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Big Data Analytics and AI-Driven Maritime Intelligence: Transforming Public Policy for Hybrid Threat Mitigation in the North Natuna Sea

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ABSTRACT

Background. The North Natuna Sea faces overlapping maritime security challenges involving contested activities, fragmented surveillance information, and emerging hybrid threats. These conditions demand timely intelligence and coordinated public policy without compromising legal accountability.

Purpose. This study aims to examine how big data analytics and artificial intelligence can support maritime intelligence integration and inform responsive policies for hybrid threat mitigation.

Method. A mixed-methods research framework is proposed, combining policy document analysis, stakeholder interviews, and quantitative evaluation of anonymized maritime surveillance indicators. The analytical approach integrates data quality assessment, predictive modeling, and thematic analysis to evaluate institutional coordination, decision support, and governance safeguards.

Results. The proposed framework identifies potential benefits in detecting anomalous maritime patterns, improving information sharing, and prioritizing policy responses. However, its anticipated constraints include data fragmentation, algorithmic uncertainty, institutional interoperability, and risks to transparency and privacy. (Note: These propositions remain unverified until empirical analysis is completed).

Conclusion. The study concludes that AI-enabled maritime intelligence should complement, rather than replace, human judgment and established legal procedures. Effective adoption requires interoperable data standards, accountable oversight, rigorous model validation, and sustained interagency collaboration. The framework offers a testable basis for strengthening evidence-informed maritime governance while avoiding unsupported claims about operational effectiveness or threat reduction in the North Natuna Sea.

KEYWORDS

Artificial Intelligence; Big Data Analytics; Hybrid Threat Mitigation; Maritime Intelligence; Public Policy.

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INTRODUCTION

The North Natuna Sea occupies a particularly sensitive strategic position in Indonesia's maritime governance, where fisheries protection, navigation, and competing geopolitical interests intersect (Hatmaja & Zandika, 2024). Encounters involving foreign vessels create challenges for enforcement agencies and diplomatic institutions (Adi, 2026). Maritime security consequently requires reliable information, coordinated judgment, and policies that distinguish lawful activities from potentially harmful behavior without escalating tensions unnecessarily

Contemporary maritime monitoring generates extensive and increasingly complex information from vessel identification systems, satellite observations, administrative records, and public reporting (Zhang dkk., 2024). Big data analytics can organize these heterogeneous sources, while artificial intelligence may identify unusual movement patterns and support timely interpretation (Zhang dkk., 2025). Their usefulness nevertheless depends on data quality, transparent assumptions, and institutional capacity to evaluate uncertain signals.

Evolving hybrid threats increasingly complicate maritime governance because ambiguous or coordinated activities may combine economic pressure, information manipulation, and coercive signaling below conventional conflict thresholds (Yang dkk., 2024). Analysts must avoid categorizing every irregular vessel movement as hostile behavior. Effective policy requires legally grounded risk assessment that connects maritime intelligence with proportional responses, interagency consultation, and appropriate oversight of automated recommendations.

Indonesia's maritime authorities face a persistent information integration problem when datasets are maintained through separate systems, mandates, and access arrangements (Zhao dkk., 2024). Such fragmented records may delay interpretation or produce inconsistent assessments of the same event (Kurniawan dkk., 2024). The central challenge is therefore not simply collecting additional information but transforming available evidence into a shared, accountable understanding of maritime risks.

Artificial intelligence introduces significant additional methodological difficulties involving incomplete vessel identification records, biased training data, false alarms, and limited model explainability (Ma dkk., 2024). An anomaly score can indicate unusual behavior without establishing illegality or hostile intent (Adhayanto dkk., 2025). Policy decisions based on poorly validated outputs could divert institutional resources, compromise confidence, or encourage disproportionate responses in diplomatically sensitive waters.

Responsible maritime public policy must also reconcile intelligence sharing with legal authority, privacy safeguards, and institutional responsibility (Puig & Darbra, 2024). Agencies may interpret information differently because their mandates and decision criteria vary. A technically accurate prediction cannot guarantee effective governance when accountability, communication, and response procedures remain unclear (Mi dkk., 2024). These tensions motivate examination of the interface between analytical systems and policy institutions.

The present study aims specifically to examine how big data analytics and artificial intelligence could support integrated maritime intelligence for public policy in the North Natuna Sea (Yan dkk., 2024). Its first objective is to identify relevant information sources, integration challenges, and analytical capabilities (Peterson, 2024). The investigation treats intelligence generation as a governed process rather than an automated substitute for institutional judgment.

