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Spatial decision-making model for priority development of Indonesia coast guard stations

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Abstract
Indonesia Coast Guard (IDNCG) is a paramilitary agency in charge of security and safety patrols in Indonesian maritime waters. The research objective is to develop priorities for the development of 35 IDNCG stations *are expected to be constructed within 3 years and are considered priority project to face the increasing threats at sea. However, there is presently no system to provide support for the scientific solutions to prioritize station development despite the need for immediate decisions. This research was used to design model for determining station development priorities using the integration method of Geographic Information Systems (GIS), Analytical Hierarchy Process (AHP), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). GIS was used as an effective tool for identifying and taking measurements in certain areas. Meanwhile, multi-criteria decision-making (MCDM) methods such as AHP and TOPSIS provided structural and pairwise quantification, as well as comparisons between elements and criteria for ranking station construction priorities. The most suitable alternative stations to be prioritized were determined by integrating the three methods which were classified as cost-effective for decision-making. Model was based on four criteria, including distance to Archipelagic Sea Lanes (ASL), Distance to the port, vulnerability coverage, and vessel density coverage. Stations were ranked based on a three-year development plan. The location ranking is then expressed in the form of a map to be used by policy makers in determining priorities for developing IDNCG Stations which will have an impact on increasing security and safety in Indonesian waters.*

Keywords:
Indonesia Coast Guard (IDNCG);
Decision;
GIS;
AHP;
TOPSIS:

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INTRODUCTION

Indonesia is one of the largest archipelagic countries in the world covering an estimated area of 7.81 million km^2 with 17,499 islands. The analysis of the region shows that 3.25 million km^2 is ocean and 2.55 million km^2 is the Exclusive Economic Zone (EEZ) while only approximately 2.01 million km^2 is land. With so much potential that can be explored from Indonesia's territorial waters, of course this will have an inevitable impact, namely the emergence of threats to Indonesia's national interests, especially in the maritime sector. Threats can come from various sources, both from certain countries and from non-state actors, with varying threat intensity. With the reality of the emergence of various types of threats, Indonesia needs to respond with adequate maritime security capabilities and strength, so that these various threats can be reduced to a minimum. However, we are all aware that implementing maritime security is not easy, because it requires systematic structuring or governance, as well as good regulation or management. The importance of maritime security in supporting the concept of Indonesia as the

World Maritime Axis (WMA) which is focused on five main pillars, namely: (i) Rebuilding Indonesia's maritime culture; (ii) Protecting marine resources and creating marine food sovereignty by placing fishermen as the main pillar; (iii) Giving priority to infrastructure development and maritime connectivity by building sea highways, deep seaports, logistics, shipping industry and maritime tourism; (iv) Implementing maritime diplomacy, through proposals to increase cooperation in the maritime sector and efforts to deal with sources of conflict, such as fishing theft, violations of sovereignty, territorial disputes, piracy and marine pollution with an emphasis that the sea must unite various nations and countries and not separate them; and (v) Building maritime power as a form of responsibility for maintaining shipping safety and maritime security.

The WMA focuses on Indonesia's national development activities at sea, strengthening and developing maritime connectivity [1]. This has led to development of 14 stations supported by early static and dynamic detection technologies by IDNCG as part of the Early Warning System (EWS) for marine security and safety [2]. The strategic plan of IDNCG for 2020-2024 is to build 35 stations in three years. The determination of stations was based on a survey conducted by the Land Task Force team to fill the monitoring gaps at locations with heavy ship traffic. One of the inputs suggested for the operation was the ability to receive and analyze all events occurring at sea based on the relay time which was measured in minutes. Moreover, the relay time was explained as the time to convey verified incidents at sea in order to provide immediate response by other sub-organizations and related stakeholders. This is necessary because the management of a safe sea traffic system is important in terms of economic competition and national integrity. However, the process required the existence of complete facilities constructed with large costs to ensure easy accessibility of resources.

Stations in the strategic plan are state facilities expected to be placed on the outermost outpost of Indonesian marine security and safety. Several efforts have been made from 2020 up to the present time to strengthen the role of coast guards by determine the appropriate locations for these stations to be constructed in stages for a period of 3 years. The prioritization of stations to be developed has been based on expert judgment such as the directions and policies implemented by the leadership. This shows there is presently no scientifically proven decision support system. Therefore, the urgency of this research is to overcome decision-making problems related to determining priorities for IDNCG stations to be developed which will contribute directly to support national maritime security and safety.

A spatial decision model was proposed through the integration of the Geographic Information System (GIS), Analytic Hierarchy Process (AHP), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The purpose was to assist policymakers in ranking, describing, classifying, and grouping alternative stations. This was expected to be based on some problems such as location selection, resource allocation, network routing, location-allocation, and service coverage [3]. A spatial decision model "can translate science into policy and vice versa and ultimately integrate the exploration of ideas with participatory and direct evaluation" [4]. The problem-solving method used was based on previous research conducted on location selection through the application of GIS and Multiple Criteria Decision Making (MCDM) procedures. It is important to state that GIS is a set of computer hardware, software, and geographic data designed to efficiently acquire, store, modify, manage, analyze, and show all forms of geographic information [5]. However, the key challenges around the uptake of spatial decision-making are data issues, challenges of accessibility, availability, accuracy, consistency, manageability, and integration of data [6]. GIS is normally used to solve spatial data measurement problems. This shows the possibility of using the method to map the distance between stations and areas prone to maritime security and safety, determine the density of passing ships, and monitor the range of each station. Meanwhile, AHP method was used to determine the weight of selection criteria for each station. TOPSIS was applied to evaluate priority ranking of stations. The aim was to ensure decision makers select the most appropriate priorities to avoid wasting a lot of time and money [7]. Moreover, this research was expected to serve as input for IDNCG's top management in the process of deciding on stations to be prioritized for development. The intention is to ensure empty gaps identified at choke points are filled as soon as possible in order to provide benefits for sea users in particular and the Indonesian nation in general.

