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Exploring Key Factors of Coastal Defense System from Military Perspective in Surabaya Region using Delphi and Interpretive Structural Modeling

Aris Tri Ika Rakhmadi[1], Mohammad Khusaini[1], Dhiana Puspitawati[1], M.F. Aminuddin[1], A.K. Susilo[2,*]

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ABSTRACT

In recent years, the expansion of coastal regions and the challenges posed by climate change have necessitated enhanced protection measures for coastlines, often through the deployment of coastal defense structures. Recognizing the importance of incorporating military insights into coastal defense strategies, this research aims to examine and integrate military perspective-driven factors into the planning and development process, leveraging interpretive modeling. The research draws upon coastal zone management and coastal defense systems theories, employing a qualitative descriptive statistical methodology and consulting with 18 experts. The Delphi method and Interpretive Structural Modeling (ISM) were applied to gather and analyze data. This research was carried out in Surabaya, a historically significant port city situated on the coastal edge of Java Island. The findings reveal 15 key factors related to coastal defense, identified through literature review and expert evaluations. Using the ISM approach, these factors were analyzed to understand their interrelationships, resulting in a hierarchical structure of seven digraph levels. Intelligence (F7) emerged as a primary factor at level 1, while Legal Framework (F15) and Infrastructure (F3) were identified at the lower echelons of the hierarchy. Additionally, a MICMAC analysis was conducted, categorizing ten coastal defense factors into an independent cluster, three into a linkage cluster, and two into a dependency cluster, with no factors falling into the autonomous category. This classification underscores the significance of all identified factors in coastal defense planning and implementation.

1. Introduction.

Recent decades have witnessed significant developments in coastal areas, alongside the escalating impacts of climate change, necessitating enhanced protection measures for coastlines. This has predominantly involved the deployment of robust coastal defense structures (Sauvé, Bernatchez and Glaus, 2022b). The rising sea levels, a consequence of environmental changes and climate change, mean that many existing coastal defenses are now facing pressures beyond their original design parameters, highlighting the urgent need for adaptations (Formentin, 2021). Concurrently, there's a growing recognition of the benefits of incorporating natural elements into coastal defense strategies to improve resilience (Kindeberg et al., 2022). Despite this, the financial burden of developing such defenses remains substantial (Maia, 2015), and there is a clear demand from coastal communities for effective defense mechanisms (Huang, 2016). The motivations behind implementing coastal defenses are diverse, with the primary focus being on safeguarding roads and homes, pointing to solutions that may not necessarily involve construction directly on the shoreline (Portocarrero, 2011).

The commitment to constructing infrastructure that serves a range of functions, from coastal defense to transportation, is seen as vital for ensuring future human well-being (Cozzoli et

[1]Brawijaya University, Ketawanggede, Lowokwaru, Malang, Indonesia.
[2]Indonesia Naval Technology College, Bumi Moro, Morokrembangan, Surabaya, Indonesia.
*Corresponding author: April Kukuh Susilo. E-mail Address: aprilkukuh53@gmail.com.

al., 2017). Traditional approaches to designing coastal defenses have relied heavily on the analysis of historical data through statistical methods (Foti, Musumeci and Stagnitti, 2020). Recently, there has been a push towards the widespread adoption of ecologically friendly designs for man-made coastal defenses, now a prevalent aspect of urban coastal landscapes (Evans et al., 2017). However, a significant hurdle in advancing coastal defense initiatives is the deficiency of essential knowledge among local government bodies regarding the adoption of nature-based solutions (Morris et al., 2019).

Morris et al., (2022) highlight the need for future research to integrate field observations with both physical and numerical modeling studies to enhance predictive accuracy. Moreover, they suggest that to augment scientific input in decision-making, future studies should focus on a detailed characterization of coastal defense systems and examine a broader range of beach types (Sauvé et al., 2023). Zhang & Hou (2020) advocate for research efforts to delve into the factors influencing shifts in coastal defense lines and their environmental repercussions. Additionally, Sauvé et al., (2022a) point out the absence of decision-support tools that effectively incorporate scientific insights into the decision-making process for coastal defense management. Mai (2006) calls for comprehensive investigations into the determination of maritime boundaries and their interaction with coastal defense mechanisms, including an analysis of related aspects. Hence, it is crucial to consider coastal defense-related factors from a military standpoint and integrate these into decision-making through physical and numerical modeling.

This research aims to examine and incorporate military perspective - related factors in coastal defense into a systematic development framework using interpretive modeling. It is underpinned by coastal zone management and coastal defense system theories, employing a qualitative descriptive statistical methodological approach. The research utilizes the Delphi method and interpretive structural modeling. Conducted in Surabaya, a regional city with a significant history as a port and predominantly located on the coastal edge of Java, Indonesia, this research involved consultations with 18 experts to gather data and insights.

The urgency of research focused on the exploration and integration of coastal defense factors is multifold. Firstly, such research is crucial for incorporating precise scientific knowledge into the decision-making process, serving as a vital tool for informed planning and implementation (Sauvé, Bernatchez and Glaus, 2022a). Secondly, it aims to create a model that harmonizes the demand for human infrastructure with the imperative of preserving coastal ecosystems, striking a delicate balance between development and conservation. Thirdly, this research endeavors to formulate a model that encapsulates both community needs and perspectives, thereby ensuring that coastal defense strategies are not only effective but also socially and economically sustainable. Fourthly, gaining an understanding of the intricate interplay among various determinants that affect coastal defense is instrumental in devising infrastructure development plans capable of addressing future challenges and safeguarding coastal communities.

This research contributes in several significant ways. First, by deciphering the factors influencing coastal defense, it lays the groundwork for more effective planning and decision - making in coastal management, enabling stakeholders to navigate the complexities of coastal defense with greater precision. Second, investigating these factors aids in the creation of predictive models that forecast future changes in coastal zones, thereby enhancing the ability of decision-makers to prioritize and allocate resources more judiciously for coastal defense planning and management. Third, the application of interpretive modeling offers a methodology for amalgamating diverse viewpoints into the decision-making process, enhancing the legitimacy and efficacy of coastal defense policies. Fourth, this research provides insights into how these factors contribute to the vulnerability of coastal areas to various threats, knowledge that is pivotal for developing interpretive models capable of evaluating the risks and impacts associated with different coastal defense strategies.

2. Literature Review.

2.1. Coastal Zone Management (CZM).

Coastal zones are regions of critical change, especially in the context of escalating climate change and burgeoning global populations (Sauvé et al., 2023). These areas are densely populated and serve as hubs for a myriad of economic activities due to the presence of ports, industries, and communication infrastructures (Foti, Musumeci and Stagnitti, 2020). The coastal zone is a dynamic interface between human and natural systems, extending both seaward and landward from the coastline. Its boundaries are defined by the scope of natural processes and human activities occurring within it. Coastal Zone Management (CZM) extends both to land and sea, tailored to meet specific management objectives (Wright, 2004). CZM has emerged as an effective approach to addressing the challenges posed by competing uses and pressures in coastal areas, promoting integrated planning to resolve common management dilemmas. It encompasses not only the utilization of coastal areas by humans but also the conservation of their physical and biological environments. Consequently, CZM transcends mere coastal protection or maritime defense, evolving into the more comprehensive framework of Integrated Coastal Zone Management (ICZM) (Wright, 2004).