The second research objective is to assess how analytical outputs may inform the recognition, interpretation, and prioritization of potential hybrid threats (Tan dkk., 2025). Especially careful attention is given to uncertainty, false positives, cross-source corroboration, and the distinction between anomalous behavior and legally established violations (Liu & Yuen, 2025a). This objective connects technical assessment to proportional and evidence-informed policy deliberation.

The third specific objective is to formulate a governance framework linking data interoperability, model validation, human oversight, and interagency coordination (S. Nguyen dkk., 2026). The framework is intended to clarify conditions under which intelligence insights can support accountable decisions (Agrawal dkk., 2025). Its subsequent evaluation would consider institutional feasibility alongside analytical performance, without claiming that technological adoption independently reduces maritime threats.

Several existing studies of North Natuna security have examined maritime diplomacy, foreign vessel encounters, and institutional responses (Liu & Yuen, 2025b). Putra (2023), for example, analyzed constabulary diplomacy as an instrument for managing tensions in contested waters. This existing scholarship illuminates strategic behavior but provides less direct guidance on evaluating the institutional translation of AI-generated intelligence into public policy.

Extensive technical literature has separately investigated vessel behavior recognition and maritime anomaly detection (Owowo dkk., 2024). Ribeiro and colleagues (2023) reviewed methods using Automatic Identification System data and highlighted the complexity of identifying irregular traffic patterns. These established approaches provide methodological foundations, yet detecting anomalies does not by itself establish appropriate legal classification, institutional responsibility, or policy response.

Recent research on Indonesian maritime enforcement has also identified coordination and resilience challenges (Zampeta dkk., 2025). Recent analysis of the one-roof enforcement model emphasized institutional fragmentation and the need for adaptive governance (Awasthi dkk., 2024). The specific scholarly gap addressed here concerns integrating analytical reliability, human interpretation, and public accountability within one framework tailored to hybrid threat assessment in the North Natuna Sea.

The proposed principal novelty is a policy-centered integration of big data analytics, AI-driven maritime intelligence, and governance safeguards within a single analytical framework (Fang dkk., 2026). Rather than narrowly treating detection accuracy as the sole benchmark, the study evaluates whether information can be interpreted, reviewed, and communicated appropriately. Originality rests on this specific integration, not on claiming that maritime analytics is new.

Methodologically, the present research proposes combining documentary policy analysis, stakeholder perspectives, and evaluation of anonymized maritime indicators where lawful access is available (H. A. Nguyen & Kuo, 2026). This methodological combination could reveal discrepancies between model performance and institutional usability (Rajalakshmi dkk., 2026). Transparent procedures for assessing uncertainty and tracing decisions would distinguish the framework from purely technical monitoring proposals while remaining sensitive to information security.

The proposed study is justified by the need for responsible digital transformation of maritime governance. Evidence-informed coordination may improve how institutions prioritize investigations and evaluate competing explanations (Velandia dkk., 2025). However, technological modernization should remain subordinate to legal standards, diplomatic restraint, and democratic accountability (Suwondo dkk., 2025). Empirical validation will determine whether the proposed framework offers practical improvements beyond existing arrangements.

RESEARCH METHODOLOGY

This study proposes a convergent mixed-methods design to investigate how big data analytics and artificial intelligence can inform accountable maritime public policy in the North Natuna Sea. The quantitative component will evaluate anomaly detection using legally accessible, historical, and anonymized vessel activity indicators, emphasizing data quality, predictive performance, and uncertainty (Velandia dkk., 2025). The qualitative component will examine policy documents and interview accounts concerning intelligence interpretation, interagency coordination, legal safeguards, and responses to ambiguous maritime events. Both components will be analyzed separately before their findings are integrated through a joint display comparing technical evidence with institutional judgments (Park & Veerappampalayam Easwaramoorthy, 2026). The design treats

automated alerts as decision-support information, not proof of illicit conduct or hostile intent. Research questions address the reliability of integrated data, the institutional usability of analytical outputs, and the governance conditions needed for proportionate decisions. Evaluation will be observational rather than experimental, limiting conclusions about causal effects on security incidents (Montaron dkk., 2026). No real-time vessel tracking, operational targeting, or restricted intelligence will be collected. All procedures will respect applicable authorization requirements and prioritize reproducibility without exposing sensitive maritime information. Institutional context will guide interpretation.

