day of landing, supplier responsiveness may determine whether a consignment can be rescheduled or regraded before deterioration occurs. Hence, delivery performance and realized price are partly consequences of that responsiveness rather than independent attributes. Sustainability may similarly influence supplier stability by supporting the long-term availability of the catch base. Price (C2) attains the highest prominence score (6.0218), indicating it is the most interactive criterion, as it both receives and exerts influence. Delivery (C3) records the lowest prominence (4.2525), confirming its status as an outcome determined by other criteria. Using a threshold of α = 0.5027, eleven significant relationships were identified; these are shown as arrows in the impact-relation map of Fig. 2.

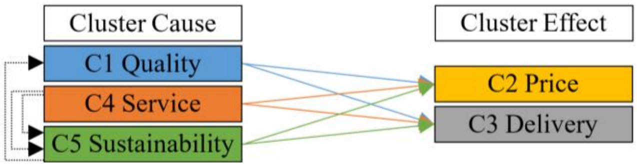

Fig. 2 Impact-relation map of criteria (cause and effect groups)

Fig. 2 depicts the causal relationships among the five main criteria. Solid arrows indicate the primary causal influences from the cause cluster (Quality, Service, and Sustainability) toward the effect cluster (Price and Delivery). Dashed arrows within the cause cluster show notable reciprocal interactions among the driver criteria. Quality and Sustainability exhibit a strong two-way relationship (T = 0.6552 and T = 0.7329, respectively), and Service significantly influences Sustainability (T = 0.5357). This structure is consistent with earlier DEMATEL applications in supplier selection, where quality and service act as drivers and delivery is an outcome [23]. The settings diverge on price: prior work on manufactured inputs treats it as a cause, whereas here the effective price is the per-kilogram price of usable meat and is therefore partly determined by grade at receipt.

3.2 Fuzzy ANP network structure and weights

The network structure was developed in Super Decisions based on the significant relationships identified by DEMATEL. Fig. 3 represents Quality (C1), Service (C4), and Sustainability (C5) as driver nodes with outgoing arrows toward Price (C2) and Delivery (C3), consistent with the DEMATEL results.

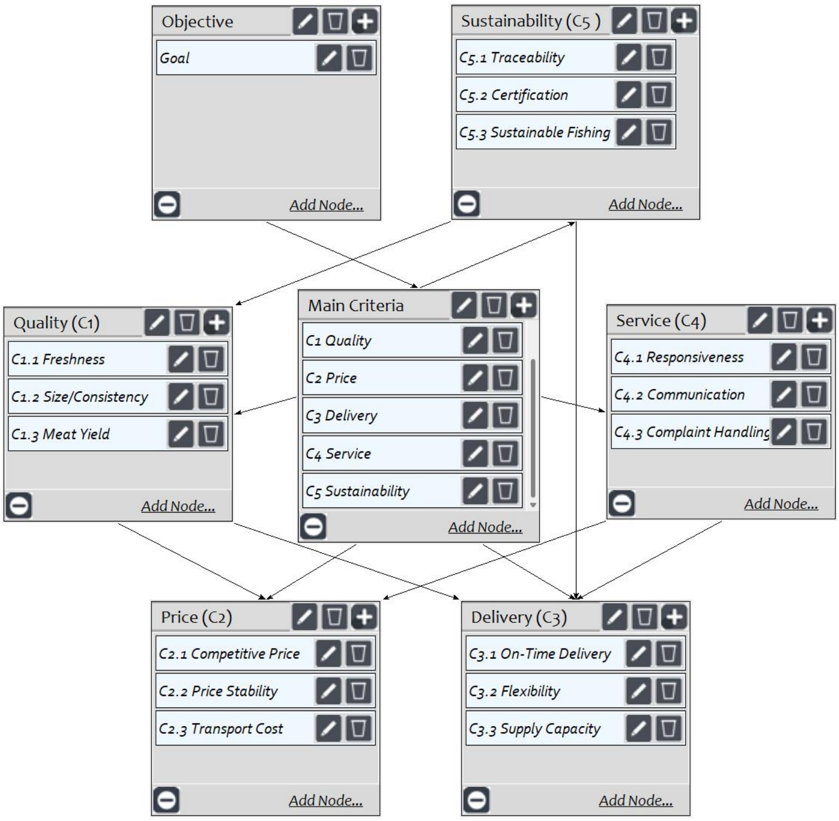

Fig. 3 Fuzzy ANP network structure

The consistency ratios of all pairwise comparison matrices were below 0.10. Table 3 presents the global priority weights obtained from the limit supermatrix. The fifteen sub-criterion weights sum to approximately 0.5857 rather than 1.0 because the five main-criterion nodes also carry limiting weight within the network, absorbing the remaining 0.4143. The vector is rescaled to unity before ranking, a monotone transformation that does not affect the resulting order.

