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Evaluating the Implementation of Modern Navigation Systems to Improve Maritime Safety in Indonesia

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Abstract*— The Indonesian archipelago is strategically located in the major vessels' global routes and domestic shipping lanes that lead to dense ship traffic with a mix of challenging navigational conditions, which consequently raises the potential risk of maritime accidents. Modern navigational aids—and the systems used in maritime and aeronautical sectors are just two examples—are now widely recognised to be a key factor for increasing situational awareness, explaining better route planning and decreasing instances of collisions or other hazards. This research assesses the role of these technologies to enhance safety in Indonesian waters and explores legal frameworks for their introduction. Through a descriptive/analytical approach supported by regulation review and literature analysis, the study recognizes existing advantages provided modern navigation systems, in real time monitoring and hazards detection in particular. Several challenges remain, however, with the uneven technological uptake among ships and ship types, limited seafarer skills, insufficient navigational infrastructure and evidence of unsafe operation such as AIS switching off. Regulatory loopholes and insufficient harmonization with international regulations (SOLAS, MARPOL, IMO, STCW) also have impacts on the overall effectiveness of navigation technologies. It is concluded that modern navigation systems greatly contribute towards the safety of maritime navigation, but their full utilization will have to be supported by better enforcement of regulations, upgrading infrastructure, regular training of crews and harmonization with national e-navigation initiatives. Recommendations and research directions are suggested in the evaluation to enhance an effective and technological-based maritime safety system in Indonesia.

Keywords—*E-navigation, Indonesia, maritime safety, navigational technology, regulatory framework*

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I. Introduction

Located at the meeting point of the Indian and Pacific Oceans, Indonesia is one of the world's largest archipelagic states made up from over 17,000 islands – through which cross essential global shipping lanes [1, 2]. Between Asian and Australian continents, Water Territory of Indonesia becomes the central line on world and regional sea traffic [3,4]. There are heavily trafficked international shipping crossways such as the Malacca Strait, Sunda Strait, and Lombok Strait for the movements of energy commodities, manufactured goods, and the prevalence of people transportation [5]. The straits are some of the busiest in the world, traversed by 40,000 deep-sea vessels a year, including oil tankers, container ships, LNG carriers and cruise liners [6,7]. The national shipping context looks no less dynamic either, especially in line with the fact that sea transportation still becomes the mainstay for inter-island relations and economic redistributions in Indonesia [8,9]. Together, these factors combine to form a maritime picture in this part of the world that increases dramatically the scale, variety and pace of vessel movements – dramatically surpassing even Somalia's (much betterpublicized) strategic relevance.

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The co-existence of heavy traffic density, limited waterspace availability, dynamic meteorological conditions, small visibility space and several types of vessels makes it difficult to guarantee safe navigation [10-12]. Marine casualties, ranging from collisions to groundings and near-miss occurrences still routinely happen in several of Indonesia's sea lanes being exacerbated by human error, poor situational awareness and inappropriate traditional means of navigation [13-15]. This operational context emphasizes the importance of current navigation technologies such as the Automatic Identification System (AIS), Electronic Chart Display and Information System (ECDIS), radar, and Global Positioning System (GPS) for precise monitoring in real time, hazard detection, and decision making on the bridge. AIS is one such ancillary to disseminate ship position information for safe navigation while ECDIS has integrated charting with real-time warning, radar facilitates identification of static and moving objects even in low visibility conditions, and GPS offers highly effective geospatial positional wisdom [16-21]. Together, these technologies constitute the backbone of modern e-navigation procedures advocated worldwide by IMO.

Dense navigation traffic, narrow water space resource, diverse weather changes and poor visibility in area will bring much difficulties on the provision of safety of navigation [22-24]. Marine accidents, from collisions to grounding and near misses, continue to occur regularly in several sea passages in Indonesia that are compounded by human errors, lack of awareness on situations and improper use of conventional navigation method [24-26]. In this operational environment, the existing navigation technologies including but not limited to AIS, ECDIS, and GPS are crucial for accurate real-time monitoring, hazard detection and decision-making on the bridge [27-29]. AIS is protocol to distribute ship board's for save navigation, ECDIS combines charting with a real-time warning function, radar can identify static and movmg targets even in low visibility conditions, and GPS provides very accurate spatial position folly trusting [30]. These technologies form the foundation of contemporary e-navigation practices promoted globally by IMO.