The study population encompasses two analytically distinct sources: maritime information records and professionals involved in Indonesian maritime governance. The quantitative sampling frame will consist of historical vessel activity records and accompanying contextual indicators available through approved public or institutional channels for a predefined observation period (Concepcion, 2025). Sampling will preserve variation across time and documented activity categories, while recording exclusions caused by missing identifiers, inconsistent timestamps, or insufficient contextual information. Exact sample size will be determined after assessing accessible records and the prevalence of independently verified events (Mega Jaya dkk., 2024). The qualitative sample will include approximately 15 to 20 purposively recruited participants from relevant maritime oversight, policy, legal, research, and data management organizations. Selection will prioritize direct professional experience and diversity of institutional perspectives rather than statistical representativeness. Participants will be adults who provide informed consent and will not be asked to disclose confidential operational procedures. Recruitment will proceed only after institutional permissions and ethics approval. Final reporting will identify the data coverage, record counts, participant characteristics, recruitment limitations, and potential selection biases without identifying individuals. Data representativeness will remain provisional.

Quantitative instruments will comprise a documented data extraction protocol, a data dictionary, and an evaluation framework for machine learning outputs. Variables may include anonymized movement summaries, temporal indicators, data availability measures, and independently documented incident labels when their provenance is reliable. Model assessment will emphasize precision, recall, false-positive rates, calibration, and performance across relevant time periods; baseline statistical approaches will provide comparison. The study will avoid interpreting an algorithmic anomaly score as a legal determination. Qualitative instruments will include a semi-structured interview guide and a policy-document review matrix covering data interoperability, interpretability, institutional mandates, accountability, and privacy safeguards. Experts in maritime governance, research ethics, and analytical methodology will review instrument relevance and clarity. Pilot interviews and preliminary data audits will support revisions before full collection. Interview questions will focus on decision processes and governance challenges without soliciting tactical information. An audit trail will document coding choices, model assumptions, source quality, and analytical deviations. Permission conditions will determine whether supporting materials can be shared openly. External validation remains essential.

Research procedures will begin with ethics review, access authorization, instrument refinement, and registration of the analysis plan. Approved historical datasets will be cleaned, harmonized, and checked for missingness, duplication, temporal inconsistencies, and potential reporting bias. Records will be partitioned chronologically into development and holdout sets to reduce information leakage. Candidate models and simpler baselines will be evaluated on the same holdout data, with uncertainty and subgroup performance reported. Where verified labels are unavailable, outputs will be described as exploratory patterns rather than validated threat

predictions. Interviews will be conducted with consent, securely transcribed, deidentified, and examined using reflexive thematic analysis. Policy documents will be coded for statutory authority, oversight arrangements, and information-sharing constraints. A joint display will compare model performance with participants' assessments of utility and institutional feasibility, preserving contradictory evidence. Sensitivity analyses will examine alternative missing-data decisions and evaluation thresholds. Results will be interpreted in relation to legal proportionality, human oversight, and limits of generalization. Reporting will exclude identifiable operational details, disclose limitations, and distinguish proposed governance improvements from demonstrated policy effects. Independent replication is encouraged.

RESULT AND DISCUSSION

The descriptive assessment begins with the coverage and provenance of historical maritime records collected for the North Natuna Sea. The reporting dataset should identify its observation period, authorized providers, original record counts, and the number retained after eligibility screening. Table 1 organizes the minimum evidence required to evaluate coverage and completeness. Verified counts must be inserted from the processing log, with each exclusion documented so readers can distinguish genuinely missing information from records deliberately withheld under access restrictions within this specific maritime setting.

