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Implementation of the fuzzy analytical hierarchy process method in the determination of fishery shipyard clusters in Indonesia, preliminary study

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ABSTRACT

This research investigates the clustering of fishing shipyards in Aceh and identifies key locations based on fishery shipyard clusters using the fuzzy analytical hierarchy process (fuzzy AHP). Fuzzy AHP, an advancement of the classic AHP method, requires establishing criteria before data processing. The criteria in this study include the area of fishing land, the number of fishing fleets, and the amount of capture fisheries production. The research evaluates several alternative locations across districts and cities in Aceh, including North Aceh Regency, Lhokseumawe City, Bireuen Regency, Pidie Jaya Regency, Pidie Regency, Aceh Besar Regency, Banda Aceh City, Sabang City, West Aceh Regency, Nagan Raya Regency, South Aceh Regency, and Aceh Singkil Regency. Results indicate Aceh Singkil Regency has the highest priority (Cluster A), Bireuen Regency has medium priority (Cluster B), and Aceh Besar Regency or Sabang City has the lowest priority (Cluster C). The fuzzy AHP method ensures realistic and accurate assessments by considering uncertainty and subjectivity in human judgment, providing valuable insights for developing essential shipyard locations in Aceh.

Keywords: fuzzy AHP, fishery shipyard cluster, alternative location.

INTRODUCTION

The potential wealth of Aceh's fishery products is known to be the driving force behind the growth of ships. This is evident through the significant number of fishing fleets in 2020, comprising 17.322 motorboats, 17.231 boats with outboard motors, and 3769 boats without motors. Furthermore, the presence of strategically located shipyards is essential to support the existence of a seaworthy and reliable fishing fleet. Shipyards are facilities situated along the coast or waters, which are dedicated to the construction of new ships as well as the maintenance and repair of existing vessels. Ship maintenance, which makes up around 40% of the industry's operating expenditures, is the second most important component in the marine sector (1). The shipbuilding industry in Aceh still retains a relatively traditional approach, primarily crafting vessels from wood. The craftsmen source the required wood based on customer specifications from factories. These traditional shipyards are typically smaller in size compared to modern variants due to the lack of mass production. Traditional shipbuilding often relies on experience rather than a detailed line plan.

The shipyards in Aceh are confronted with various obstacles, such as inadequate human resources, land, infrastructure, and production capacity. These problems include a lack of organizational structure, an insufficient number of competent people, antiquated technologies, unreliable working hours, a lack of annual production targets, and locations of facilities on less strategically important territory (2). These challenges necessitate further investigations to optimize key indicators that hinder Aceh from achieving a seaworthy and reliable fishing fleet.

Previous research on using the fuzzy AHP method to solve various problems in shipyards has been carried out. Among them, is research on selecting shipyard locations (3), selecting shipyards (4), and selecting technology in shipyards (5). Aside from that, prior shipbuilding research addresses a range of topics, including shipyard comparisons and cost-effective shipbuilding procedures (6), development of systems for stable production in shipyards (7), capacity of shipbuilding (8), Planning and management of shipyards (9), shipyard development (10), suitability of shipyard locations and models (11), and oceanography as an indicator of shipyard development (12). Nevertheless, there has never been any research done on shipyard clustering using the fuzzy AHP approach. Fuzzy set theory and the AHP have been extensively employed in multicriteria decision making processes (MCDM) that use fuzzy numbers to more accurately simulate human judgment (13). This study uses the fuzzy AHP method, which reduces complex decision issues to simpler ones. Furthermore, both quantitative and qualitative data can be used in a single model using the Fuzzy AHP approach (14). Other than that, no other approach to address clustering issues in shipyards has been discovered. For a number of reasons, including reducing wait times, maximizing shipbuilding and repair efficiency, and lowering construction and maintenance periods for both new and old ships, shipyard clustering is crucial. Creating a welcoming and well-organized work environment lowers operating expenses, boosts productivity in overseeing all facilities, and makes it easier to undertake thorough maintenance on the shipyard's infrastructure and facilities. Thus, the purpose of this study is to categorize Aceh's fishing shipyards into clusters and then select the best site for each cluster.

MATERIALS AND METHODS

Research location

This study was carried out in 13 districts and cities in the Aceh Province, which included the cities of Lhokseumawe, Banda Aceh, Sabang, North Aceh, Bireuen, Pidie Jaya, Pidie, Aceh Besar, West Aceh, Nagan Raya, South Aceh, and Aceh Singkil Regencies.