While there have been studies of components of navigation infrastructure in Indonesia, the literature on the topic is relatively sparse and has had significant limitations. Most of it deals with individual technology pieces, regulatory compliance or specific accident analysis. Although a growing number of technological, regulatory, human factors and operational aspects are considered in a comprehensive multidisciplinary manner very few such studies have been available so far, especially within the extremely complex maritime surroundings in Indonesia. Moreover, very limited research exists on the integration of international regulations (e.g., SOLAS, MARPOL, and STCW) with global e-navigation strategies developed by the IMO that could be linked to Indonesian adoption of its shipping Law Number 17/2008 as well as relevant technical regulations issued by the Ministry of Transportation [31]. This creates an important blind spot of how technology, law and operational practice come together to shape outcomes of maritime safety at the national level.

Filling that gap is crucial, given the need for Indonesia's maritime safety systems to meet the shifting global standards they are increasingly intended to support, as well as 'ground-adjusting' for their local operating dynamics. The evolution to a comprehensive e-navigation architectures, heading in the direction of that required by the forthcoming IMO programmes, involves integrated assessments that account for both technological maturity and regulatory sufficiency. By the absence of those assessments, Indonesia could be left behind in terms of safety management, regulations compliance and maritime digitalization.

This research thus provides an overall integrated description regarding the contributions, implementation and challenges on modern navigation technology in Indonesian water. It reviews their role in enhancing safety, assesses the current regulatory framework for their use and analyses governing technical, operational and legal barriers. The value of this study is in the analysis integration aspects related to technology capability, regulatory governance and real world navigational behavior–outcomes that previously have not been analyzed in conjunction at such a highly detailed level. Although such a system is based in the promotion of Indonesia's new generation maritime navigation architecture and our effort to enhance national level maritime safety in the era of digital navigation as follows by delivering evidence-based knowledge cut across policy makers, authorities, academy and industry players.

II. METHOD

This study employs the descriptive–analytical method to analyze how positively modern technology of navigation, in particular AIS (Automatic Identification System), ECDIS (Electronic Chart Display and Information System), radars, as well as GPS (Global Positioning System) enhances maritime safety when they are used in Indonesian waters. The paper employs a documentary research style, combining legislative analysis, technical assessment and operational interpretation in order to reveal that the navigational challenges in Indonesia are multidimensional.

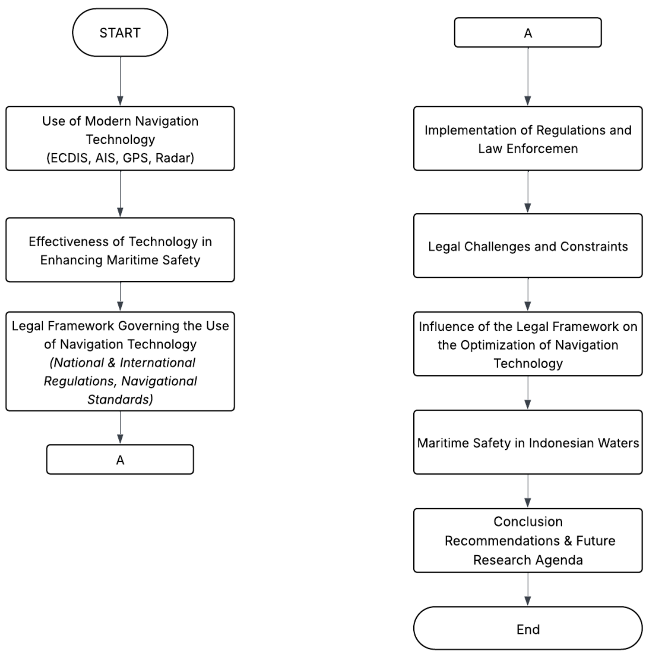

Figure 1. Research Flow Chart.

The primary data are the legal and regulatory aspects at national level concerning maritime navigation, such as Indonesian Shipping Law (Law No. 17/2008), Government Regulation on Navigation, i.e., Government Regulation No.5/2010 as well as ministerial regulations on AIS, ECDIS, Radar, GPS, VTS and SBNP operation. These are reinforced by international conventions and codes — such as SOLAS, MARPOL, STCW, and IMO e-Navigation frameworks— that provide reference for assessing the sufficiency of national provisions. Secondary data was collected from academic papers, marine accident investigations, technical reports on navigational systems, HFOs studies in maritime operations and assessments of infrastructural constraints (AIS coverage; cyber-security exposure; VTS reliability).