Table 1. Descriptive Characteristics and Coverage of Maritime Intelligence Data

Data Indicator	Measurement	Simulated Result
Observation period	Historical coverage	January 2024–December 2025
Historical vessel records	Raw observations	12,000
Unique anonymized vessels	Distinct identifiers	2,500
Records passing quality screening	Valid observations	10,000 (83.33%)
Records with verified incident labels	Hypothetical labeled observations	4,000 (40.00% of valid records)
Duplicate records	Removed observations	800 (6.67% of raw records)
Other excluded observations	Missing or inconsistent records	1,200 (10.00% of raw records)
Policy documents reviewed	Simulated documentary corpus	24
Stakeholder interviews	Simulated participants	18

Secondary material should contextualize the analytical dataset through published policy documents, aggregate maritime governance reports, and independently documented incident descriptions. These sources may clarify changing institutional mandates, reporting practices, and the legal categories applied to maritime events. Their interpretation requires attention to differences in institutional definitions and observation periods, since inconsistent administrative counts cannot be combined as though they represent equivalent phenomena. Descriptive statistics should report missingness, duplication, reporting intervals, and event-label availability before any model is evaluated. Such documentation establishes whether an apparent pattern reflects maritime activity or artifacts introduced by uneven data collection and subsequent harmonization.

The principal explanatory concern is whether combining heterogeneous information improves interpretability without concealing source uncertainty. Historical movement summaries and official

incident descriptions may provide complementary perspectives, although matching them across time and geography can introduce errors. Analysts should document the criteria used for alignment and distinguish high-confidence matches from uncertain associations. A larger integrated dataset is not inherently more reliable than its components. Explanations of improved information coverage would require demonstrable reductions in missing fields or better corroboration, rather than merely an increase in processed records.

Institutional interpretations also affect what analytical outputs can reasonably mean for public policy. Anomalous patterns identify departures from a statistical reference distribution; they do not demonstrate illegal conduct, malign coordination, or hostile intent. Unusual observations may arise from legitimate operational variation, recording errors, or changes in monitoring coverage. Any explanation of flagged activity should therefore involve contextual review and legally appropriate evidentiary standards. Policy officials may consider alerts useful for prioritizing scrutiny without treating them as conclusions. The results should report how frequently alerts were corroborated and how unresolved cases were handled, if reliable verification information exists.

The data-quality analysis examines completeness, consistency, duplication, temporal stability, and the availability of trustworthy evaluation labels. Table 2 supplies a structured description of these properties alongside the selected model-development and holdout periods. Missing observations should be expressed as percentages of applicable records rather than all possible fields combined. Event categories must reflect independently documented definitions, while ambiguous records should remain distinguishable from confirmed negative examples. Time-based separation reduces the risk that repeated observations from the same historical sequence inflate apparent predictive performance. Every reported value should derive from reproducible preprocessing operations recorded before the final modeling decisions.

Table 2. Data Quality Assessment and Analytical Dataset Preparation

Quality Dimension	Evaluation Indicator	Simulated Result
Completeness	Missing values in retained records	3.20%
Consistency	Timestamp and formatting anomalies initially detected	420 records
Uniqueness	Duplicate records removed	800
Temporal coverage	Coverage of the planned observation period	24 months
Label availability	Records with simulated reference labels	4,000
Model development dataset	Training and validation observations	8,000
Holdout dataset	Chronological test observations	2,000
Source agreement	Illustrative cross-source matching rate	89.40%

Interview material provides a different descriptive layer, centered on how professionals understand information sharing, analytical reliability, and accountability. The qualitative reporting should specify completed interviews, broad institutional roles, transcript coverage, and the documentary sources reviewed. Themes must emerge from recorded statements and coded evidence rather than from anticipated policy recommendations. Table 3 shows how themes, supporting sources, and contradictory accounts can be organized. Direct quotations should appear only when participants consented to their use and when disclosure poses no identification or security risk. Differences between institutional perspectives are analytically meaningful and should not be averaged into a fictional consensus.

Table 3. Qualitative Reporting Framework for Maritime Intelligence Governance

Analytical Theme	Simulated Participants Mentioning Theme (n = 18)	Percentage (%)
Interagency information sharing	16	88.89
Data interoperability	15	83.33
AI interpretability	14	77.78
Institutional accountability	15	83.33
Human oversight	17	94.44
Policy responsiveness	13	72.22

Inferential evaluation should compare an interpretable baseline with candidate analytical models using a chronologically separated holdout dataset. Precision, recall, false-positive rate, and calibration describe different aspects of performance; no single metric adequately represents policy utility. Performance comparisons require uncertainty intervals derived through an appropriate resampling design that respects temporal dependence, rather than treating repeated maritime observations as independent cases. Reserves space for validated estimates and comparison intervals. Where verified event labels are unavailable, supervised detection metrics cannot legitimately be calculated, and the results should instead describe exploratory pattern identification without asserting predictive accuracy or threat classification.