ICZM represents a governance model that includes the legal and institutional frameworks necessary to ensure the integration of various development initiatives, with the goal of environmental protection achieved through the participation of all stakeholders (Anton, Gasparoti and Rusu, 2020). It is not designed to supplant sector-specific management strategies but to synchronize and augment them. A key facet of ICZM is its integration into prevailing policies, including public and urban (regional) planning. Powell et al. (2019) highlight that investments in natural coastal infrastructure can yield tangible benefits for coastal communities, enhancing ecological resilience. Moreover, Foti et al. (2020) argue for the necessity of simple yet effective enhancements to existing coastal defenses to mitigate the effects of climate change, alongside the implementation of resilient interventions.

2.2. Coastal Defense.

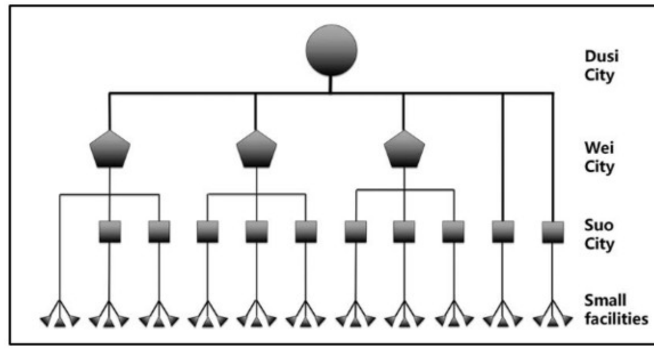
Coastal defense encompasses a comprehensive array of warning and protective measures deployed by a nation in its coastal and offshore territories to guard against foreign invasions, pirate activities, and to quell internal insurrections. This defense mechanism, primarily military, extends beyond mere physical installations and personnel; it also involves the formulation of strategic policies tailored for coastal security (Chen, 2021). The Coastal Defense Forum plays a pivotal role in this context, promoting strategic discussions on coastal defense challenges, facilitating cooperation and information sharing among relevant entities, and highlighting best practices in coastal defense planning and execution (Wright, 2004).

Coastal defense strategies and infrastructure aim to shield a country's coastlines from potential threats, including enemy incursions and naval assaults. The primary goal is to safeguard national waters, ports, and coastal infrastructures from any form of external aggression. This objective is achieved through a comprehensive defense strategy that includes military deployment, fortifications, surveillance, and naval resources to deter and neutralize potential adversaries. Coastal defense remains a critical consideration, especially for nations with less powerful and smaller naval forces (Geoffrey Till, 2009). The evolution of naval strategies reflects a shift in naval capabilities: from a focus on localized coastal defense to a more expansive capacity for operations in adjacent seas. This shift towards "far sea operations" signifies a transformative approach in naval strategy and capability development (Li, 2009).

In contemporary settings, coastal defense has embraced state-of-the-art technologies such as radar systems, unmanned aerial vehicles (UAVs), coastal defense cruise missiles, and integrated command and control networks. These technological advancements have significantly enhanced surveillance, early warning, and rapid response mechanisms against maritime threats (Kindeberg et al., 2023). Although the benefits of coastal defense initiatives may not be immediately apparent, their value becomes evident over the medium to long term (Maia, 2015). Coastal defense is a multifaceted responsibility that not only involves repelling invasions during wartime but also mitigating sporadic attacks, ensuring comprehensive protection of the coastline (G, Chester; Jr, 2016).

Figure 1 illustrates the hierarchical model of military settlements employed in coastal defense, aligning with the fractal theory as applied to representation models in Cantor's third intermediate set. Fractal theory in urban system studies facilitates the analysis of urban structures through the examination of the physical geographic distribution of cities alongside the allocation of physical and human resources (Tan et al., 2020). In the context of ancient defensive military settlements, the primary objective was defense. Consequently, it was crucial to identify and emphasize the core components of military defense in these settlements (Cao and Zhang, 2018).

Figure 1: Coastal defense hierarchical model.



Source: Authors.

3. Methodology.

This paper aims to examine and construct the contextual relationships among factors influencing coastal defense through a structured hierarchical approach using interpretive modeling. The research integrates a two-stage sequential research methodology, employing the Delphi method and Interpretive Structural Modeling (ISM) techniques. Initially, the Delphi method, a qualitative approach, was utilized to pinpoint factors pertinent to coastal defense. Subsequently, the ISM approach, a multi-criteria decision-making tool, was applied to delineate the interconnections among these coastal defense factors. The methodology adopted in this research is depicted in Figure 2.

The research was conducted between 2023 and 2024 in Surabaya, Indonesia, known for its extensive coastal regions. A cohort of experts was engaged to construct an ISM model that illustrates the interplay among various coastal defense-related factors. The outcomes derived from the ISM were further elaborated through MICMAC diagram analysis, which helped uncover the driving forces and dependencies associated with each factor. Based on these insights, the research proposes a coastal defense model that leverages these driving forces and dependencies. This model aims to aid policymakers in prioritizing factors critical to coastal defense, thereby facilitating informed decision-making.

3.1. Selection criteria for the expert panel.

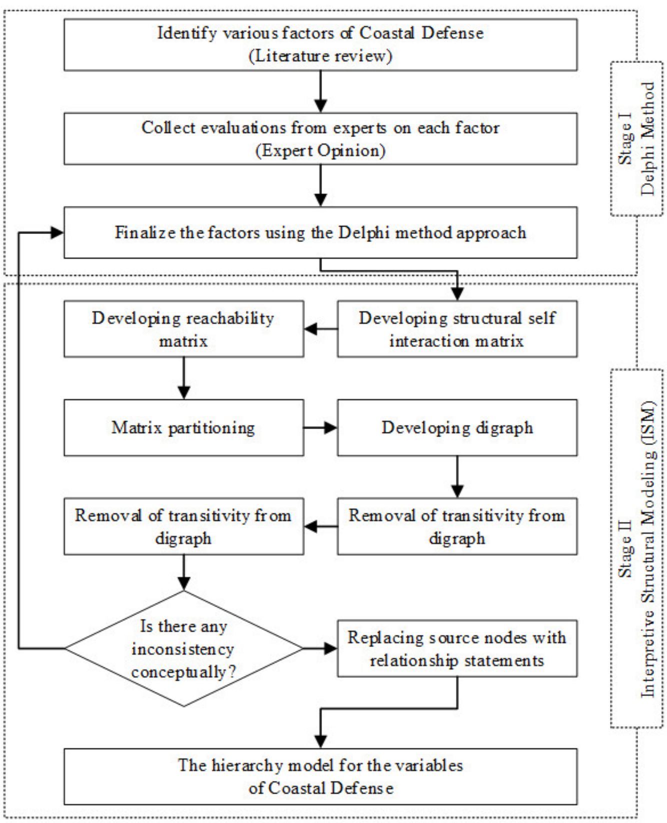
The essence of the Delphi method lies in identifying experts who can provide insightful information regarding the issue under investigation (Flanagan et al., 2016). In any qualitative research, experts play a crucial role; therefore, it is essential to provide demographic details about the credentials of the qualified experts. This step is necessary to assess their level of expertise and knowledge, ensuring they are suitable to contribute to this research as experts. Experts are selected based on a predefined set of criteria, including their level of education, area of expertise, experience, and professional activities. These criteria are established to maintain the research's integrity, ensuring that the selected specialists are both trustworthy and esteemed in their respective fields (Table 1). Previous studies emphasize that experts should possess robust scientific knowledge and adequate experience and skills (Moradi et al., 2023).