Data collection procedures

This study employed a survey methodology to streamline procedural tasks and gather direct feedback from s representative subset of the population at the incident side. A questionnaire was administered to ascertain participant perspectives on the identified research problem. Data collection encompassed both primary and secondary sources.

Primary data were derived from structured interviews conducted using e questionnaire. The gathered information included respondent opinion on various aspects of capture fisheries, such as the designed land area, fishing fleet size, and production levels. Respondent selection for these interviews followed a purposive sampling approach involving experts, stakeholders from each district and city's maritime and fisheries service, and fishing fleet owners from the respective regions. Secondary data comprised capture fisheries statistics from 2020 to 2022, supplemented by relevant journal articles and books. The collected data was analyzed through a combination of fuzzy hierarchy and analytical processes (15).

Fuzzy AHP numerical analysis

Many multicriteria decision-making problems have been solved by using the AHP approach. But the uncertainty and ambiguity associated with converting an individual's preferences into a numerical value or ratio proved to be too much for conventional AHP methods to handle (16). A popular multi-criteria decision-making method based on pairwise comparisons was the AHP, which was used to establish criteria weights and alternative priorities in an organized way. Owing to the possibility of imprecise subjective judgments during comparison, AHP and the fuzzy set were merged to create fuzzy AHP, also known as FAHP (17). This inquiry used fuzzy AHP data analysis. The present study introduced a novel approach by employing the fuzzy analytic hierarchy process (F-AHP) multi-criteria decision-making model (MCDM) to assess the relative criticality of the identified methods. F-AHP's primary advantage over standard counterpart AHP when comparing two alternatives in a hierarchical analysis was that it allowed respondents to provide imprecise or unclear information (18). Moreover, FAHP had developed into a useful technique for addressing uncertainty, human comprehension and judgment, and other parameters in multi-criteria decision-making (19, 20). This approach could also improve the validity measurement of a single object (21).

The steps of the fuzzy AHP method are described as follows:
1. Develop a hierarchy of problems;
2. Develop a comparison matrix between criteria;
3. Change the weighting results into fuzzy numbers using the triangular fuzzy number scale (Table 1):

The value of fuzzy synthetic extent (Si) determined using the following method in the primary criteria matrix (22):

$$Si = \sum_{j=1}^{m} M_{g^i}^{\,i} \oplus \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g^i}^{\,i}\right]^{-1} \tag{1}$$

For every primary matrix, the inverse sum of the TFN findings could be computed using the following formula:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g^i}^{\,i}\right]^{-1} = \left(\frac{1}{\sum_{j=1}^{m} l_j}, \frac{1}{\sum_{j=1}^{m} m_j}, \frac{1}{\sum_{j=1}^{m} u_j}\right) \tag{2}$$

where: Si – fuzzy synthetic extent, M – triangular fuzzy number (TFN), i – row index, j – column index, $\sum_{j=1}^{m} M_{g^i}^{\,i}$ – total value of every column in every column, beginning with column 1, $\sum_{j=1}^{m} l_j$ – the first column's total value (bottom), $\sum_{j=1}^{m} m_j$ – the first (medium) m columns' total value, $\sum_{j=1}^{m} u_j$ – total in the first (top) column of u.

The priority vectors, or eigenvectors, were used to express the element weights. The vector's priority value was determined using the following formula :

$$V\,(M_2 \geq M_1) = \begin{cases} 1 & if\ m_2 \geq m_2 \\ 0 & if\ l_1 \geq u_2 \\ \dfrac{(l_1 - u_2)}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \tag{3}$$

where: M_l – triangular fuzzy number of each criterion (K_i), V – vector or comparison, m – median value (middle possibility), l – lower value (lowest possibility), u – upper value (top possibility).

With M1 as the benchmark, the values V(M2M1) and V(M1M2) are used to compare the values of M1 and M2. In the event that the M1 value exceeds the M2 value, the result is 1. Using the following formula, if the M1 value is less than the M2 value:

$$V\,(M_2 \geq M_1) = \frac{l_1 - u_2}{((m_2 - u_2) - (m_1 - l_1))} \tag{4}$$

Determine the normalized weight value, or vector weight value (W) – step by step standardizing the equation yielded the following (5):

$$W(d(A_1), d(A_2), \ldots, d(A_n)) \tag{5}$$

where: W – is a non-fuzzy number.