The determination of the best alternative location to develop some facilities often requires considering several criteria [1]. This has led to the implementation of GIS in several cases to obtain geographic information needed for spatial analysis to offer in-depth assessments such as the application to determine the suitability locations. GIS was used in this research to solve the problem of measuring spatial data with a focus on the distance from stations to the Indonesian

Archipelagic Sea Lanes (ASL) and ports, coverage of vulnerabilities and density of passing ships.

The integration of GIS and MCDM is considered an ideal method to solve problems containing several factors. These include the evaluation of spatial suitability of wind farms sites [8][9][10], to assess drought risk [11] and determination of shipyard locations [12]. Moreover, GIS, AHP, and TOPSIS had been previously combined to assess the danger of flooding in Vietnam [13], rank potential station locations for expanding the bicycle sharing system [14], evaluate suitable locations for development of industrial areas [15], selection of multipurpose utility tunnel, [16] and solving ammunition distribution network design problem [17]. The combination of these methods was considered appropriate to analyze the selection of alternatives in development priorities of the IDNCG stations.

This research was used to develop a priority selection model for IDNCG station development. The model is achieved using GIS for measuring spatial data while MCDM for decision making through theories, processes and analytical methods related to aspects of uncertainty, dynamics and multi-criteria. The combination of the two methods has received more attention in recent years due to its ability to provide more precise and practical results [14]. In addition, the research objective is to develop a spatial decision-making model to prioritize the construction of IDNCG Stations which will address the increasing threats in Indonesian seas.

METHOD

The three main methods used in conducting this research were GIS, AHP, and TOPSIS [18] [19], [20]. These are explained further as follows:

Spatial data measurement using GIS

The term GIS is generally understood as a special type of information system that works with information related to positional or geographical characteristics. The concept was further explained by ESRI company as "a collection of computer hardware, software and geographic data designed to obtain, store, modify, manage, analyze and show all forms of geographic information efficiently" [5]. Some of the characteristics of GIS are stated as follows:

a) A sub-system for input to accommodate and process spatial data from different sources such as contour maps and elevation points.

b) A sub-system for storing and recalling which allows spatial data to be updated, recalled, and edited.

c) A sub-system for analysis to determine data roles, separation and grouping, estimate parameters and constraints, and perform modeling functions.

d) A sub-system for reporting which can present part or all of the database in the form of maps, tables, and graphics.

Calculating criteria weighting using the AHP

AHP is a method that simplifies complex and unstructured problems through a series of pairwise comparisons by arranging decision criteria in a hierarchical structure and connecting them with weights related to the contribution made to the desired goal [21]. It was popularized by Thomas L. Saaty around the 1970s followed by a partnership with Ernest Forman around 1983 to develop Expert Choice software. The process led to the extensive research and refinement of AHP since then [22].

The method is considered fairly accurate in measuring the weight of criteria for decision. Moreover, the process of estimating the relative magnitude of factors through pairwise comparisons requires the experience of experts. This is usually achieved by allowing each respondent to compare the relative importance of each pair of items using a specially designed questionnaire. However, AHP has some limitations which include ineffectiveness when used in a case with many criteria and alternatives Another is the dependence on the main input which is experts, leading to subjectivity of the results. Furthermore, AHP is a mathematical method without statistical tests and this shows a lack of confidence limit to determine the truth of model formed. The limitation shows the need to include other methods in the process to produce more effective results. The stages of implementing AHP are stated as follows:

a) Develop a hierarchical structure,
b) Prepare a pairwise comparison matrix of criteria and alternatives,
c) Conduct consistency tests and,
d) Determine the weight of the criterion indicators.

Determine development priority preferences using the TOPSIS

TOPSIS is a MCDM method compiled by Yoon and Hwang in 1981. It was developed further by Yoon around 1987 and Hwang, Lai, and Liu in 1993. The scheme requires the selected alternative to be at the farthest distance from the negative ideal solution and the closest to the positive. This is normally achieved from a geometric perspective using Euclidean distance to determine the relative closeness of an alternative to the optimal solution. Moreover, TOPSIS has been widely used in several research to practically solve complex decision-making problems [23]. The stages often involved are stated as follows:

a) Develop a decision matrix,
b) Prepare a normalized decision matrix,
c) Formulate a weighted normalized decision matrix,
d) Determine the positive and negative ideal solution matrix,
e) Determine the distance between the value of each alternative and the positive and negative ideal solutions,
f) Calculate the closeness of alternatives to the ideal solution.

Research Methodology

A model was produced in this research to prioritize development of IDNCG stations. There are three phases to the methodology's execution, the first stage is analysis of existing conditions which includes analysis of 35 candidate stations, identify criteria, discussion and verification with Focus Group Discussion (FGD). Following that, data processing stage involved spatial data measurement using GIS, determining the level of importance of criteria using AHP and calculating development priority preferences using TOPSIS. Finally, priority station mapping based on priority ranking which is the result of calculations in previous stages.