Table 1: Demographic information of the experts.

Expert	Field	Position
E1; E2; E3; E4	PhD in Defense Study	Academic and Professional
E5; E6; E7	PhD in Operation Research	Academic and Professional
E8; E9	PhD Student in Defense Management	Academic
E10; E11; E12	PhD in Defense Resource Management	Academic
E13; E14;	PhD in Operation Management	Professional
E15; E16	PhD in Coastal Research	Professional

Source: Authors.

Figure 2: Proposed research framework.



Source: Authors.

An initial email invitation is dispatched to the identified experts, which is subsequently followed by a questionnaire that they are required to complete. The Google Forms platform facilitates the distribution and collection of these questionnaires. During the preliminary phase of the Delphi study, the experts were requested to evaluate factors pertinent to coastal defense. The Content Validity Index (CVI) was employed to ascertain the extent of consensus among the jurors concerning the categorization of items. Should the CVI fall below 0.75, or in case any suggestions for improvement are provided, a revised version of the form—incorporating the modified items and feedback—is circulated among the judges. The questionnaire utilized a 5-point Likert scale to gauge the varying degrees of importance attributed to each factor, spanning from "not important" to "very important," represented numerically from 1 to 5 (Qureshi et al., 2022).

The CVI serves as a metric for evaluating expert assessments, calculated by aggregating the relative frequencies of responses indicating either "Agree" (4) or "Strongly agree" (5). This calculation aims to gauge the consensus level among judges regarding the adequacy of items under evaluation (Mahran et al., 2021). The overall CVI is derived by summing the individually computed CVIs for each item and then dividing this total by the number of items evaluated. An overall CVI of 0.75 or higher is considered indicative of each item's adequacy to the comprehensive assessment of the instrument (Coimbra et al., 2021).

3.2. *Delphi Technique.*

The Delphi technique is a systematic approach aimed at consolidating expert opinions on complex issues through structured group communication, facilitating consensus-building over several rounds of iteration to guide future directions (Chand, Thakkar and Ghosh, 2020). The process emphasizes meticulous design, planning, and execution, with detailed strategies for defining the problem, selecting panel members, deciding on the panel size, and conducting Delphi rounds (Munasinghe et al., 2023). It starts with a clear problem definition, outlining the necessary objectives and scope to ensure a thorough investigation of the issue with a methodology aptly suited for attaining the desired outcomes (Jannat et al., 2020).

The Delphi method aims to gather and clarify insights on various challenges through comprehensive inquiries directed at experts and stakeholders within a real-world context. The procedure unfolds in several stages (Venkatesh, Rathi and Patwa, 2015): (1) Formation of the expert panel; (2) Identification of challenges and development of a feedback mechanism; (3) Implementation across three rounds. Given the iterative nature of the Delphi technique, which typically necessitates multiple feedback cycles, securing a commitment from potential panel members for their participation through successive questionnaire rounds and feedback sessions is paramount (Rathore et al., 2022). Thus, panelists need to remain engaged and motivated throughout the process, ensuring the consistency and reliability of responses across the study's duration (Ullah et al., 2021).

3.3. *Interpretive Structural Modeling (ISM).*

Interpretive Structural Modeling (ISM) is a methodology that leverages group judgment and consensus to analyze complex systems. Developed by Warfield (1974), ISM employs a collaborative learning process to systematically organize and model interconnected factors affecting the system under research (Wu et al., 2023). It is an interactive approach for exploring the interrelations among a system's components, grounded in the expertise of participants. The "interpretive" aspect of ISM arises from its reliance on expert judgment to determine the relationships between variables, while it is deemed "structural" because it facilitates the construction of a distinct framework elucidating these relationships. As a "modeling" technique, ISM enables the creation of visual models that depict the interconnections between variables, thus aiding in the understanding of complex systems (He and Elhami Khorasani, 2022).

The steps involved in the ISM process are detailed in subsequent sections and draw upon the work of researchers, highlighting its application and utility in structuring complex problem spaces (Chand, Thakkar and Ghosh, 2020; Ullah et al., 2021) as follows.

- Factors that influence the process are listed. This research identifies factors related to Coastal defense from a military perspective.
- Establishment of contextual linkages between the factors under study.
- Pairwise relationships between factors were developed through the formulation of a structural self-interaction matrix (SSIM).
- An affordance matrix is created to check transitivity. The transitivity rule assumes A has a relationship with B and B has a relationship with C, then A has a real relationship with C.
- The final reachability is built through the application of the transitivity rule which is divided into several parts.
- A directed graph is drawn based on the relationship of the final reachability matrix, and the transitive links are eliminated.
- The final digraph is transformed into an ISM by replacing the element nodes with statements.
- To ensure valid results, the theoretical interpretive structural model was retested in case of inconsistencies and adjustments had to be made.

3.4. MICMAC Analysis.

The Matrices d'Impacts Croises Multiplication Appliquee a un Classement (MICMAC) analysis is a strategic method used to categorize variables into four distinct groups, aiming to pinpoint the key factors that have both direct and indirect influences on each other (Moradi et al., 2023). This approach has been applied, for instance, by Rathore et al., (2022) to uncover the indirect relationships among factors influencing coastal defenses, utilizing the concept of driving forces and dependencies associated with each factor. By calculating the sum of each row and column corresponding to a factor, its coordinates are determined, allowing for its placement on a two-dimensional graph. Subsequently, these factors are sorted into four quadrants, as detailed by Qureshi et al., (2022) as follows.