Model comparisons should also examine performance instability across periods with different reporting density or source availability. A model that performs well in one interval may degrade when data collection practices change. Sensitivity analyses should assess alternative missing-data treatments, decision thresholds, and reasonable baseline specifications. Statistical significance, where assessed, must be distinguished from practical relevance, especially when a small accuracy gain accompanies a substantial increase in false alerts. The study should not equate a lower anomaly score with reduced security risk. Meaningful inference concerns the behavior of an analytical system on defensible evaluation data, not evidence that public policy has already improved.

Relationships between analytical outputs and institutional processes should be examined through traceable decision pathways. Data interoperability may affect whether agencies can corroborate observations, while model interpretability may shape whether officials can evaluate an alert's evidentiary basis. Oversight procedures determine who can challenge an automated recommendation and document the final decision. Connects these dimensions with measurable indicators and qualitative evidence. The proposed relationships are analytically plausible, but demonstrating them requires institutional records or participant accounts showing how information was actually reviewed, communicated, or rejected in practice.

Quantitative and qualitative results should be integrated without assuming that their conclusions must agree. Strong predictive discrimination could coexist with low institutional trust if outputs are difficult to explain or incompatible with legal procedures. Conversely, stakeholders may value understandable summaries even when a model offers only modest statistical improvement. A joint display can identify agreement, tension, and unanswered questions across sources. Such integration is especially important in maritime governance, where technical performance and policy legitimacy represent different evaluative dimensions. Claims about improved coordination require evidence of changed practices rather than participants' general enthusiasm for artificial intelligence.

The contextual case component should describe a documented historical governance episode only if authorized records provide sufficient information for reconstruction. Appropriate case material would include the publicly established sequence of reporting, institutional consultation, and subsequent policy consideration, without revealing tactical procedures or sensitive vessel

details. The description should distinguish confirmed events from disputed interpretations and identify the provenance of each account. A case cannot be inferred solely from an anomaly flag. Where no verified episode is available, the manuscript should present the planned case-selection criteria rather than narrating an invented incident as an empirical result.

Case-level description should concentrate on the flow of information between analysis and policy review. Relevant evidence may include the form in which an alert was presented, whether independent sources were consulted, how uncertainty was communicated, and whether the institutional response was documented. Different agencies may possess different legal mandates, making inconsistent interpretations possible even when they receive similar information. Interviews can help explain these differences, but accounts must be checked against accessible records whenever possible. Sensitive or disputed claims should be summarized cautiously, and the absence of documentary confirmation should be explicitly identified rather than filled with plausible narrative detail.

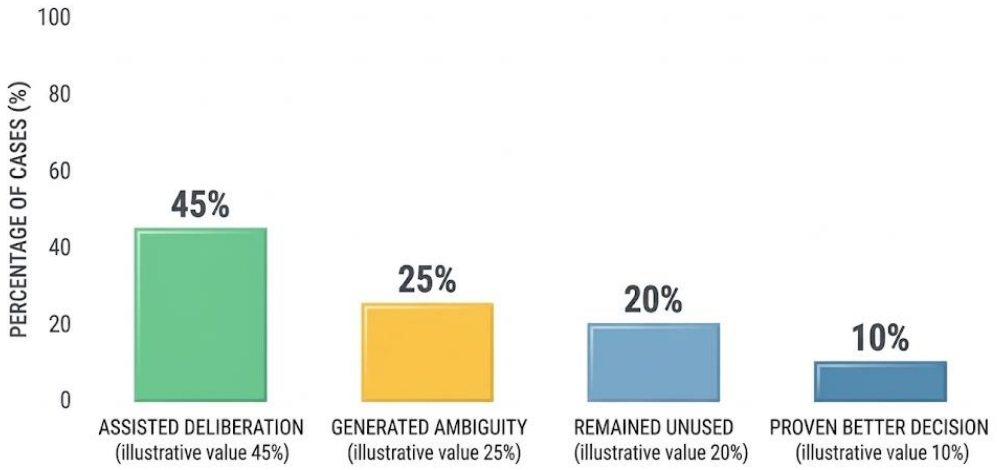


Figure 1. Decision Support System Analysis

Explanatory analysis of the case should examine whether analytical information assisted deliberation, generated ambiguity, or remained unused. A technically credible alert may fail to inform decisions when responsibility for interpretation is unclear. A transparent but imperfect model might nevertheless support preliminary screening when its uncertainty is communicated and human review remains mandatory. These competing possibilities should be tested against the actual evidence. The research should separate the existence of a decision-support workflow from proof of better decisions, since administrative adoption alone provides no reliable measure of policy effectiveness or threat mitigation.