Research stages as in Figure 1 need to be created so that research is carried out in a structured, sequential and systematic manner. his research will produce a draft model for selecting priorities for the development of INDCG stations. Based on the results of the problem and needs analysis, input data will be obtained, namely in the form of primary and secondary data. Primary data consists of spatial data and non-spatial data. Meanwhile, secondary data will be obtained from Directorate Data and Information IDNCG.

Flowchart of the research used in solving the problems associated with prioritizing the location to develop stations. Initial data were collected after the issuance of a permit to conduct the research from the partner organization, IDNCG, on April 6, 2023.

The first thing to do was collect data on 35 IDNCG stations with a focus on location coordinates, addresses, area and permit status. This data was obtained from the IDNCG land survey team which has conducted surveys throughout the location. Data validation was carried out by matching the survey coordinates with Google Maps (Street View mode) which was validated by the IDNCG survey team.

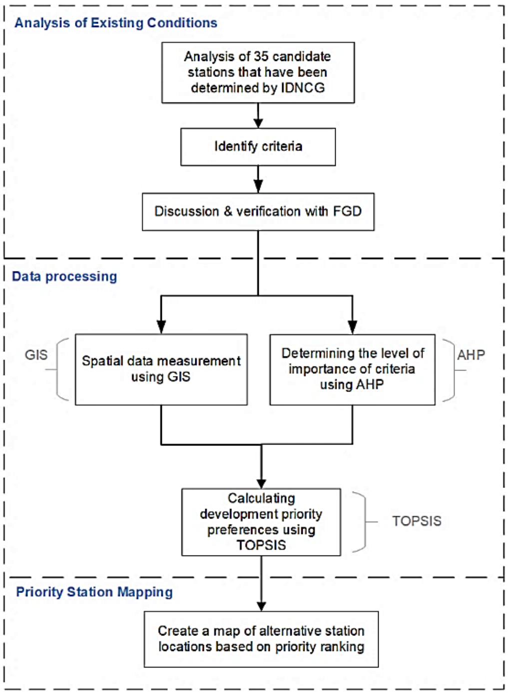

Figure 1. Research methodology

Data on the vulnerability of Indonesia's waters was obtained from the results of data collection at directorate data and information of IDNCG. Vulnerability data includes maritime security and safety data which contains coordinate point data, type of vulnerability, time of occurrence and source of information. This data was collected by the IDNCG data and information team over the last 5 years. Likewise with ship density data and port location points obtained from the IDNCG data and information team.

In this research, the criteria taken in selecting a location refer to a literature review of similar previous research. The literature review includes collecting journals, books and articles about location selection. Criteria relevant to the research were then discussed during Focus Group Discussion activities to validate their suitability for current conditions with 5 experts who were officers from IDNCG.

The data that has been obtained, such as data on the 35 station locations, criteria data and other historical data will be input into the ArcGIS 10.8 application, then data processing will be carried out with the "Near" feature for distance measurements, while to obtain coverage data, the feature will be used "Erase (Coverage)". After the spatial data is processed using the ArcGIS application, data will be produced on the distance from the station to ALKI, the distance from the station to the pier, the station's coverage on vulnerability and the station's coverage on vessel density along with a map display from the results of processing the spatial data.

Next, in the AHP method stage, what will be done is to assess the level of importance of the criteria resulting from interviews with experts. AHP itself is an approach that simplifies complex and unstructured problems through a series of pairwise comparisons by arranging decision criteria in a hierarchical structure and linking them with weights related to their contribution to the desired goal.

Evaluation of IDNCG station development priority preferences using the TOPSIS method. This method has a scheme where the selected alternative must have the furthest distance from the negative ideal solution and the closest distance from the positive ideal solution from a geometric point of view by using Euclidean distance to determine the relative closeness of an alternative to the optimal solution.

The integration of the three methods can be seen from the criteria data measured using the GIS method which will be converted and grouped into a range of suitability values. This data will be used in calculating the normalized decision matrix using the TOPSIS method together with the importance level value data resulting from the AHP method calculation. The results of the integration of the three methods are a development priority ranking along with a visual display in the form of a station development priority ranking map.

The final stage of the multi-criteria spatial decision-making model for the development priority of IDNCG stations is the creation of a location preference map based on priority ranking. It is hoped that this map can help policy makers and it is also hoped that this model can be used by IDNCG as a model that will provide scientific decision support in cases of similar decision making that can help overcome national maritime security and safety problems.

RESULTS AND DISCUSSION

Analysis of Existing Conditions

Analysis of 35 candidate stations

The data analysis process was initiated through the confirmation of the 35 candidate locations previously determined by IDNCG based on the Bappenas Green Book to be developed in stages for a period of 3 years as presented in Table 1. The street view feature on Google Maps was used to match coordinate points with address and survey data and was further confirmed directly by the land task force team. The location of prospective stations along with the surveillance system at each station are presented in Figure 2. Moreover, long-range cameras were used to visually monitor locations around station. AIS receivers were also applied to capture signals from passing ships using transponders. Coastal radar was used to sweep and identify objects around station while GMDSS radio was applied to conduct security communications with passing ships.