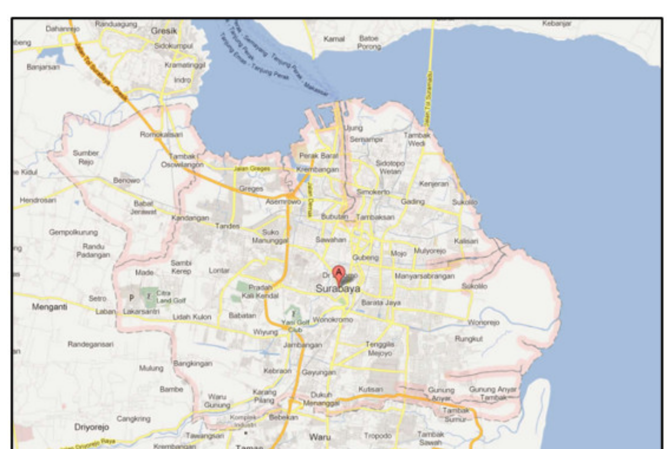
- Autonomy (Quadrant I) - factors under this quadrant have low driving force and dependency. Therefore, they do not exert much influence.
- Dependency (Quadrant II) - factors in this quadrant have weak driving forces but strong dependency forces. Other factors usually influence these factors in the lower levels of the ISM model.
- Interdependence (Quadrant III) - factors in this quadrant have strong driving forces and strong interdependence forces. They are unstable, and any action involving these factors will result in subsequent reactions that affect them and other factors.
- Independent or driving (Quadrant IV) - Factors under this quadrant are considered to be the most important factors with strong driving forces but weak dependency. This means that they can strongly influence other factors. Therefore, they require immediate attention as other factors that depend on them may be impacted.

4. Results.

4.1. Research Area.

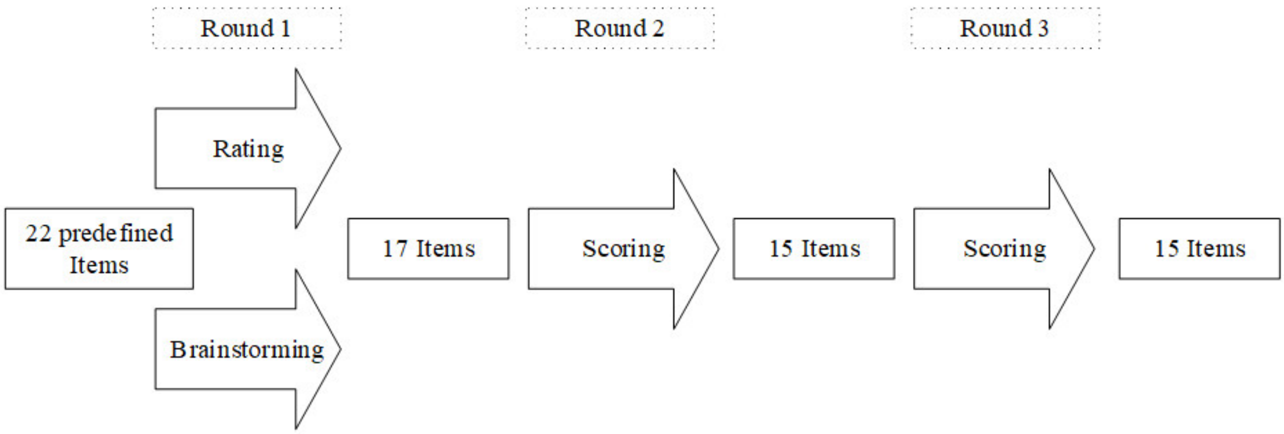
Surabaya, strategically situated on the north coast of Java Island and bordered by the Madura Strait to the north, is a pivotal hub for international trade via sea routes. As Indonesia's second-largest city Jakarta, Surabaya is characterized by its high population and building density, a trait that varies across different urban zones within the city. The city center and commercial districts, in particular, exhibit higher building densities compared to the more sparsely populated residential or rural areas (Putri and Maulana, 2023). Located in the province of East Java, Indonesia, Surabaya serves as the provincial capital and spans an area of 350.5 km^2. With a population density exceeding 9,900 people per square kilometer in the city center and tapering to about 2,200 people per square kilometer at the metropolitan outskirts, Surabaya stands as a significant urban center in Indonesia (Izzuddin, Rachmawati and Hadi, 2021).

Figure 3: Surabaya City Map.



Source: Authors.

Figure 4: Overview of different rounds and amount of factors.



Source: Authors.

4.2. Key Factors of Coastal Defense from Military Perspective.

The identification of influencing factors was achieved through a comprehensive literature review and insights from experts. A diverse panel consisting of 16 professionals, academics, and stakeholders convened to undertake the research (Table 1). Employing the Delphi method, this research aimed to assess the consensus among experts regarding criteria for coastal defense from a military standpoint, to pinpoint crucial factors. To this end, a meticulously compiled list of factors pertinent to coastal defense was incorporated into a questionnaire. The experts were then solicited to express their agreement or disagreement with the listed criteria, utilizing verbal variables for responses.

In the first round of the Delphi process, each dimension's average importance rating surpassed a mean value of 3, with the Item-Content Validity Index (Item-CVI) ranging between 0.67 and 1, thereby validating all instrument items and reducing the list from 22 to 17 items by eliminating five specific items (Interoperability with Allied Forces, Diplomatic Considerations, Public Support and Awareness, Rapid Deployment Forces, and Environmental Considerations). The second round saw further refinement, removing two items related to Resilience and Redundancy and Civil-Military Cooperation, which narrowed the list down from 17 to 15 items. After adjustments, a third round of evaluation aimed at assessing final validity confirmed the critical nature of each dimension, as all maintained an average importance rating above 3. Notably, the Item-CVI for almost all items reached 1, indicating a unanimous agreement among experts, and the overall Scale-Content Validity Index (S-CVI) stood at 87%. This high level of I-CVI marked the successful completion of the instrument's validation phase (Table 2 and Figure 4).

4.3. Developing the Hierarchy factors of Coastal Defense.

In this section, the Interpretive Structural Modeling (ISM) methodology is applied to analyze coastal defense strategies from a military viewpoint. The ISM approach is heavily dependent on insights from experts, which are collected via diverse management-oriented ideation techniques such as brainstorming and nominal group techniques. The application of the ISM methodology to coastal defense is detailed in the subsequent subsections as follows.

4.3.1. Structural self-interaction matrix.

The ISM (Interpretive Structural Modeling) approach facilitates the identification of contextual relationships among factors by leveraging the insights of experts. These specialists possess extensive experience in addressing issues pertinent to coastal defense from a military perspective. During these sessions, they assess the nature of interactions among factors, employing "influence" type contextual relationships to elucidate these connections. The methodology involves a questionnaire designed to map the directional relationship between pairs of variables (i and j). To describe the tendencies of relationships between any two elements (i and j), four distinct symbols are utilized: 'V' signifies that factor i drives the achievement of factor j; 'A' indicates that factor j drives the achievement of factor i; 'X' denotes mutual contribution between factors i and j towards their respective achievements; and 'O' represents a lack of relationship between elements i and j. Drawing upon these classifications, a Structural Self-Interaction Matrix (SSIM) was constructed to illustrate the direct relationships among the thirteen identified factors, as detailed in Table 4.