After all the calculations were carried out, a ranking was made based on the most effective criterion and the most necessary option.

Weighting analysis

Weighting using the fuzzy AHP method involves mapping comparison values between criteria. The first step is determining the comparison value between each pair of criteria, as shown in Table 2. These values indicate the relative importance of one criterion over another. Next, these values are converted into a fuzzy pairwise comparison matrix (Table 3), which structures the comparisons according to the fuzzy AHP approach. This matrix allows for more realistic assessments and manages uncertainty in decision-making. It helps calculate criteria weights accurately, determining the

Table 1. Fuzzy AHP pairwise comparison scale

Relative importance of two sub elements	Fuzzy triangular number	Fuzzy reciprocal value
Equally important	1 1 1	1, 1, 1
Middle value between 1 and 3	1 2 3	1/3, 1/2, 1
Little important	2 3 4	1/4, 1/3, 1/2
Middle value between 3 and 5	3 4 5	1/5, 1/4, 1/3
Important	4 5 6	1/6, 1/5, 1/4
Middle value between 5 and 7	5 6 7	1/7, 1/6, 1/5
Very important	6 7 8	1/8, 1/7, 1/6
Middle value between 7 and 9	7 8 9	1/9, 1/8, 1/9
Absolutely important	9 9 9	1/9, 1/9, 1/9

Table 2. Comparison values between criteria

Criterion	Capture fisheries land	The number of fishing fleets	Total capture fisheries production
Capture fisheries land	1	3	5
The number of fishing fleets	0	1	7
Total capture fisheries production	0	0	1

priority of alternatives. This process ensures that criteria weighting is more objective and reflective of real conditions, making decision results more reliable. After mapping comparison values between criteria and converting them into a fuzzy pairwise comparison matrix, the next step is to calculate the geometric mean value for each criterion. This provides a relative weight for each criterion, detailed in Table 4. Table 5 presents in-depth calculation results, including triangular fuzzy numbers (TFN) to represent uncertainty and variation in criteria assessment.

Table 5 also shows fuzzy synthesis calculations, integrating TFN values for each criterion to produce weights reflecting their overall importance. Vector weight calculations, derived from fuzzy synthesis, indicate the relative priority of each criterion. These vector weights are then normalized so that the total equals one, ensuring consistency for comparison and further analysis.

The normalization process, shown in Table 5, ensures all weights are on a consistent scale, allowing for more accurate and informed decisions. Overall, Tables 4 and 5 provide detailed information on the fuzzy AHP weighting process, from geometric mean calculation to fuzzy synthesis, vector weights, and normalization, forming a strong basis for objective decision-making.

After comparing the criteria, the next step is to evaluate each alternative against these criteria, as shown in Table 6. This involves assessing various potential shipyard cluster locations based on criteria like the area of capture fisheries land,

Table 3. Conversion of comparison values to fuzzy pairwise matrices

Criterion	Capture fisheries land			The number of fishing fleets			Total capture fisheries production		
	l	m	u	l	m	u	l	m	u
Capture fisheries land	1	1	1	1	1.5	2	2	2.5	3
The number of fishing fleets	0.5	0.667	1	1	1	1	3	3.5	4
Total capture fisheries production	0.33	0.4	0.5	0.25	0.286	0.333	1	1	1

Table 4. The geometric mean for each criterion

Criterion	Capture fisheries land			The number of fishing fleets			Total capture fisheries production		
	l	m	u	l	m	u	l	m	u
Capture fisheries land	1	1	1	0.5	0.66	1	0.33	0.4	0.5
The number of fishing fleets	1	1.5	2	1	1	1	0.25	0.28	0.33
Total capture fisheries production	2	2.5	3	3	3,5	4	1	1	1

Table 5. Calculation results for several criteria

Criterion	Triangular fuzzy number			Fuzzy synthesis			Vector weight	Normalization	
	l	m	u	l	m	u	Value	Min	Value
Capture fisheries land	4	5	6	0.289	0.422	0.595	0.951	0.95	0.947
The number of fishing fleets	4.5	5.167	6	0.325	0.436	0.595	1.1	1	0.996
Total capture fisheries production	1.583	1.686	1.833	0.114	0.142	0.182	-0.94	-0.94	-0.943
Total	10.08	11.85	13.83						

the number of fishing fleets, and capture fisheries production. By doing so, we can identify each location's strengths and weaknesses. Next, we calculate the weight of each criterion for the alternatives, as seen in Table 7. This determines the influence of each criterion on the selection of locations, indicating the relative priority based on how well they meet the criteria. The location with the highest weight is considered the most suitable for shipyard development. This process ensures decisions are based on comprehensive and objective analysis, minimizing subjectivity and bias. The weight calculations provide a strong basis for determining strategic shipyard locations, supporting the effective and efficient development of the fishing industry by utilizing the best potential sites.