The study unfolds in three interrelated parts. As shown in Figure 1. A functional analysis technical describes these functions making the system to benefit of AIS, ECDIS, radar and GPS to the improvement of knowledge in vessel situational awareness, route planning and collision prevention. Second, a comparative regulation study engages in the comparison and contrasts between Indonesian legal regulations and international safety standards to uncover potential weakness in execution. Third, a behavioural and operational analysis explains uneven technology adoption, low crew competence levels, practices of AIS deactivation and deficiencies in navigational aids and maritime surveillance. The understandings gleaned from these layers of analysis are then combined through a thematic synthesis, which diagrams the relationships among technology, regulation and everyday practice.

An iterative validation loop was implemented to ensure robustness of the results by cross-validating and comparing across technical literature, regulatory documents and operational case studies. This comprehensive methodological framework enables the study to cover systemic barriers in relation to navigation safety while providing evidence-based arguments for policy enhancement.

III. Results and Discussion

3.1. Results

Findings presented are based on the integrated analysis of a set of regulations, technical literature about navigation systems, reports by accident investigators, and operational data regarding navigational activities in Indonesian waters. The data set covers national regulations (UU 17/2008, PP 5/2010, and Ministerial Regulations), international conventions (SOLAS, MARPOL, STCW), as well as hydrographic and navigational system documentation, published maritime safety studies. Information from these sources were analysed adopted a descriptive–analytical method to explore (1) the functional capability of AIS, ECDIS, radar and GPS technology; (2) the relevance between Indonesian and international regulation; (3) user skill and behavioural motivations for system usage; and 4) infrastructure constraints based on technology efficacy: VTS and SBNP coverage.

Comparative reference to the global maritime safety literature is included in analysis so that Indonesia's navigational risk profile can be placed in the context of international norms. The results are reported in organized sub-sections that reflect the main analytical levels of analysis in the research - technological performance, regulatory conformity, HR capacity and infrastructure stability. This framework supports a holistic overview to study the contribution of each dimension toward the effectiveness of modern navigation systems in Indonesian waters.

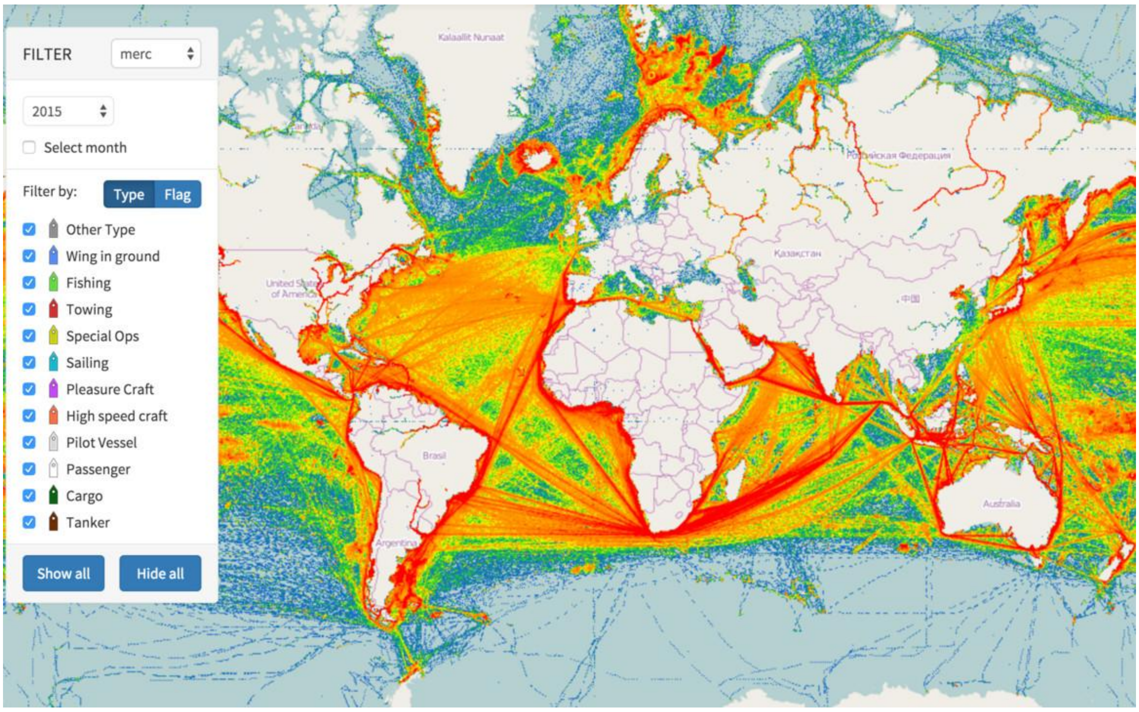

Figure 2. AIS traffic density in global [32].