4.3.2. Final Reachability matrix.

In the process of ISM (Interpretive Structural Modeling) analysis, transforming the Structural Self - Interaction Matrix (SSIM) into an initial reachability matrix is a crucial step as follows:

- If entry (i, j) in SSIM is V, entries (i, j) and (j, i) are set to 1 and 0.
- If entry (i, j) in SSIM is A, entries (i, j) and (j, i) are set to 0 and 1.
- If entry (i, j) in SSIM is X, entries (i, j) and (j, i) are set to 1 and 1.

Table 2: Expert judgment results in the first, second, and third rounds.

SN	Factors	Round 1			Round 2			Round 3			Code
		Mean	CVI	Result	Mean	CVI	Result	Mean	CVI	Result	
1	Geographical Location	4.19	0.94	Accepted	3.94	0.81	Accepted	4.19	0.94	Accepted	F1
2	Coastal Topography	4.19	0.88	Accepted	4.25	0.94	Accepted	4.00	1.00	Accepted	F2
3	Infrastructure	4.31	0.94	Accepted	3.94	0.94	Accepted	4.63	1.00	Accepted	F3
4	Surveillance and Reconnaissance	4.19	0.81	Accepted	4.31	0.88	Accepted	4.25	0.94	Accepted	F4
5	Coastal Defense Assets	4.25	0.88	Accepted	3.63	0.88	Accepted	4.13	0.94	Accepted	F5
6	Command and control systems	4.50	0.81	Accepted	3.69	0.81	Accepted	4.25	0.94	Accepted	F6
7	Interoperability with Allied Forces	4.13	0.69	Rejected							
8	Intelligence	4.31	0.94	Accepted	4.06	0.94	Accepted	4.50	1.00	Accepted	F7
9	Awareness	3.94	0.81	Accepted	4.31	1.00	Accepted	4.63	1.00	Accepted	F8
10	Diplomatic Considerations	4.06	0.75	Rejected							
11	Resilience and Redundancy	4.19	0.94	Accepted	3.94	0.75	Rejected				
12	Public Support and Awareness	3.75	0.69	Rejected							
13	Air Defense	4.50	0.94	Accepted	4.19	0.94	Accepted	4.50	0.94	Accepted	F9
14	Coastal Artillery and Missile Systems	4.31	0.88	Accepted	4.00	0.88	Accepted	4.50	1.00	Accepted	F10
15	Fortifications	4.06	0.81	Accepted	4.25	0.88	Accepted	4.44	1.00	Accepted	F11
16	Amphibious Assault	4.19	0.81	Accepted	4.44	0.88	Accepted	4.44	0.94	Accepted	F12
17	Electronic Warfare	3.94	0.81	Accepted	4.44	0.94	Accepted	4.19	1.00	Accepted	F13
18	Civil-military cooperation	4.19	1.00	Accepted	3.63	0.69	Rejected				
19	Logistics Support	4.25	0.81	Accepted	4.38	1.00	Accepted	4.31	1.00	Accepted	F14
20	Rapid deployment forces	3.81	0.69	Rejected							
21	Legal Framework	4.19	0.94	Accepted	4.44	0.94	Accepted	4.31	1.00	Accepted	F15
22	Environmental Considerations	3.88	0.75	Rejected							

Source: Authors.

- If entry (i, j) in SSIM is O, entries (i, j) and (j, i) are set to 0 and 0.

Based on the initial affordability matrix, construct the final affordability matrix by considering the transitivity rule. According to the rule, some cells containing 0 should be replaced with 1. The results are shown in Table 5.

4.3.3. Level Partitions.

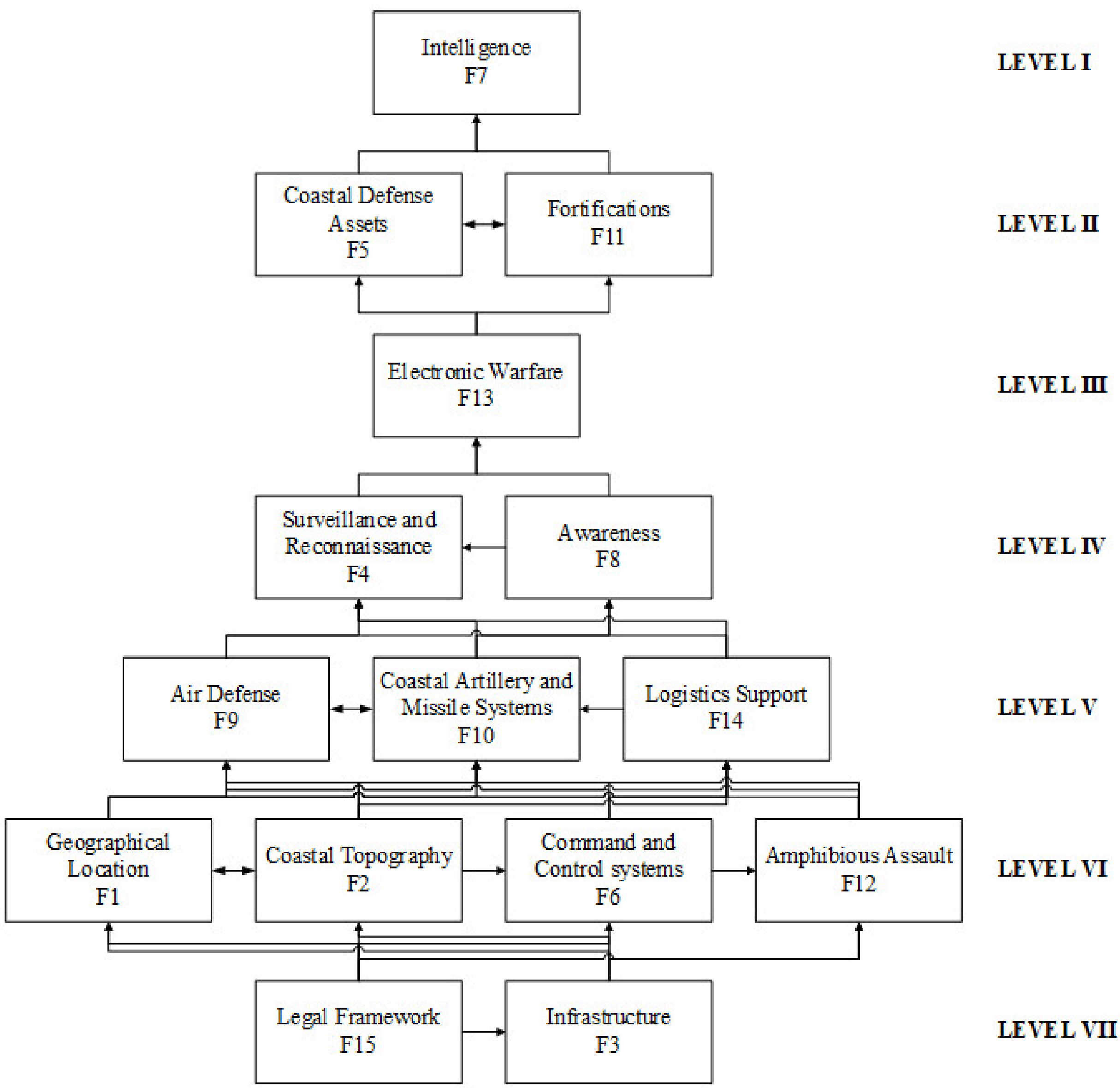
Level partitioning organizes components into a hierarchy by evaluating relationships among variables, a method introduced by Warfield (1974). This approach utilizes the final reachability matrix to determine each component's preliminary set and reachability, initially identifying high-level factors such as affordability and intersectionality to define the top tier of the ISM table. This iterative process separates high-level aspects and then categorizes remaining elements into classification levels, facilitating the development of a directed graph (digraph) and the final ISM model (Moradi et al., 2023). The process identifies reachable factors, antecedents, intersections, and the initial and final levels of each element, requiring five iterations to complete the level assessment and producing a hierarchical structure with seven levels for the drivers under consideration.