The final stage of this calculation is to determine the ranking order for each analyzed alternative based on the weights obtained in Table 7. This ranking identifies the most optimal and suitable alternatives for the research objectives by sorting the weight values from highest to lowest. The alternative with the highest weight is ranked first, indicating it is the most suitable for becoming a shipyard cluster, while lower weights indicate lesser suitability.

The ranking results are presented in Table 8, clearly showing the relative position of each alternative based on the calculated weights. This helps identify the top alternatives for consideration in the final decision. The ranking provides an objective view of each alternative's performance and aids in transparent decision-making.

Table 6. Conversion of criteria weight values for each alternative

Alternative	Capture fisheries land	The number of fishing fleets	Total capture fisheries production
Banda Aceh	0.75	0.75	0.75
Aceh Besar	1.00	0.5	0.5
Sabang	1.00	0.5	0.5
Aceh Barat	0.25	0.25	0.25
Aceh Selatan	1.00	0.75	1.00
Aceh Singkil	1.00	1.00	0.25
Pidie	0.25	0.5	0.75
Pidie Jaya	0.75	0.75	1.00
Bireuen	0.5	1.00	0.5
Lhokseumawe	0.5	1.00	1.00
Aceh Utara	0.75	0.25	0.75
Aceh Timur	0.25	1.00	1.00
Nagan Raya	0.5	0.25	0.25

Table 7. Calculation of weighted criteria values for each alternative

Alternative	Capture fisheries land	The number of fishing fleets	Total capture fisheries production	Value
Banda Aceh	0.710	0.747	-0.707	0.75
Aceh Besar	0.947	0.498	-0.471	0.973
Sabang	0.947	0.498	-0.471	0.973
Aceh Barat	0.236	0.249	-0.235	0.25
Aceh Selatan	0.947	0.747	-0.943	0.751
Aceh Singkil	0.947	0.996	-0.235	1.707
Pidie	0.236	0.498	-0.707	0.027
Pidie Jaya	0.710	0.747	-0.943	0.514
Bireuen	0.473	0.996	-0471	0.998
Lhokseumawe	0.473	0.996	-0.943	0.526
Aceh Utara	0.710	0.249	-0.707	0.252
Aceh Timur	0.236	0.996	-0.943	0.289
Nagan Raya	0.473	0.249	-0.235	0.486

Decision-makers can focus on top-ranked alternatives, allocate resources effectively, and plan strategic steps for shipyard development. The ranking results can also be used for further discussion and validation with experts and stakeholders, ensuring decisions are based on comprehensive considerations and consensus. Overall, determining the ranking order is crucial for making the best choice aligned with the set objectives and criteria. Table 8 provides clear guidance for effective and efficient decision-making in selecting the optimal shipyard cluster locations.

Table 8. Ranking order of alternatives

Alternative	Value
Aceh singkil	1.707
Bireuen	0.998
Aceh Besar	0.973
Sabang	0.973
Aceh Selatan	0.751
Banda Aceh	0.75
Lhokseumawe	0.526
Pidie Jaya	0.514
Nagan Raya	0.486
Aceh Timur	0.289
Aceh Utara	0.252
Aceh Barat	0.25
Pidie	0.027

RESULTS AND DISCUSSION

Selecting a location for a shipyard is a very important thing to do before building a shipyard to support fishing activities. Choosing the right location can increase operational efficiency and support the sustainability of the fishing industry. Based on the research results carried out by implementing the fuzzy AHP approach for selecting shipyard locations and clustering shipyards, three locations were obtained with high ranking weight values, namely Aceh Singkil, Bireuen, and Aceh Besar (Figure 1).

The costs involved in establishing a modern shipbuilding business are high. For this reason, it is imperative that the amenities offered at this shipyard be prepared as thoroughly as possible. from the choice of location to the movement of materials. The shipyard's site needs to be near a port to make material supply easier. It also needs to be close to human resources, as both will have a significant impact on the shipyard's performance. A number of factors, including ship size, docking expenses, effective and efficient operation, minimal maintenance costs, and ease of use, are taken into consideration when choosing a ship docking type (23).