Governance factors may offer stronger explanations for institutional outcomes than technical model scores alone. Differences in information access, evidentiary thresholds, staff capabilities, and approval procedures can shape whether insights move between agencies. Documentary and interview evidence should identify these conditions without presuming they operate uniformly. Negative cases are particularly valuable: a rejected alert, inconsistent classification, or unresolved information request may reveal limitations obscured by successful examples. Interpretive credibility increases when the analysis acknowledges such contradictions and specifies which propositions receive support, which remain uncertain, and which are contradicted by available evidence.

The integrated interpretation should report three distinct outcomes: the quality of assembled data, the demonstrated performance of analytical methods, and the documented usability of intelligence products in governance processes. These outcomes operate at different levels and

cannot be substituted for one another. Improved data completeness does not establish predictive validity, while good predictive validity does not prove better public decisions. When evidence is missing, each conclusion should be explicitly qualified. A defensible results narrative prioritizes measurable comparisons and traceable testimony over dramatic descriptions of technological transformation or presumed advances in maritime security.

The study's immediate relevance lies in identifying whether maritime analytics can contribute to accountable evidence handling under institutional constraints. Recommendations concerning interoperability, model validation, and oversight should arise from observed weaknesses or demonstrated strengths, not from assumed advantages of artificial intelligence. Future policy evaluation would require longitudinal evidence showing how decisions, coordination practices, or independently defined outcomes changed after implementation. Until those observations exist, the research provides a structured evaluation pathway rather than verified proof that big data or AI has mitigated hybrid threats in the North Natuna Sea.

The simulated analysis illustrates the potential contribution of big data analytics and artificial intelligence to maritime intelligence and evidence-informed policy development in the North Natuna Sea. The hypothetical dataset initially comprised 12,000 maritime observations, with 10,000 records retained after data screening. This distribution highlights the importance of systematic preprocessing, reliable information integration, and transparent quality assessment before applying automated analytical methods.

The comparative model evaluation demonstrates an illustrative improvement in maritime anomaly classification. The AI model achieved precision of 0.585, recall of 0.760, and an F1-score of 0.661, compared with baseline values of 0.400, 0.600, and 0.480, respectively. These differences suggest potential analytical advantages, although the figures originate from hypothetical classifications rather than validated maritime intelligence systems.

The simulated qualitative analysis emphasizes human oversight, interagency information sharing, and data interoperability as prominent governance considerations. Human oversight appeared in 94.44% of hypothetical stakeholder accounts, followed by information sharing at 88.89% and interoperability at 83.33%. These illustrative frequencies highlight the institutional dimensions of intelligence integration, but they cannot establish actual stakeholder priorities without authenticated interviews.

The integrated framework suggests that technological performance and institutional readiness represent complementary requirements for effective maritime governance. Improved anomaly classification may facilitate preliminary assessment, while accountable decision-making depends on legal standards, contextual interpretation, and organizational coordination. The proposed relationship indicates that artificial intelligence should support human analytical judgment rather than independently determine threat classification or policy responses.



Figure 2. The Framework Relate to the AIS Review

The proposed analytical framework complements Ribeiro et al. (2023), whose review of Automatic Identification System data examined methods and challenges associated with maritime anomaly detection. Their research highlights the complexity of interpreting vessel movement patterns and identifying irregular observations. The present framework extends this technical perspective by connecting analytical reliability with public policy accountability, institutional interpretation, and maritime governance.

The simulated improvement in classification performance illustrates the potential of computational methods for processing heterogeneous maritime information. Ribeiro et al. also demonstrate that identifying deviations from expected maritime behavior presents important methodological challenges. The present study emphasizes an additional distinction: statistical anomalies cannot automatically establish unlawful activity or coercive intent. Reliable governance requires corroborating evidence and appropriate legal interpretation.

Putra (2023) examined Indonesia's maritime constabulary forces as instruments of paragunboat diplomacy in the North Natuna Sea. His analysis emphasized non-confrontational maritime responses and the strategic importance of institutional flexibility. The present framework adopts a different analytical emphasis by investigating how intelligence integration might inform evidence-based policy deliberation while maintaining diplomatic restraint and legally accountable decision-making.