Table 3 Global priority weights from Fuzzy ANP

Sub-Criteria	Code	Global Weight
Freshness	C1.1	0.0963
Size/Consistency	C1.2	0.0358
Meat Yield	C1.3	0.0182
Competitive Price	C2.1	0.0994
Price Stability	C2.2	0.0494
Transport Cost	C2.3	0.0381
On-Time Delivery	C3.1	0.1186
Flexibility	C3.2	0.0606
Supply Capacity	C3.3	0.0482
Responsiveness	C4.1	0.0049
Communication	C4.2	0.0015
Complaint Handling	C4.3	0.0008
Traceability	C5.1	0.0089
Certification	C5.2	0.0032
Sustainable Fishing	C5.3	0.0020

On-Time Delivery (C3.1, weight = 0.1186) is the most critical sub-criterion, highlighting the importance of timely delivery for perishable raw materials. Competitive Price (C2.1, 0.0994) and Freshness (C1.1, 0.0963) rank second and third. At the main-criterion level, Delivery (C3) carries the highest aggregate weight (≈0.2273), followed by Price (C2, ≈0.1869) and Quality (C1, ≈0.1502). Reviews commonly identify these three as the dominant economic dimensions; what differs here is the order within the trio, attributable to perishability, since timeliness determines whether the material is usable at all. Service (C4) and Sustainability (C5) carry markedly lower weights (≈0.0071 and ≈0.0140), in contrast with green supplier selection in agri-food settings where environmental criteria are decisive [24]. The difference may reflect the governance environment rather than a general weakness of the method. These sub-criteria serve as qualifying thresholds that every active supplier already meets, thereby weakly separating the alternatives, even though DEMATEL identifies them as drivers.

3.3 Supplier ranking

The Fuzzy TOPSIS evaluation produced the closeness coefficients and rankings shown in Table 4. Rembang (A4) ranks first (CC = 0.7530), followed by Tuban (A3, 0.6912), Madura (A1, 0.6820), Pasuruan (A2, 0.5504), and Cirebon (A5, 0.1494), as visualized in Fig. 4.

Table 4 Fuzzy TOPSIS results

Supplier	D^+	D^-	CC_i	Rank
Madura (A1)	0.03944	0.08459	0.6820	3
Pasuruan (A2)	0.05549	0.06792	0.5504	4
Tuban (A3)	0.03842	0.08598	0.6912	2
Rembang (A4)	0.03048	0.09292	0.7530	1
Cirebon (A5)	0.10490	0.01842	0.1494	5

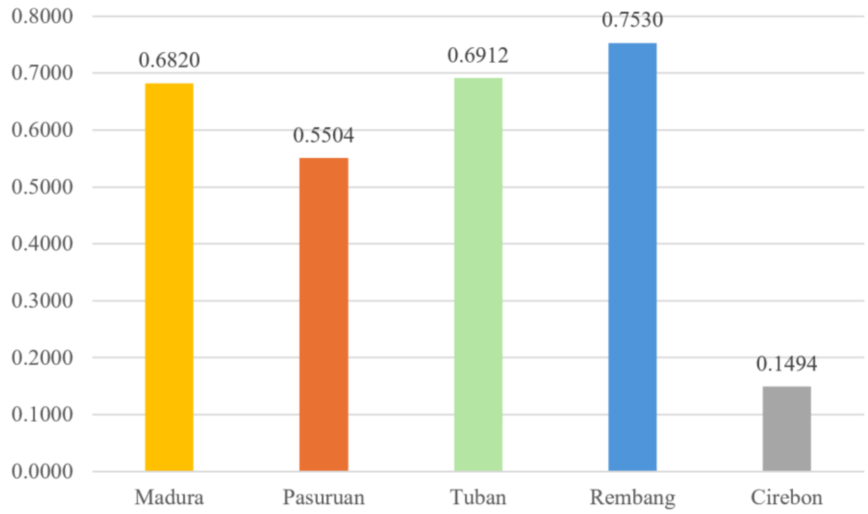

Fig. 4 Closeness coefficient bar chart

Fig. 4 presents the CC values for all five supplier alternatives. The substantial gap between the top four suppliers and Cirebon (A5) indicates significant deficiencies in delivery and price competitiveness, worsened by its considerable distance from the processing plant.

Rembang's top ranking is primarily driven by strong performance in On-Time Delivery (C3.1), Supply Capacity (C3.3), and Meat Yield (C1.3). Tuban's second position reflects uniform performance across the quality and service dimensions. Madura benefits from proximity to the plant, which lowers logistics costs and supports fresher material, although its OTD rate (87.5%) trails the top two. Pasuruan ranks fourth due to a low OTD rate (82.1%) and a high rejection rate (7.12%), while Cirebon ranks last due to poor delivery timeliness (79.6%) and high transportation costs.