The utilization of technology in the shipbuilding sector greatly aids in streamlining the production process (24). Skilled manpower is needed to

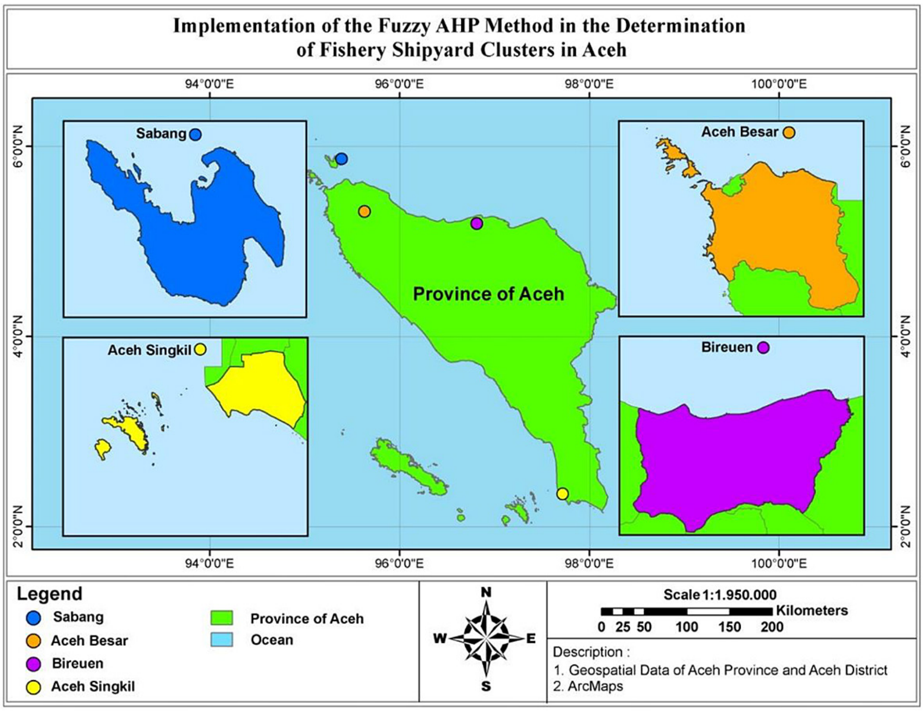

Figure 1. Location map for the shipyard cluster

finish shipbuilding in the quickly expanding shipbuilding industry. A company's ability to meet its production targets depends heavily on labor. The availability of natural and human resources is crucial for the sustainability of shipbuilding, in addition to funding for the construction of infrastructure like shipyards (25). A shipyard is a location that is necessary to be near the coast or seaside for the construction or repair of ships. Shipyards can be classified into a number of categories according on the work they perform: First, a unique shipyard that serves as a unique facility for building and repairing new ships and creating them in accordance with owner directives. Secondly, a ship repair and maintenance yard that specializes in ship maintenance. Third, a multipurpose shipyard that constructs, maintains, repairs, and modifies ships (26).

The production complexity of the shipbuilding sector nowadays is fairly significant. Large ships are produced annually by the modern shipbuilding industry, thus sufficient facilities are required (27). According to (28) Shipbuilding productivity growth requires concerted efforts to boost shipyard efficiency, with a three-pronged strategy. First, using technology to reduce the number of jobs at shipyards or streamlining the production process to boost productivity. Second, creating and utilizing specialized production techniques and cutting-edge production technologies to maximize the efficiency of the production process. Third, cutting overall expenses and improving the effectiveness of shipyard management operations in order to lower shipyard expenditures.

Shipbuilding and ship repair comprise the two primary segments of the maritime industry. A number of procedures are always needed for both of these tasks, including labor, material, infrastructure, cost, and working environment considerations. These procedures also entail contacts between the shipyard's departments, auxiliary industries, outside organizations, and the surrounding environment (29). In the shipbuilding sector, expenses, processing times, and output quality are critical factors (1). In planning a shipyard, location selection cannot be done without careful calculations and must meet the following factors: water conditions, availability of raw materials, transportation, electricity, consumer/market share, worker/human resources and the environment (30).