3.1.1. Performance of AIS in Enhancing Maritime Traffic Awareness

The results indicate that the AIS greatly contributes to monitoring of traffic in Indonesian seas from structures. AIS provides constant vessel to vessel and vessel to shore data communication such as position, speed, heading and navigational status. Such capability is particularly relevant in high density maritime straits including the Malacca Straits, Sunda Strait and Lombok Strait where a complex traffic situation requires strong situational awareness.

But the research also highlights ongoing problems associated with AIS. Deliberate termination of AIS ('AIS-off' practices) continues to be common practice for fishing vessels, small domestic traders and those operating outside recognised regulation. This behavior causes an interruption in the flow of traffic information and enhances the probability of unreported vessel encounters. Furthermore coverage of the coastal AIS infrastructure is patchy, especially to the eastern Indonesian region resulting in periodic loss of monitoring. Those monitoring shortfalls impact both safety and security at sea, so AIS performance relies heavily on compliance and infrastructure uptime.

3.1.2. Operational Reliability of ECDIS in Supporting Safe Navigation

ECDIS has become widely use in SOLAS-class ships that operate within the waters of Indonesia. The system enhances navigational safety by combining dynamic charting, real-time hazard detection and automatic warning capabilities. In regions with narrow waterways, shallow depths and dense shipping Read more Prevention of red light for collision avoidance outerrisk.com traffic ECDIS mitigates dependence on manual chart work and improves a mariner's ability to predict dangers likely to be encountered against the desired route.