3.4 Sensitivity analysis

The sensitivity analysis results are presented in Table 5. Across the six scenarios, the ranking remained stable in all but one case: when the Quality weight was decreased by 20% (Scenario S1−), Madura (A1) and Tuban (A3) exchanged positions. Otherwise, the ranking remained A4 > A3 > A1 > A2 > A5, with Rembang first and Cirebon last throughout. Stability is better read through the margins than the number of scenarios: the leading and trailing alternatives differ by a wide interval in the closeness coefficient (0.7530 against 0.1494), whereas the second and third differ by less than 0.01. Minor variation in expert judgment can therefore exchange ranks two and three, as it does in one scenario, but cannot affect the identity of the preferred or the rejected supplier. The weight vector is itself the aggregate of eleven independent instruments combined by the geometric mean, so individual fluctuations are damped before the weights enter the model.

Table 5 Sensitivity analysis - CC values per scenario

Supplier	Baseline	S1− (−20% C1)	S1+ (+20% C1)	S2− (−20% C2)	S2+ (+20% C2)	S3− (−20% C3)	S3+ (+20% C3)
Madura (A1)	0.6820	0.6798	0.6839	0.6729	0.6902	0.6946	0.6713
Pasuruan (A2)	0.5504	0.5622	0.5399	0.5360	0.5633	0.5536	0.5477
Tuban (A3)	0.6912	0.6782	0.7026	0.6871	0.6948	0.7097	0.6753
Rembang (A4)	0.7530	0.7566	0.7498	0.7706	0.7372	0.7317	0.7712
Cirebon (A5)	0.1494	0.1390	0.1585	0.1579	0.1418	0.1506	0.1484

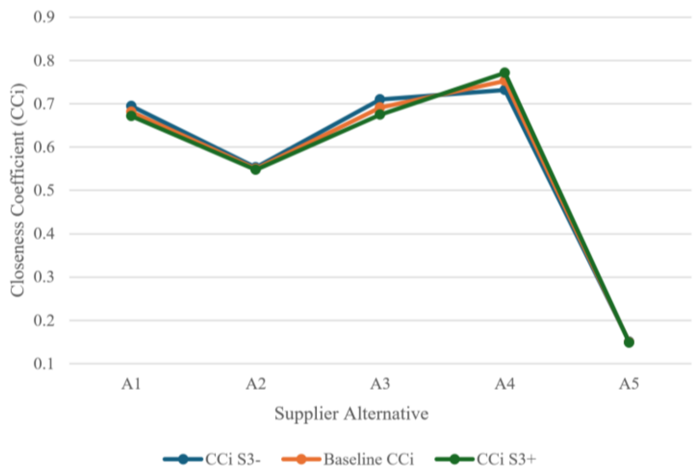

Fig. 5 Sensitivity analysis - CC values under delivery weight variation (scenario S3)

Fig. 5 illustrates the sensitivity of each supplier's CC values to ±20% changes in the weight of the Delivery criterion, under which the ranking remains unchanged. The only rank exchange across the six scenarios occurs elsewhere, in scenario S1−, when the Quality weight is reduced by 20%, and it involves Madura and Tuban. It occurs because Tuban's advantage is concentrated in the quality sub-criteria, so lowering the weight of that dimension reduces the margin separating it from Madura, whose performance is distributed more evenly across the five dimensions. Rembang is never displaced, because its advantage rests on the delivery dimension, which carries the largest aggregate weight. Cirebon remains last throughout, since its deficit is present in all five dimensions rather than concentrated in one, so no reweighting can improve its position. These patterns indicate that the exchange between the middle alternatives reflects performance proximity rather than model instability.

3.5 Validation with historical data

The model ranking was compared against supplier performance records for 2023-2025 (Table 6), with agreement quantified by the Spearman rank correlation and exact p-values. The ranking reproduces the on-time delivery ranking exactly (rho = +1.000, p = 0.008) and the supply contribution ranking with a single adjacent inversion (rho = +0.900, p = 0.042), both significant at the five percent level, providing supporting evidence for the consistency of the model ranking with historical supplier performance.

The rejection rate behaves differently, and this is treated as a finding rather than an anomaly. The correlation is negative and indistinguishable from zero (rho = −0.200, p = 0.658), and the supplier ranked first records the highest rejection rate (9.57%). The contradiction can be explained by the fact that the two indicators are measured at different points: on-time delivery at the plant gate, rejection after sorting and grading. Rembang accounts for the largest volume share and the largest number of consignments, so the cold-chain is loaded most heavily on that lane, and residence time increases with consignment size. Controlled trials on swimming crab report measurable deterioration of muscle quality within the first 18 hours of cold-chain transport [30]. Rejection at receipt is therefore governed principally by conditions in transit rather than by supplier attributes captured in the criteria [9], and the appropriate response is targeted cold-chain investment on that lane rather than reallocation away from the leading supplier. With only five alternatives, the test has limited power, so these correlations corroborate the model rather than establish predictive accuracy.