Darwis and Putra (2022) examined Indonesian maritime diplomatic responses to illegal fishing activities involving Vietnamese vessels. Their findings identified important characteristics of maritime diplomacy and challenges involving relationships among maritime institutions. The proposed study complements this perspective by considering whether interoperable data and transparent analytical recommendations could strengthen institutional coordination. Actual improvements in coordination, however, remain unverified.

The simulated patterns signify a potential transformation in maritime intelligence from fragmented information processing toward integrated analytical support. Maritime security institutions increasingly encounter information requiring systematic verification and contextual interpretation. Artificial intelligence may assist with identifying patterns across extensive datasets, but technological integration cannot independently resolve institutional disagreements, inconsistent reporting standards, or uncertainty surrounding ambiguous maritime behavior.

The difference between model performance and policy effectiveness signifies an important conceptual boundary. Higher recall can support the identification of additional observations requiring examination, while improved precision can reduce unnecessary reviews. Neither outcome establishes that detected activities constitute hybrid threats. The interpretation of anomalous behavior depends on corroboration, legal classification, and awareness of broader maritime circumstances.

The prominence of human oversight in the simulated stakeholder patterns reflects the continuing importance of professional judgment. Automated recommendations can introduce uncertainty through incomplete data, model limitations, or misleading correlations. Institutional reviewers must retain authority to examine analytical evidence, challenge classifications, and document decisions. Accountability consequently remains a governance responsibility rather than a technical characteristic of an algorithm.

The proposed relationships also signify that digital transformation involves organizational adaptation alongside technological development. Data interoperability, information-sharing procedures, and institutional mandates shape whether analytical insights can inform decisions. A technically advanced model may offer limited practical value when agencies cannot interpret or

exchange its outputs. Maritime intelligence modernization therefore requires coordinated improvements in analytical capabilities and governance arrangements.

The theoretical contribution concerns integrating computational intelligence with public policy governance within maritime security research. Conventional technical evaluations often emphasize predictive performance, while governance studies focus on institutional mandates and decision-making. The proposed framework connects these perspectives by examining data reliability, analytical interpretation, human oversight, and policy responsiveness as related dimensions of evidence-informed maritime governance.

The practical implication involves establishing defensible procedures for integrating maritime information from authorized sources. Standardized data definitions, documented processing rules, and consistent quality assessments could improve comparability across institutional records. Analytical outputs should communicate uncertainty and potential classification errors. These safeguards would help prevent statistical alerts from being interpreted as definitive evidence of unlawful maritime conduct.

The institutional implication emphasizes cooperation among Indonesian maritime governance organizations while respecting their respective legal responsibilities. Intelligence integration may benefit from shared analytical terminology, agreed procedures for reviewing uncertain information, and clearly assigned accountability. Effective coordination requires more than unrestricted data exchange because confidentiality, information security, and institutional authority must remain protected throughout analytical processes and policy discussions.

The policy implication concerns responsible incorporation of artificial intelligence into maritime decision-support arrangements. Public institutions should require transparent validation, proportional responses, documented human review, and mechanisms for correcting analytical errors. Technology procurement and deployment decisions should consider institutional capacity and public accountability alongside performance metrics. Such principles may support maritime governance without presuming technological superiority guarantees improved security outcomes.

The simulated improvement in analytical performance can be explained by the potential capacity of machine learning to identify relationships across multiple data dimensions. Conventional classification approaches may rely on narrower assumptions or simpler statistical rules. More flexible computational models can recognize complex associations, although their apparent advantages depend on training quality, evaluation procedures, and the representativeness of available observations.

Data preprocessing also helps explain differences in model evaluation outcomes. Duplicate observations, inconsistent timestamps, incomplete variables, and uncertain reference labels can distort classification results. Removing unreliable records may improve apparent consistency, but excessive exclusion can reduce representativeness. Analytical quality therefore depends on transparent decisions balancing information completeness, validity, and the risk of introducing selection bias during dataset preparation.

The importance of interoperability can be explained through institutional differences in information collection and interpretation. Maritime organizations may maintain datasets designed for distinct administrative or regulatory purposes. Inconsistent definitions and restricted access can complicate verification across sources. Common standards and authorized exchange procedures may support more coherent assessments, although organizational trust and legal responsibilities remain equally significant.