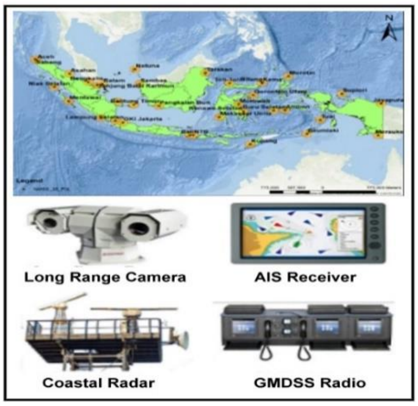

Figure 2. Confirmed Candidate Locations for IDNCG Stations

Table 1. Identification of the 35 IDNCG Candidates

No	Location	Zone	Coordinate
1	Aceh	West	5°38'55.4"N 95°26'23.7"E
2	Natuna	West	3°57'56.6"N 108°23'54.6"E
3	Batam	West	1°11'06.4"N 104°06'58.4"E
4	Bangka Belitung	West	2°11'6.6"S 106°10'43.2"E
5	Sambas	West	1°11'44.5"N 108°59'18.0"E
6	Tanjung Balai Karimun	West	0°59'45.7"N 103°26'43.8"E
7	Sabang	West	5˚51'3.34" N 95˚15'32.17 E
8	Asahan	West	3°06'36.5"N 99°46'46.7"E
9	Nias Selatan	West	0°35'42.8"N 97°45'10.0"E
10	Bengkalis	West	01°33'4,6"N 102°14'54,2"E
11	Belitung Timur	West	2°43'54.2"S 108°14'27.1"E
12	Pesisir Barat Lampung	West	5°13'37.2"S 103°55'12.9"E
13	Lampung Selatan	West	5°44'48"S 105°47'53"E
14	DKI Jakarta	West	6°06'06.6"S 106°47'55.8"E
15	Mentawai	West	2°03'36.2"S 99°39'36.8"E
16	Tarakan	Central	3°16'26.3"N 117°39'06.2"E
17	Bali	Central	8°27'39.6"S 115°38'03.9"E
18	Kema	Central	1°22'01.7"N 125°04'40.4"E
19	Bitung	Central	1°25'08.4"N 125°07'09.1"E
20	Konawe Selatan	Central	4°02'11.7"S 122°40'17.8"E
21	Makassar	Central	5°03'58"S 119° 28'22"E
22	NTB	Central	08°27'64" S 116°2'17"E
23	Pangkalan Bun	Central	2°58'31.3"S 111°31'19.7"E
24	Toli-Toli	Central	1°19'13" N 120°48'29"E
25	Morowali	Central	2°40'07" S 122°01'07"E
26	Gorontalo Utara	Central	0°55'35" S 123°55'59"E
27	Ambon	East	3°46'40.8"S 128°06'21.7"E
28	Kupang	East	10°10'33.4"S 123°32'09.5"E
29	Tual	East	5°36'04.6"S 132°45'32.6"E
30	Jayapura	East	2°31'05.4"S 140°44'19.6"E
31	Merauke	East	8°30'15.3"S 140°22'29.2"E
32	Buru Selatan	East	3°49'16.8"S 126°37'39.7"E
33	Morotai	East	2°38'4.08"N 128°33'25.5"E
34	Saumlaki	East	8°13'54.3"S 130°59'32.7"E
35	Supiori	East	0°40'04.0"S 135°35'42.6"E

The research was conducted to map outstations to be prioritized based on a larger scale of importance. This was determined through the assessment of the criteria measured using GIS.

Identify criteria

The criteria used to select the appropriate location were based on the review of similar previous research as well as brainstorming and verification of data from Focus Group Discussions with experts. The literature review included journals, books, and articles about location selection. The four criteria used in this research are presented as follows:

1. Distance to ASL
The implementation of Indonesian ASL is affecting the security and safety of ships crossing the channel. This is due to the status of ASL as an open area and a route required to be passed by the ships. Therefore, a suitable location for station should be close to shipping lanes to improve the response time to a distress signal from an incident at sea.
2. Distance to port
Ports are considered very important to maritime security and safety. This is because the distress signals sent by sea users need to be immediately broadcast and received by station. An immediate response is required from station by providing information to the ship elements at the port. This shows that the distance to the port can also affect coordination time and speed of rescue to the location.
3. Coverage with vulnerable areas
The vulnerability data for the last 5 years obtained from secondary sources were represented as a heatmap using GIS and later measured using the "Clip (Coverage)" analysis feature with candidate stations. The results showed a wider coverage of stations with vulnerability led to more reach into other vulnerable areas. Therefore, it was considered more appropriate to build stations first in order to maintain the security and safety of sea users.
4. Coverage with ship density
Ship density data is very important in determining a suitable location for stations. This is necessary because a location with a large coverage area for passing ships is considered more useful for sea users. The consideration is based on the usage of the location as a source of information and also to provide a sense of security. For example, density has been used as a criterion to select multipurpose tunnel locations in multi-criteria spatial analysis research [16].

Discussion and verification with FGD

The criteria designed to be used are presented in Table 2 based on the references from previous research. Moreover, the range, level of suitability, and score were determined through the discussion and validation by experts during the FGD session held on August 30, 2023, at the Aston Kartika Grogol Hotel. A total of 5 experts from IDNCG and 7 academics from Universitas Trisakti participated in the discussion with a focus on three main parts, including confirmation of 35 candidate IDNCG Stations, selection of appropriate research methods, and ratification of the criteria.