4.3.4. Interpretive Structure Modeling (ISM).

The partition levels presented in Table 6 serve as the foundation for constructing a hierarchical model that identifies the supporting factors affecting coastal defense from a military standpoint. This involves plotting the relationships between various characteristics. An interval is established for the scores, and any relationship with an average score below this threshold is excluded from the diagram, resulting in a directed graph, or digraph. Following the ISM methodology, by removing transitivity, this digraph is converted into the ISM model depicted in Figure 5. The ISM model illustrates the interdependencies between various supporting factors across seven distinct levels.

Utilizing the partition levels mentioned earlier, we develop a hierarchical structural model depicted in Figure 5. In this model, drivers are organized hierarchically across levels 1 to 7, with drivers positioned at lower levels influencing those at higher levels. Generally, drivers possessing significant driving

Figure 5: ISM-based model from factors of Coastal Defense.



Source: Authors.

Table 3: Factors related to coastal defense from military perspective..

Code	Factors	Sources
F1	Geographical Location	Chen et al. (2023); Ke (2015); Tan et al. (2020); Wang et al. (2023)
F2	Coastal Topography	Young et al. (2014); Zhang et al. (2021); Tan et al. (2022); Col, (2014)
F3	Infrastructure	Shutz (2021); Evans et al. (2017); Iuorio et al. (2024); Kantamaneni et al. (2022)
F4	Surveillance and Reconnaissance	Li (2009); Kung & Ma (2014); Col (2014); Ng (2017); Portocarrero (2011); Shao et al. (2023)
F5	Coastal Defense Assets	Balkan & Yeşiltaş (2023); Col (2014); Li (2009); Morris et al. (2019); Riley (1999); Wallis et al.(2010)
F6	Command and control systems	Balkan & Yeşiltaş (2023); Col (2014); Li (2009); Ng (2017); Chester, Jr (2016)
F7	Intelligence	Li (2009); Zhang et al. (2021)
F8	Awareness	Balkan & Yeşiltaş (2023); Chester, Jr (2016); Ng (2017); Shi (2021); Xiaoyan (2014)
F9	Air Defense	Li (2009); Ng (2017); Zhang et al. (2021)
F10	Coastal Artillery and Missile Systems	Balkan & Yeşiltaş (2023); Col (2014); Li (2009); (Papelitzky (2019); Shi (2021); Zurndorfer (2016); Shao et al.(2023)
F11	Fortifications	Col (2014); Portocarrero (2011); Shao et al.(2023); Shen et al. (2023); Tan et al. (2022)
F12	Amphibious Assault	Balkan & Yeşiltaş (2023); Col (2014); Henderson (Henderson, 2019)
F13	Electronic Warfare	Alsemairi (2022); Li (2009)
F14	Logistics Support	Cao & Zhang (Cao and Zhang, 2018); Chen (2019); Col (2014); Li (2009); Ku (2019)
F15	Legal Framework	O'Connor et al. (2009); Cardiff University (2004)

Source: Authors.

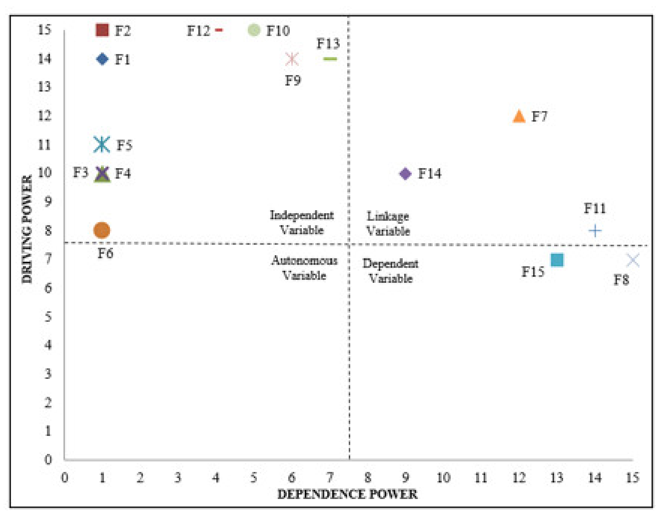
power are placed at the lower levels of the hierarchy, whereas those with greater dependence power are situated at the higher levels.

4.3.5. MICMAC Analysis.

The MICMAC analysis is designed to assess the driving force and the degree of dependence among elements within the Interpretive Structural Modeling (ISM) framework. This analysis was specifically applied to evaluate the driving and dependency powers of drivers crucial to coastal defense. In the analysis, dependability and driving force are plotted on the Y and X axes, respectively. Utilizing the final affordance matrix, a straightforward MICMAC analysis was conducted to examine the impact of 15 influential drivers identified in this research. Based on their driving power and dependency power, these drivers are categorized into four groups: autonomous, independent, linkage, and dependent, as illustrated in Figure 6.

Figure 6 from the MICMAC analysis delineates the roles of different variables in coastal defense based on their driving and dependency forces. It shows that Legal Framework and Awareness are dependent variables with strong dependency but weak driving forces, indicating they are more influenced than influential. In contrast, a group of ten variables including Geographical Location, Coastal Topography, Infrastructure, Surveillance

Figure 6: Driving power and dependency diagram from factors of Coastal Defense.



Source: Authors.

Table 4: Structural self-interaction matrix from factors of Coastal Defense.