Fuzzy AHP was chosen as the method because the AHP approach has various advantages, such as ease of use, the ability to organize problems systematically, and the ability to calculate criteria weights and alternative priorities. The fuzzy AHP method, which applies fuzzy numbers to AHP, maintains these advantages and is also able to handle uncertainty during the decision-making process (17). Prior to executing fuzzy AHP, it's critical to clearly characterize the issue that has to be resolved. It is vital to create a hierarchical structure model in order to accomplish this. The Fuzzy AHP hierarchical model typically consists of three levels: the top level specifies the assessment's general objective, the second level specifies its criteria, and the bottom level offers a number of ways to reach the objective (31).

Because AHP is a subjective process in and of itself, the fuzzy AHP technique is just a partial answer because it relies on experts to assess the importance (or priority) of criteria in a possibly biased manner. It is impossible to totally exclude decision makers' subjectivity. Nonetheless, fuzzy AHP makes sure that subjectivity's impact on the optimal solution can be reduced (32). There are four primary steps to the fuzzy AHP algorithm. First, a hierarchy comprising objectives, criteria, and subcriteria is constructed. Each criterion is thoroughly evaluated before being converted into a subcriteria. Designing and evaluating five different BAPV system designs for the pilot project is the second step. The final step involves using a questionnaire and the assistance of specialists to evaluate the hierarchy. Expert comments on the numerical scale comparison of criteria, subcriteria, and alternatives are required. The last step is calculating the expert opinions using fuzzy numbers after getting their input (33). The selected solutions that provide innovation to the current inquiry are evaluated for relative criticality using the fuzzy analytic hierarchy process (F-AHP) multi-criteria decision making model (MCDM). Experts can use fuzzy ratios instead of exact ratios because F-AHP is founded on the core AHP paradigm. F-AHP has a basic advantage over its traditional cousin, AHP, in that respondents can provide unclear information or imprecise replies when comparing two alternatives in a hierarchical analysis. AHP's subjective evaluation, selection, and preference of decision makers often do not take into account the diversity of human thought patterns. Moreover, the main use of the AHP approach in near-sharp (non-fuzzy) choice applications may lead to an uneven evaluation scale. Consequently, fuzzy AHP – a fuzzy extension of AHP – was created to address the hierarchical fuzzy problem in order to prevent such performance hazards (18). Furthermore, in multi-criteria decision making, FAHP has proven to be an efficient way to address human comprehension and judgment, ambiguity, and many factors (19,20), Fuzzy AHP approach can improve validity measurement of a single object (21).

Efforts to cluster shipyards were carried out by mapping the areas with the highest ranking as cluster A (Aceh Singkil), cluster B (Bireuen), and cluster C (Aceh Besar or Sabang). In cluster C, there are two regions because they have equal alternative ranking values. This cluster determination was also carried out by considering several basic criteria for clustering shipyards in Aceh. The selected criteria include the area of capture fisheries land, the number of fishing fleets, and the amount of capture fisheries production. However, the criteria chosen cannot claim that the results obtained are an absolute decision. The results of location selection and cluster determination using the Fuzzy AHP method are considered very logical for the current conditions. However, if assessed in the future, the results of this decision may change according to developments and the criteria set.

This research highlights the importance of strategic location selection for shipyards and how the Fuzzy AHP approach can provide more accurate and realistic solutions. By considering various criteria and involving experts in the assessment process, this method is able to overcome uncertainties and biases that may arise. This research also shows that the fuzzy AHP method can be applied flexibly, adapting to changes that occur in the future, so that the results obtained remain relevant and reliable.

CONCLUSIONS

Essential locations for determining shipyard clusters have been identified in this research. Three main clusters that have been determined, namely Aceh Singkil as Cluster A, Bireuen as Cluster B, and Aceh Besar or Sabang as Cluster C. Aceh Singkil was chosen as Cluster A because it has the highest ranking based on predetermined criteria. Bireuen, is in the middle ranking and designated as Cluster B. Meanwhile Aceh Besar or Sabang, which has a balanced ranking value, is placed in Cluster C. Although this research has identified the locations of these clusters, further research is still needed to evaluate the technical aspects and economics of the shipyard cluster in Aceh. This further research is important to ensure that each cluster that has been determined is optimal in terms of location and efficient in terms of operations and costs. Technical aspects that need further research include existing infrastructure, production capabilities, and technology that will be used in each cluster. In addition, the economic analysis must consider investment costs, potential profits, and the economic impact on the surrounding area. With further research, it is hoped that a more comprehensive picture can be obtained regarding the sustainability and effectiveness of shipyard clustering in Aceh. This will help decision makers in designing better policies and support the development of the fishing industry in Aceh as a whole.

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