The questions asked during the FGD session and the answers provided are presented in Table 3. It is important to state that all the questions were answered and became a common understanding for the research.

Table 2. Criteria for IDNCG priority development

Crit	Range	Suitability	Score	Ref
Dist. to ASL (Nm)	0-200 200-400 400-600 600-800 >800	High Suitable Moderately Marginally Not suitable	5 4 3 2 1	[10], [13], [14], [15], [16], [17], [24], [25]
Dist. to Port (Nm)	0-10 10-20 20-30 30-40 >40	High Suitable Moderately Marginally Not suitable	5 4 3 2 1	Highly suitable Suitable Moderately suitable Marginally suitable Not suitable [1], [8], [9], [25]
Cov with Vuln Area (%)	>80 70-80 60-70 50-60 <50	High Suitable Moderately Marginally Not suitable	5 4 3 2 1	Highly suitable Suitable Moderately suitable Marginally suitable Not suitable [8], [9], [10], [16], [25]
Cov with Ship Dens (%)	>40 30-40 20-30 10-20 0-10	High Suitable Moderately Marginally Not suitable	5 4 3 2 1	Highly suitable Suitable Moderately suitable Marginally suitable Not suitable [9], [12], [14], [16], [17], [24]

Table 3. Questions and answers in the FGD

No	Questions	Answers
1	Has the selection of the 35 locations been adapted to similar facilities owned by stakeholders?	All selected locations have been adjusted to fill monitoring gaps in Indonesia
2	Is the use of the Cut-off Point method appropriate for this research?	The Cut-off Point method can be used to filter if there are quite a lot of criteria in this research
3	Are the 8 criteria in this research able to accommodate IDNCG's needs in solving priority problems for station development?	The aim of this research is to propose a model to solve this problem, but in the future, this research can be developed further by exploring criteria that are appropriate to IDNCG conditions.

Data Processing

Spatial data measurement using GIS

The locations of the prospective IDNCG stations were compared based on the nearest distance to the ASL and the Port. This was followed by the assessment of the coverage with the vulnerable area. Stations with a wide coverage were considered more suitable to be prioritized for development. The last stage was the consideration of the coverage with ship density. The locations closer to busy ship traffic were considered ideal for the handling of security and safety disturbances in Indonesian seas.

The results obtained from measuring the distance of prospective stations to the ASL using ArcGIS are presented in Figure 3. Moreover, the closest distance to the port was South Lampung Station with 17.6 Nm while the farthest was Sabang Station with 2140.39 Nm as shown in Figure 4. ASL was also compared to a toll road at sea to ensure high ship traffic in the area. This was necessary because proper station placement could provide a sense of security and reduce disruptions to maritime security and safety.

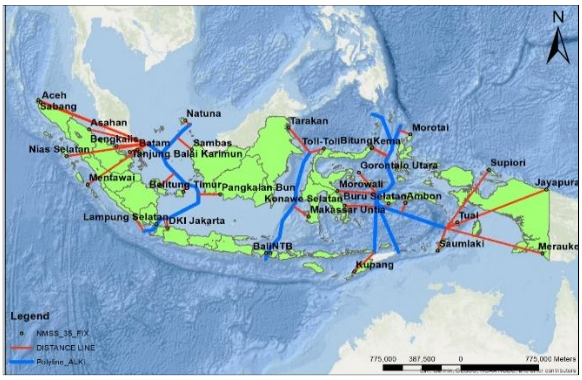

Figure 3. Distance map of prospective locations to the ASL

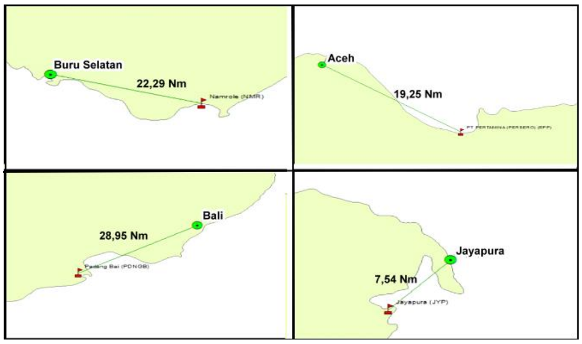

Figure 4. Distance map of prospective locations to the port

The measurement of the distance between the prospective locations and the nearest port showed that DKI Jakarta Station was the closest at 0.14 Nm while the furthest was Morotai Station at 38.39 Nm. However, the survey conducted showed that the local government was planning to develop the IDNCG Morotai Station soon.

Vulnerability coverage measurement results showed that North Gorontalo Station had the highest coverage of 94.78%. This shows that the location has high vulnerability and exists within the monitoring range. Meanwhile, the lowest, 38.47 %, was recorded for Pangkalan Bun Station. The value showed the low vulnerability of the location and existence beyond coverage as presented in Figure 5. The existing data further showed that the vulnerability was lesser in eastern Indonesia and this was associated with the busier traffic factor in western Indonesia.

The coverage of prospective stations was examined based on the density of passing ships. The results showed that Morotai Station had the highest figure of 63.97% while the lowest, 5.69%, was in Tanjung Balai Asahan Station as presented in Figure 6. This shows that traffic is outside the 40 Nm range of station or the path of small ships without an automatic identification system (AIS).