Code	Factors	Factors														
		F15	F14	F13	F12	F11	F10	F9	F8	F7	F6	F5	F4	F3	F2	F1
F1	Geographical Location	V	V	V	V	V	V	V	X	V	V	V	V	V	X	-
F2	Coastal Topography	V	V	V	V	X	V	V	X	V	V	X	X	V	-	
F3	Infrastructure	A	V	V	V	A	V	V	A	X	V	X	X	-		
F4	Surveillance and Reconnaissance	A	V	V	V	A	V	X	A	X	X	V	-			
F5	Coastal Defense Assets	A	V	X	V	X	X	V	A	V	V	-				
F6	Command and Control Systems	A	A	X	V	A	V	X	X	X	-					
F7	Intelligence	X	X	X	V	X	V	V	X	-						
F8	Awareness	X	V	V	V	X	V	V	-							
F9	Air Defense	A	A	X	V	A	X	-								
F10	Coastal Artillery and Missile Systems	A	A	X	X	A	-									
F11	Fortifications	X	X	V	V	-										
F12	Amphibious Assault	A	X	X	-											
F13	Electronic Warfare	A	A	-												
F14	Logistics Support	X	-													
F15	Legal Framework	-														

Source: Authors.

Table 5: Final reachability matrix from factors of Coastal Defense.

Code	Factors															DP*
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	
F1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	14
F2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
F3	0	0	1	1	1	1	1	0	1	1	0	1	1	1	0	10
F4	0	1	1	1	1	1	1	0	1	1	0	1	0	1	0	10
F5	0	1	1	0	1	1	1	0	1	1	1	1	1	1	0	11
F6	0	0	0	1	0	1	1	1	1	1	0	1	1	0	0	8
F7	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	12
F8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
F9	0	0	0	1	0	1	0	0	1	1	0	1	1	0	0	6
F10	0	0	0	0	1	0	0	0	1	1	0	1	1	0	0	5
F11	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
F12	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	4
F13	0	0	0	0	1	1	1	0	1	1	0	1	1	0	0	7
F14	0	0	0	0	0	1	1	0	1	1	1	1	1	1	1	9
F15	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	13
DEP*	3	6	9	10	10	13	12	7	14	15	8	15	14	10	7	

*DEP= Dependence Power; DP= Driving Power

Source: Authors.

and Reconnaissance, Coastal Defense Assets, Command and Control Systems, Air Defense, Coastal Artillery and Missile Systems, Amphibious Assault, and Electronic Warfare are classified as independent due to their strong driving force and weak dependency, highlighting their significant influence on the system with minimal external influence on them. Linkage variables, consisting of Intelligence, Fortifications, and Logistics Support, exhibit both strong driving and dependency forces, making them highly dynamic and interdependent, indicating that changes in these variables significantly impact others. Notably, no variables are categorized as autonomous, which would indicate weak driving and dependency forces, underscoring that all identified variables are crucial to coastal defense, emphasizing the interconnectedness and significance of each from the military perspective.

5. Discussion.

This research developed a comprehensive model for assessing coastal defense factors from a military standpoint, utilizing a combination of three rounds of the Delphi method and Interpretive Structural Modeling (ISM). This integrated approach led to a consensus among experts on two primary indices for model formulation. Through content analysis, involving open and axial coding, we identified fifteen critical factors based on qualitative interviews and Delphi feedback. To enhance accuracy, the expert panel reviewed the interpretive structural model and the results from the MICMAC analysis, confirming the model's capacity to encompass relevant factors for the current scenario. The findings are articulated through a structural discussion, delineating the factorization levels derived from the ISM model.

The ISM technique facilitated the creation of a structured

Table 6: Level partitions from factors of Coastal Defense.

Code	Reachability	Antecedent	Intersection	Level
F1	1;2;3;4;5;6;7;8;9;10;11;12;13;15	1;2;8	1;2;8	VI
F2	1;2;3;4;5;6;7;8;9;10;11;12;13;14;15	1;2;4;5;8;11	1;2;4;5;8;11	VI
F3	3;4;5;6;7;9;10;12;13;14;	1;2;3;4;5;7;8;11;15	3;4;5;7	VII
F4	2;3;4;5;6;7;9;10;12;14	1;2;3;4;6;7;8;9;11;15	2;3;4;6;7;9	IV
F5	2;3;5;6;7;9;10;11;12;13;14	1;2;3;4;5;8;10;11;13;15	2;3;4;5;10;11;13	II
F6	4;6;7;8;9;10;12;13	1;2;3;4;5;6;7;8;9;11;13;14;15	4;6;7;8;9;13	VI
F7	3;4;6;7;8;9;10;11;12;13;14;15	1;2;3;4;5;6;7;8;11;13;14;15	3;4;6;7;8;11;13;14;15	I
F8	1;2;3;4;5;6;7;8;9;10;11;12;13;14;15	1;2;6;7;8;11;15	1;2;6;7;8;11;15	IV
F9	4;6;9;10;12;13	1;2;3;4;5;6;7;8;9;10;11;13;14;15	4;6;9;10;13	V
F10	5;9;10;12;13	1;2;3;4;5;6;7;8;9;10;11;12;13;14;15	5;9;10;12;13	V
F11	2;3;4;5;6;7;8;9;10;11;12;13;14;15	1;2;5;7;8;11;14;15	1;2;5;7;8;11;14;15	II
F12	10;12;13;14	1;2;3;4;5;6;7;8;9;10;11;12;13;14;15	10;12;13;14	VI
F13	5;6;7;9;10;12;13	1;2;3;5;6;7;8;9;10;11;12;13;14;15	5;6;7;9;10;12;13	III
F14	6;7;9;10;11;12;13;14;15	2;3;4;5;7;8;11;12;14;15	6;7;11;12;14;15	V
F15	3;4;5;6;7;8;9;10;11;12;13;14;15	1;2;7;8;11;14;15	7;8;11;14;14	VII

Source: Authors.

model to pinpoint and organize factors influencing coastal defense from a military lens, revealing a seven-tiered model. According to Figure 6, ”Intelligence” (F7) emerges as the sole factor at level one, signifying its pivotal role. The MICMAC analysis further underscores the ”Intelligence” factor’s critical position, showing high levels of both dependence and driving power, thus marking it as a crucial linkage variable. Effective intelligence gathering and analysis are vital for coastal defense, offering insights into potential threats, adversary capabilities, intentions, and vulnerabilities. Key intelligence components in military coastal defense include surveillance through radar systems, unmanned aerial vehicles (UAVs), satellites, and maritime patrol aircraft, all crucial for monitoring sea and coastline activities (Li, 2009). Reconnaissance missions play a significant role in gathering intelligence on enemy movements, identifying potential targets, and evaluating the effectiveness of defense strategies (Solmaz, 2017).