Table 6 Cross-validation with historical data (2023-2025)

Supplier	Model Rank	OTD Rate (%)	OTD Rank	Reject Rate (%)	Reject Rank	Supply Contribution (%)	Contribution Rank
Rembang (A4)	1	93.2	1	9.57	5	42.13	1
Tuban (A3)	2	91.3	2	5.38	2	21.84	2
Madura (A1)	3	87.5	3	4.75	1	14.73	4
Pasuruan (A2)	4	82.1	4	7.12	4	16.73	3
Cirebon (A5)	5	79.6	5	6.44	3	4.57	5
Spearman rho vs model rank	-	+1.000	-	-0.200	-	+0.900	-
Exact p (one-tailed)	-	0.008	-	0.658	-	0.042	-

3.6 Theoretical and managerial implications

From a theoretical standpoint, this study adds to the MCDM and sustainable supply chain management literature by demonstrating that criteria interdependencies must be modeled explicitly rather than assumed away. The DEMATEL results show that service and sustainability are active drivers shaping price and delivery outcomes, highlighting the limitations of assuming criterion independence in AHP-based studies [25], and that the causal position of a criterion and its weight carry different managerial meanings: a criterion may drive the system while weakly discriminating among the available alternatives.

From a managerial perspective, the framework serves as a practical decision-support tool [26], and its recommendations are differentiated by each supplier's criterion-level profile rather than by the overall score. Rembang should be retained as the primary supplier for its delivery reliability and supply capacity. At the same time, its elevated rejection rate is addressed through pre-cooling at the collection point and in-transit temperature logging on that lane, with the rejection rate as the review metric. Tuban is recommended as a secondary source and Madura as a short-distance backup for peak seasons. For Pasuruan, whose deficits lie in price stability and communication, a fixed-window price agreement and a documented response-time commitment are appropriate. For Cirebon, whose deficit spans all five dimensions, a conditional twelve-month improvement agreement with defined exit criteria is preferable to delisting [27].

These recommendations also connect the procurement decision to the wider governance of the fishery. Because the chain is not vertically integrated, purchase allocation is one of the few instruments through which a processor can influence upstream practice, so the sustainability sub-criteria are best embedded as verifiable requirements linked to minimum size rules, the prohibition on landing berried females, and export-market certification [3].

4. Conclusion

This study developed and applied an integrated DEMATEL-Fuzzy ANP-Fuzzy TOPSIS framework for sustainable supplier selection in the Indonesian blue swimming crab industry, using data from 11 experts at PT. XYZ, Gresik, cross-validated against supplier performance records for 2023-2025. The key findings are summarized as follows:

(1) Quality, Service, and Sustainability are identified as causal drivers. At the same time, Price and Delivery are effect outcomes, which indicates that the causal position of a criterion and its weight carry different managerial meanings.

(2) On-Time Delivery, Competitive Price, and Freshness emerge as the most critical sub-criteria, highlighting the combined importance of reliability, economic competitiveness, and raw-material condition in a perishable seafood chain.

(3) The supplier from Rembang ranks first, followed by Tuban, Madura, Pasuruan, and Cirebon, providing a differentiated basis for supplier allocation.

(4) The ranking is robust to ±20% weight variation, with a single rank change between the second and third positions.

(5) The ranking corresponds closely to realized delivery performance and supply volume, though not to the rejection rate, suggesting that cold-chain integrity in transit may represent an important factor not fully captured by the present criteria.

Several limitations should be noted. The study is a single-company case study of a single commodity, so the weights and ranking are contingent on this processor's location, cost structure, and quality specifications; the framework, criteria hierarchy, and elicitation procedure are transferable, but the weight vector should be rederived for any new setting. An exporter facing mandatory certification would weight sustainability far more heavily than the approximately 2% obtained here. The case company employs all eleven experts, so the weights express the priorities of a single buyer and may understate dimensions that matter to regulators, suppliers, and consumers. The sensitivity analysis assesses the robustness against variation in expert judgment under normal operating conditions; robustness under structural disruption requires further analysis since such an event may alter the feasible set of suppliers and introduce criteria absent under normal operation.

Future work should extend the framework to multiple companies and commodities, incorporate supply chain risk through a scenario-based or stochastic formulation, compare the approach with other MCDM ranking methods [28], and integrate real-time cold-chain monitoring [29].

Conflicts of Interest

The authors declare no conflict of interest.

Statement of Ethical Approval

(a) Statement on the welfare of animals

For this type of study, a statement on animal welfare is not required.

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