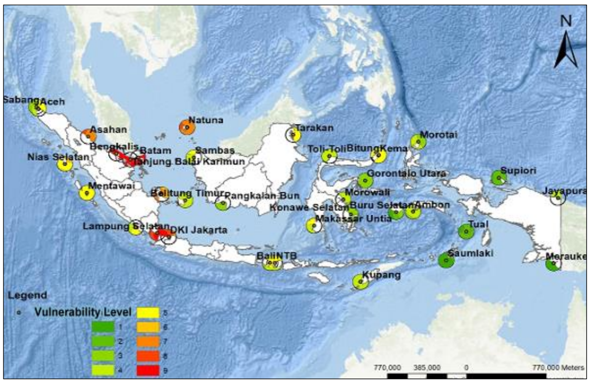

Figure 5. Vulnerability coverage

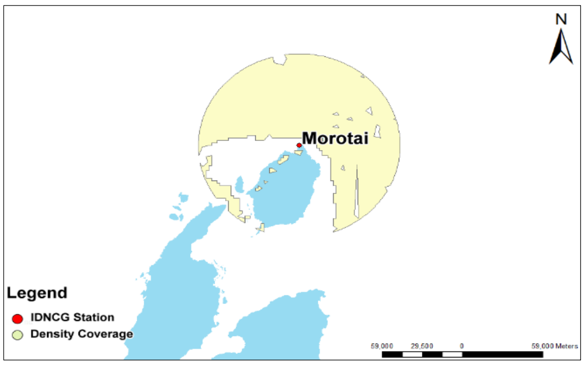

Figure 6. Ship density coverage

The summary of the results from GIS measurement is presented in Table 4. The data obtained were converted into scores determined during the FGD conducted with experts and processed further using the MCDM, including AHP and TOPSIS.

Determining the level of importance of criteria using AHP

AHP was conducted through four steps with the first focused on designing a hierarchy of decision-making problems. The hierarchy consisted of the goals at the top, other criteria or options in the central position, and the alternatives at the bottom [26][27]. The second step was to develop a pairwise comparison matrix based on the recommendation of experts as follows:

$$B = \begin{bmatrix} 1 & x_{12} & \cdots & x_{1m} \\ x_{21} & 1 & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & 1 \end{bmatrix} \quad (1)$$

where, x_{ij} (1 ≤ i ≤ m, 1 ≤ j ≤ m) is the relative importance provided for criterion i to j by the experts. This was based on the rules proposed by Buckley to select x_{ij} through nine linguistics ranging from 1 to 9 as explained in the following Table 5.

The paired comparison questionnaire was provided for 5 experts to determine the weight of each criterion. Moreover, the third step was the consistency test which was achieved by calculating the maximum eigenvalue, λ, followed by the counting of consistency index CI = $\frac{\lambda - m}{m-1}$. The random consistency index (RI) for 4 criteria was found to be 0.90 which was relative to the number of M indicators. This was followed by the determination of *consistency ratio* based on the suggestion of Saaty that only values smaller or equal to 10% were acceptable while those higher were considered random and needed to be corrected. Furthermore, the fourth step was to determine the weights of the indicators.

Table 4. Recapitulation of calculation results using GIS method

No	Location	ASL	Score	Port	Score	Vulnerable	Score	Density	Score
1	Aceh	2091.3	1	19.25	4	71.78	4	27.72	3
2	Natuna	117.75	5	4.35	5	89.83	5	29.14	3
3	Batam	221.29	4	4.55	5	85.75	5	9.95	1
4	Bangka Belitung	356.26	4	20.01	3	53.79	2	12.08	2
5	Sambas	364.77	4	13.47	4	53.04	2	42.64	5
6	TBK	358.74	4	32.2	2	75.81	4	12.08	2
7	Sabang	2140.3	1	13.32	4	84.94	5	24.88	3
8	Asahan	1098.1	1	29.29	3	53.49	2	5.69	1
9	Nias Selatan	1494.8	1	55.8	1	83.70	5	28.43	3
10	Bengkalis	566.86	3	3.39	5	61.71	3	9.24	1
11	Belitung Timur	150	5	65.2	1	75.89	4	41.93	5
12	Lampung Barat	284.64	4	137.4	1	50.08	2	36.25	4
13	Lampung Selatan	17.6	5	46.94	1	62.75	3	12.79	2
14	DKI Jakarta	164.3	5	0.47	5	42.11	1	7.11	1
15	Mentawai	1335	1	182.8	1	93.44	5	29.14	3
16	Tarakan	605.34	2	11.64	4	52.55	2	27.72	3
17	Bali	34.38	5	28.95	3	67.48	3	12.08	2
18	Kema	340.4	4	26.73	3	74.87	4	39.80	4
19	Bitung	338.02	4	14.66	4	76.75	4	41.22	5
20	Konawe Selatan	566.62	3	16.92	4	54.37	2	19.19	2
21	Makassar	348.77	4	19.25	4	49.76	1	9.24	1
22	NTB	41.44	5	53.38	1	66.96	3	16.35	2
23	Pangkalan Bun	399.02	4	32.95	2	38.47	1	17.77	2
24	Toli-Toli	265.51	4	54.08	1	70.21	4	42.64	5
25	Morowali	705.84	2	183.7	1	47.69	1	21.32	3
26	Gorontalo Utara	505.73	3	86.88	1	94.78	5	54.02	5
27	Ambon	206.9	4	22.1	3	84.24	5	51.88	5
28	Kupang	504.55	3	5.18	5	70.22	4	26.30	3
29	Tual	233.04	4	7.29	5	92.80	5	49.04	5
30	Jayapura	1958.4	1	7.54	5	60.79	3	35.54	4
31	Merauke	1795.7	1	6	5	47.01	1	19.90	2
32	Buru Selatan	98.81	5	22.29	3	60.47	3	41.22	5
33	Morotai	226.98	4	129.3	1	86.52	5	63.97	5
34	Saumlaki	442.65	3	31.76	2	90.62	5	60.41	5
35	Supiori	1352.4	1	142.4	1	87.45	5	37.67	4