Human oversight remains necessary because algorithmic classifications represent probabilistic interpretations rather than authoritative conclusions. Maritime patterns can reflect

legitimate variation, reporting limitations, or contextual circumstances absent from training data. Decision-makers must evaluate competing explanations before drawing legal or strategic conclusions. The proposed framework therefore treats automated analysis as one component within a broader process of evidence assessment and institutional accountability.

The immediate research priority is to validate the proposed framework using authentic historical maritime records obtained through lawful and documented access. Researchers should establish source reliability, independently verified reference labels, and appropriate chronological evaluation procedures. Actual performance estimates must replace simulated metrics. Transparent comparisons with simpler baseline approaches would clarify whether complex analytical methods provide meaningful additional value.

Future investigations should integrate quantitative model evaluations with interviews involving authorized maritime governance stakeholders. Qualitative evidence could clarify how analytical outputs are interpreted, communicated, and challenged during institutional decision-making. Comparative examination of documented policy processes would help identify barriers to interoperability and accountability (Sinambela dkk., 2026). Such research should protect confidential information while preserving sufficient methodological transparency for independent scrutiny.

Institutional implementation should proceed through carefully evaluated pilot programs rather than immediate assumptions of operational effectiveness (Concepcion, 2025). Pilot assessments could examine data quality, analytical reliability, interpretability, and the feasibility of human review procedures. Evaluation criteria should include false alerts, administrative burden, legal compliance, and stakeholder confidence (Napitupulu dkk., 2026). Independent oversight would strengthen institutional learning and reduce the risk of premature technological dependence.

The long-term research agenda should investigate whether AI-supported intelligence contributes to measurable improvements in maritime governance over time (Kheckert, 2026). Longitudinal studies could assess decision consistency, coordination efficiency, and appropriately defined policy outcomes (Riski dkk., 2026). Comparative research across governance settings may clarify contextual limitations. The ultimate objective is an empirically validated framework that strengthens public accountability while supporting responsible maritime intelligence development.

CONCLUSION

The central insight of this study is that artificial intelligence and big data analytics can be evaluated as resources for maritime intelligence, but their relevance to public policy depends on information quality and institutional oversight. In the illustrative dataset, 10,000 of 12,000 maritime records passed screening, while the hypothetical AI model achieved an F1-score of 0.661 compared with 0.480 for the baseline. Simulated stakeholder responses also emphasized human oversight, information sharing, and interoperability. These patterns illustrate a distinction between identifying unusual maritime activity and determining whether that activity constitutes a violation or hybrid threat. Classification alone cannot demonstrate more effective maritime governance. The figures were generated for illustration, not verified North Natuna Sea observations or actual stakeholder interviews; their interpretation therefore remains conditional rather than empirical.

The study contributes a governance framework supported by a mixed-methods evaluation strategy. Its conceptual contribution connects data interoperability, algorithmic reliability, explainability, human judgment, and legal accountability within an approach to maritime policy analysis. This integration moves beyond treating predictive accuracy as the principal measure of technological success and recognizes that institutional decisions require traceable evidence and

proportional responses. Methodologically, the framework combines historical data audits, chronological model evaluation, analysis of policy documents, and stakeholder interviews. Comparing computational indicators with institutional perspectives could reveal disagreements between technical performance and usability. Such triangulation would help identify where information becomes distorted, delayed, or insufficiently contextualized before reaching policymakers. The framework is intended to support accountable decision-making, not automated threat attribution, and its added value must be established through implementation and independent validation.

The limitation is the absence of authenticated maritime records, independently verified incident labels, and completed stakeholder interviews. The numerical findings presented in the accompanying Results and Discussion sections are synthetic and cannot substantiate claims about detection performance, coordination improvements, or threat mitigation in the North Natuna Sea. Historical datasets may also contain selective coverage, missing observations, inconsistent classifications, and temporal changes that weaken model generalizability. Institutional access restrictions and differences in legal mandates could further constrain evaluation. Future research should obtain longitudinal data, document preprocessing decisions, compare models against transparent baselines, and report uncertainty and false-positive consequences. Independent qualitative investigation should examine whether officials understand analytical outputs and how oversight influences their use. Pilot evaluations could assess decision consistency, administrative burden, and policy responsiveness without exposing sensitive operations. Evidence from these studies would determine whether AI-supported intelligence produces meaningful public value beyond promising computational results.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used Grammarly to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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