Figure 6 also highlights that the ”Legal Framework” (F15) and ”Infrastructure” (F3) factors are positioned at lower levels in the model. However, MICMAC analysis reveals that the ”Legal Framework” has a high dependency level, indicating its fundamental role in guiding local government actions without specifying how coastal protection priorities should be executed (O’Connor et al., 2009). The significance of a legal framework is accentuated in managing coastal defense and coastline preservation, especially in the context of climate change, advocating for legal and policy measures to confront these challenges through an integrated approach (Cardiff University, 2004). Conversely, ”Infrastructure” is identified as a high driving force (Evans et al., 2017), reflecting its importance in establishing effective coastal defense mechanisms through the strategic placement of assets (Col, 2014) and locations to safeguard against potential threats (Wang et al., 2023).

The MICMAC analysis within this research delineates three principal categories of variables based on their interdependencies and driving forces, as illustrated in Figure 6. These categories are crucial for understanding the dynamics of coastal defense factors from a military perspective. The analysis segments the variables into four clusters: autonomous, dependent, linkage, and independent, each reflecting different levels of influence and interconnectivity within the system.

Autonomous Cluster: This category comprises factors with both low driving force and low dependency, indicating minimal impact on the system. In this analysis, it was determined that there are no factors classified as autonomous, suggesting that all identified factors hold significance in the coastal defense context.

Dependent Cluster: Factors in this cluster possess low driving force but high dependency. They are influenced by other factors but do not exert much influence themselves. Within this category, the ”Legal Framework” (F15) and ”Awareness” (F8) are highlighted.

Linkage Cluster: Variables within the linkage cluster exhibit both high driving force and high dependency, making them highly interconnected. Actions affecting these variables will likely impact others, and they will also experience feedback effects. This cluster’s nature renders the factors within it unstable but crucial for the system’s dynamics. The factors classified under this category are ”Intelligence” (F7), ”Fortifications” (F11), and ”Logistics Support” (F14), each playing a pivotal role in the operational effectiveness and resilience of coastal defense strategies.

Independent Cluster: This cluster groups variables characterized by high driving force and low dependency. These are deemed critical factors for the system, driving changes and influencing the coastal defense framework significantly while being relatively independent of other variables. The ten factors in this cluster include ”Geographical Location” (F1), ”Coastal Topography” (F2), ”Infrastructure” (F3), ”Surveillance and Reconnaissance” (F4), ”Coastal Defense Assets” (F5), ”Command and Control Systems” (F6), ”Air Defense” (F9), ”Coastal Artillery and Missile Systems” (F10), ”Amphibious Assault” (F12), and ”Electronic Warfare” (F13). These elements are fundamental to the development and success of coastal defense initiatives, highlighting areas where strategic focus and resource allocation are most critical.

5.1. Implication.

This section is divided into two main parts: the theoretical implications of coastal defense from a military standpoint and the practical implications for management.

Theoretical Implications: this research aims to bridge existing gaps in academic and research literature by offering a detailed analysis of the key factors influencing coastal defense through a sustainable military lens. Notably, it identifies the Legal Framework and Infrastructure as pivotal elements in this context. This underscores the importance of designing and implementing interdisciplinary courses that integrate coastal defense concepts from a military perspective.

Secondly, we have developed a hierarchical model of these factors using the Interpretive Structural Modeling (ISM) method. This model elucidates the hierarchy and interconnections among the identified factors, organizing them into a structured hierarchy and pinpointing 15 distinct elements. The analysis reveals the intricate interrelationships among these factors, highlighting their collective significance. Through the application of the ISM methodology, this research offers fresh perspectives on how these factors interrelate, emphasizing the critical nature of understanding the dynamics between various variables, their dependencies, and their driving forces. However, this research stops short of examining the detailed interactions among specific driving factors, suggesting an avenue for future studies to explore these dynamics further.

Managerial / Practical Implications: this research provides actionable insights for practitioners and policymakers by introducing new methodologies for understanding and applying concepts of coastal defense from a military vantage point. It presents a systematically organized conceptual model that aids policymakers in developing defense capabilities, particularly beneficial for military strategists responsible for safeguarding extensive coastal regions.

Furthermore, this model is instrumental for government bodies in designing defense force development programs that transcend mere military training to include initiatives aimed at fostering sustainable entrepreneurship, particularly in coastal areas. This approach not only benefits policymakers but also educational institutions and incubation centers by encouraging a holistic and systematic exploration of coastal defense strategies beyond traditional military frameworks. Consequently, this research contributes to the broader knowledge base, promoting sustainable practices within coastal defense and coastal zone management realms.

Conclusions.

The research explores the integration of military - related coastal defense factors into a structured framework using interpretive modeling, leveraging a dual methodology that combines the Delphi and ISM-MICMAC approaches. This endeavor aims to fill the gap in existing literature by methodically categorizing and prioritizing coastal defense factors into a hierarchical model. Initially, through a rigorous literature review and expert evaluations via the Delphi method, 15 key coastal defense factors were identified. These factors were further analyzed using the Interpretive Structural Modeling (ISM) approach to establish their contextual relationships and construct a hierarchical model, revealing the Intelligence factor (F7) as a foundational element and positioning the Legal framework (F15) and Infrastructure (F3) at lower levels of influence.

Subsequently, the MICMAC analysis was applied to assess the interdependencies among the identified factors, categorizing ten into an independent cluster, thereby underscoring their critical role. Additionally, three factors were recognized as linking variables, and two were classified as dependent, illustrating a complex network of interactions. Notably, the absence of factors in the autonomous category emphasizes the significance of each factor within the coastal defense framework.

Limitation and Future Work.

This research is subject to several limitations. Firstly, the exploratory nature of our analysis is primarily due to the utilization of the Delphi Approach. Future investigations could employ questionnaire-based surveys, gathering insights from a broader range of stakeholders to assess potential tangible or intangible threats and their implications for coastal defense strategies.

Secondly, while the model developed herein offers valuable insights, it is acknowledged that it is not without its imperfections. Nonetheless, it serves as a useful reference for further studies concerning coastal defense and the broader field of coastal zone management. Future research endeavors could adapt and test this model across different geographical locales by modifying the relevant factors to suit specific regional contexts. To further substantiate the model's validity, integrating Interpretive Structural Modeling (ISM) with Structural Equation Modeling (SEM) is recommended for more rigorous statistical validation and empirical analysis of the results.

Thirdly, the scope of this research could be broadened to encompass the examination of coastal defense mechanisms outside the military domain by incorporating a diverse array of driving factors. The application of the Delphi technique, followed by interpretative structural modeling (ISM), facilitated the identification of interrelationships among 15 critical drivers based on the study's findings. For future verification of these results, employing alternative methodologies such as the Analytical Hierarchy Process (AHP), Decision-Making Trial and Evaluation Laboratory (DEMATEL), Analytical Network Process (ANP), and approaches involving fuzzy logic and system dynamics is suggested.

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