Table 5. Assess the level of importance

Intensity	Remark
1	Both elements are equally important
3	One element is less important than the others
5	One element is more important than the others
7	One element is clearly more important than the others
9	One element is absolutely more important than the others
2, 4, 6, 8	Values between two adjacent considerations

The process showed that the criterion with the highest importance in AHP calculation was distance to ASL with a value of 0.484 followed by vulnerability coverage at 0.249, density coverage at 0.183, and distance to the port at 0.084 as shown in Table 6. Moreover, the Consistency Ratio (CR) was 0.00752 which was considered consistent according to the Random Consistency Index table because the value was below 0.90.

Calculating development priority preferences using TOPSIS

TOPSIS was conducted generally through six stages which are stated as follows:

Step 1: Formulate a decision matrix based on the recommendation of experts as follows:

$$V = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mn} \end{bmatrix} \quad (2)$$

where, p_ij (1 ≤ i ≤ m, 1≤ j ≤ n) is the value of the ith alternative assessed from the jth factor. Moreover, the suitability ranking of the alternatives for each criterion was evaluated based on a 1 to 5 scale as presented in Table 7.

Table 6. Criteria importance level values

Criteria	Score	Order
ASL	0.484	1
Vulnerable	0.249	2
Density	0.183	3
Port	0.084	4

Table 7. Importance Scale

No	Importance
1	It is not in accordance with
2	Not Appropriate
3	Just Appropriate
4	In accordance
5	Very suitable

Step 2: Develop a normalized decision matrix R = $[r_{ij}]_{mxn}$, where r_{ij} can be calculated as follows:

$$r_{ij} = \frac{p_{ij}}{\sqrt{\sum_{i=1}^{m} p_{ij}^2}} \quad (3)$$

Step 3: Design a weighted normalized decision matrix Y = $[y_{ij}]_{mxn}$ where y_{ij} can be obtained by multiplying r_{ij} with the weights, w_i, determined for the criteria using AHP.

$$y = w_i \times r_{ij} \quad (4)$$

Step 4: Determine the positive and negative ideal solutions

$$A^+ = \{y_1{}^+, y_2{}^+, y_3{}^+, \dots, y_i{}^+\} \quad (5)$$

$$A^- = \{y_1{}^-, y_2{}^-, y_3{}^-, \dots, y_i{}^-\} \quad (6)$$

where, $y_i{}^+$ is maximum y_{ij} if j is the profit and minimum attribute y_{ij} if j is a cost attribute. Meanwhile. $y_i{}^-$ is minimum y_{ij} if j is the profit attribute and is maximum y_{ij} if j is the cost attribute.

Step 5: Calculate the distance to the positive and negative ideal solutions using the following formulas:

$$S_i{}^+ = \sqrt{\sum_{j=1}^{m} (y_i{}^+ - y_{ij})^2} \quad (7)$$

$$S_i{}^- = \sqrt{\sum_{j=1}^{m} (y_{ij} - y_j{}^-)^2} \quad (8)$$

Step 6: Calculate the preference value V_i for each alternative using the following formula:

$$V_i = \frac{S_i{}^-}{S_i{}^+ + S_i{}^-}, i = 1, 2, \dots, m \quad (9)$$

A larger V_i value shows the preference for the specific alternative A_i. Therefore, the ranking of the alternatives to be prioritized for development as IDNCG Station based on the V_i value is presented in Table 8.

Table 8. Station ranking based on TOPSIS

Station	Zone	D+	D-	Vi	Rank
Natuna	West	0.0082	0.1104	0.9311	1
Tual	East	0.0230	0.0933	0.8025	2
Batam	West	0.0282	0.0919	0.7652	3
Buru Selatan	East	0.0304	0.0981	0.7637	4
Bitung	Central	0.0275	0.0842	0.7536	5
Bali	Central	0.0328	0.0969	0.7473	6
DKI Jakarta	West	0.0375	0.1048	0.7365	7
Ambon	East	0.0341	0.0824	0.7071	8
Kema	Central	0.0354	0.0786	0.6895	9
Sambas	West	0.0364	0.0808	0.6890	10
Belitung East	West	0.0512	0.0967	0.6538	11
Makassar	Central	0.0458	0.0786	0.6321	12
NTB	Central	0.0546	0.0935	0.6312	13
Lampung Selatan	West	0.0546	0.0935	0.6312	14
Bangka Belitung	West	0.0442	0.0740	0.6258	15
TBK	West	0.0467	0.0746	0.6149	16
Kupang	East	0.0474	0.0733	0.6071	17
Morotai	East	0.0555	0.0785	0.5858	18
Bengkalis	West	0.0516	0.0703	0.5768	19
Toli-Toli	Central	0.0561	0.0752	0.5727	20
Pangkalan Bun	Central	0.0570	0.0702	0.5517	21
Pesisir Barat Lampung	West	0.0611	0.0705	0.5356	22
Konawe Selatan	Central	0.0553	0.0603	0.5214	23
Saumlaki	East	0.0595	0.0606	0.5046	24
Gorontalo Utara	Central	0.0683	0.0593	0.4649	25
Tarakan	Central	0.0749	0.0458	0.3795	26
Jayapura	East	0.0935	0.0546	0.3688	27
Sabang	West	0.0931	0.0514	0.3557	28
Merauke	East	0.0987	0.0507	0.3393	29
Aceh	West	0.0935	0.0463	0.3312	30
Supiori	East	0.1049	0.0359	0.2550	31
Mentawai	West	0.1052	0.0347	0.2483	32
Nias Selatan	West	0.1052	0.0347	0.2483	33
Asahan	West	0.0999	0.0266	0.2104	34
Morowali	Central	0.0922	0.0244	0.2091	35

Findings from research with the integration of GIS, AHP and TOPSIS are a priority ranking presented in the Table 8. The integration of these three methods produces a useful priority ranking in the IDNCG station development plan to overcome security and safety problems in Indonesian seas.

Showed that Natuna Station was the first to be developed with a preference value of 0.9311. This was significantly in line with the current status of North Natuna waters as the center of national and global attention. Moreover, the claiming of the Nine Dash Line by China has led to the loss of approximately 83,000 km² or 30 percent of Indonesian waters in Natuna. A similar trend was observed in other countries such as the Philippines, Malaysia, Vietnam, and Brunei Darussalam. Some areas included in the Nine Dash Line, such as the Paracel Islands, are also observed to have been claimed by Vietnam and Taiwan.

We can see that rankings 1-12 are the station locations surrounding ASL 1 and 3, where maritime insecurity most often occurs in the western region, such as fishing theft in the Natuna region and drug smuggling originating from Malaysia, while ASL 3 is a weapons smuggling from the Philippines. The results of the integration of these three methods can help overcome the problem of threats in Indonesian seas.

Priority station mapping

Create a map of alternative station locations based on priority ranking

Interesting finding from this research is that if it is divided into 3 years of development, where ranks 1-12 will be built in the first year, ranks 13-24 will be built in the second year and ranks 25-35, the station zoning distribution consists of 5 zones. West, 4 Central zones, and 3 East zones in the first and second years, then consisting of 5 West zones, 3 Central zones, and 3 East zones in the third year. As in the results of the ranking map in Figure 7, which can contribute directly to dealing with decision-making problems at the strategic level.

The results of this research are certainly quite significant in determining the direction of leadership policy in determining priorities for the construction of IDNCG stations, where previously determining priorities was still based on leadership directions. Thus, the results of this research which integrates GIS, AHP and TOPSIS can produce a priority model for developing IDNCG stations in overcoming national maritime safety and security problems.

The results of this research have been submitted to experts who attended the Focus Group Discussion activity. The experts expressed the opinion that the resulting ranking was quite relevant to the current situation of Indonesian maritime security and safety, that we should focus more on the North Natuna sea area.

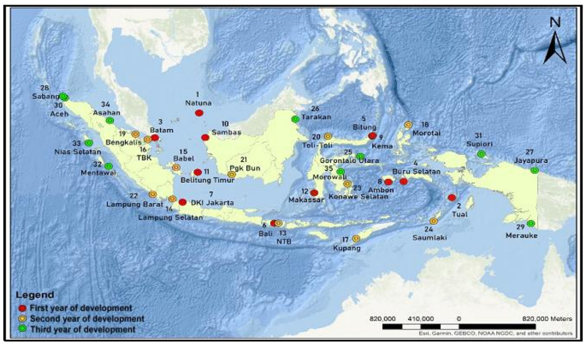

Figure 7. Ranking Map for the IDNCG Stations

The results of this study have been compared with previous research, namely GIS-MCDM method for rangking potential station locations in the expansion of bike-sharing systems in Lisbon, Portugal [14]. Both studies used same method, GIS, AHP and TOPSIS. Both studies used 4 criteria, but previous study added sub-criteria with a total of 14. The rangking result of this study are also implemented in the form of map to facilitate policy maker in decision making.

CONCLUSION

The conclusions from the series of research conducted, model prepared, and the analysis of data retrieved are presented as follows:

1. Findings from the development of a spatial multi-criteria decision model produced by combining GIS with AHP and TOPSIS methods led to the determination of four criteria, including distance to ASL, vulnerability coverage, ship density coverage, and distance to the port. A total of 35 stations used as alternative locations have been validated by experts, sorted according to their priority ranking and stated in the form of a map which will help policy makers to resolve the problem of selecting priority locations for IDNCG station development.
2. Apart from that, the findings from this research are how this model overcomes the challenges of maritime security and safety, namely the problem of territorial boundary violations and illegal fishing in North Natuna.
3. The practical application of the results of this research is aiding policymakers in decision-making processes and enhancing security and safety measures in Indonesian waters.
4. Apart from that, this research has the potential to be developed in the future, such as exploring the criteria or develop a multi-criteria spatial decision-making model to solve similar cases, such as patrol ship dispersion, patrol ship base location selection and others.

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