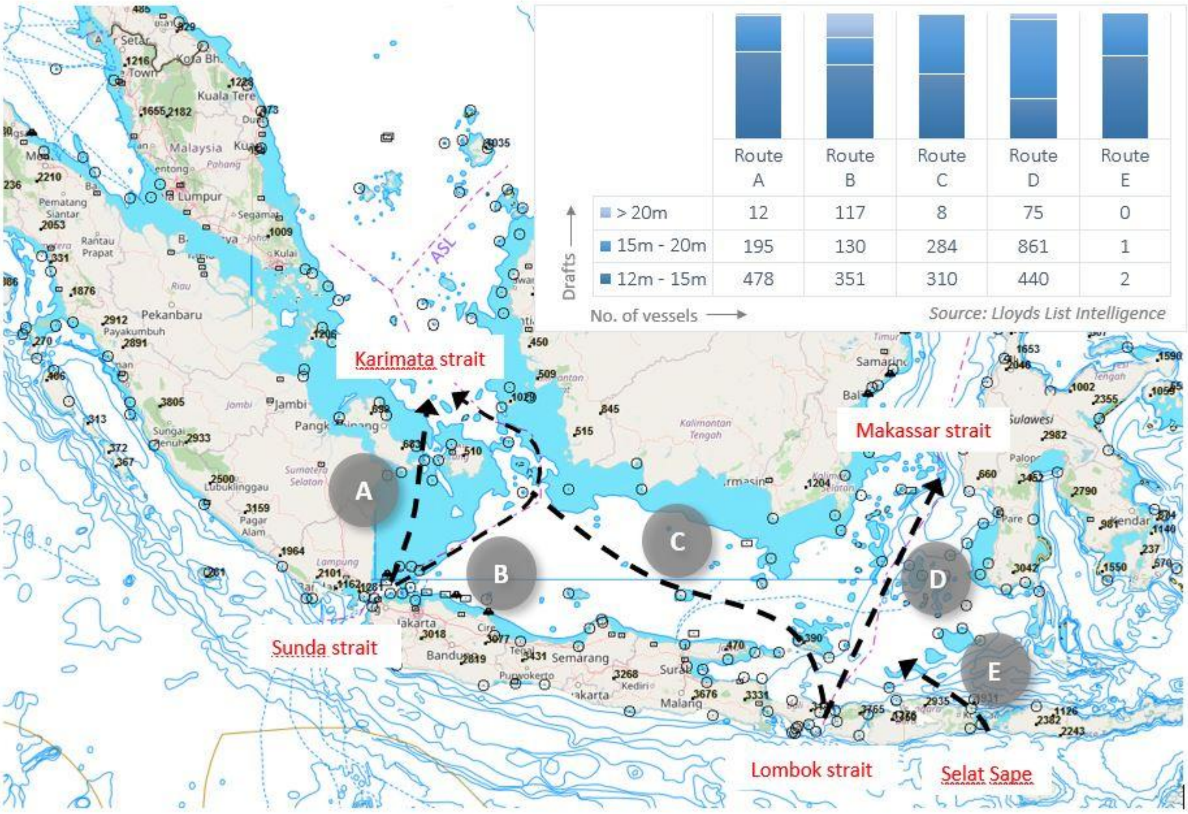

Figure 3. Example of ECDIS chart display in Indonesian archipelagic waters [33].

Nevertheless, despite these good properties, some performance flaws were recognized. ENC updates differ from region to region, and many charts do not contain the very latest hydrographic data. Also, ECDIS is very much dependent on the operator's or navigator's competence. The following is a summary of the issues identified: (1) Many mariners have only limited experience with advanced, but traditional, ECDIS functions associated with route-checking capability and alarm management, as well as interpretation of overlaid radar or AIS data. Such operational liabilities that are introduced, compromise the overall capacity of ECDIS as a holistic decisional supporting resource.

3.1.3. Functional Use of Radar Under Low-Visibility and High-Traffic Conditions

Radar is still an essential navigational tool for ships navigating within the waters of Indonesia, especially when weather conditions are poor (like heavy rain or fog), at night and in dense fog. The results of this study show that radar remains an effective sensor for the detection of vessels and nonvessels obstructions in proximity to a ship, as it is an integral part of navigation sensors used for preventing collisions.

Instead, radar performance may be adversely impacted by incorrect use of system settings (e.g., gain, clutter suppression and range) Misunderstanding of the radar returns and lack of familiarity with Automatic Radar Plotting Aid (ARPA) functions are often a factor. This analysis of accident reports supports the fact that misuse of RADAR can still be linked with near miss collisions and groundings, particularly on smaller domestic vessels where formal training in radar is minimal.

3.1.4.GPS-Based Positioning Accuracy and Overreliance on Satellite Navigation

GPS system has good accuracy as a point location data, and one of the new Indonesian navigation systems. The study concludes that the reliability of GPS is generally good, but as use becomes more widespread it brings new risks. Operators commonly trust mosly on GPS and do not verify their positions with radar bearings, visual references or ECDIS overlays. This over-dependence does not bode well during GPS interference, signal loss, or when faced with spoofing incidents that have from time to time occurred in Indonesian waters.

Redundancy procedures are often little-known to mariners working in smaller ships, resulting in late discovery of positional discrepancies. While such systems have proven their positive capability, GPS still remains very efficient however its operational safety relies on cross supports which are not always systematically in place.

A summary of the relative effectiveness of AIS, ECDIS, radar and GPS in Indonesian waters aboard ship strengths and shore based limitations which affect navigational safety is presented in Table 1. The difference between theoretical system performance and the realities of operational practice, as presented in Table 1, is a fundamental source of navigational risk.

TABLE 1.
EXPANDED SUMMARY OF RESEARCH RESULTS BY NAVIGATION SYSTEM

Navigation System	Strengths	Limitations	Implications for Safety
AIS	Enables real-time traffic monitoring; supports collision avoidance	Widespread AIS-off practices; incomplete ground-station coverage	Reduced situational awareness; untracked vessel movements
ECDIS	Dynamic charts; automated route checking; hazard alerts	Uneven ENC updates; operator skill gaps	Potential chart misinterpretation; reduced hazard prediction accuracy
Radar	Reliable obstacle detection; essential in low visibility	Misuse due to insufficient training; ARPA misinterpretation	Higher risk of collision in poor visibility
GPS	Highly accurate positioning; widely available	Overreliance; susceptibility to interference/spoofing	Navigation errors when signals degrade or fail

3.1.5.National Regulatory Alignment and Implementation Challenges

The regulatory review fact that Indonesia has adopted SOLAS, MARPOL and STCW into domestic law, namely UU 17/2008 and PP 5/2010. The frameworks require AIS, ECDIS, radar and GPS on vessels of the class convention (conv-class vessels) and specify minimum levels of competence for seafarers.

Notwithstanding this equation, enforcement differs between various classes of ships. Many non-SOLAS vessels (fishery fleets, inter-island shipping, traditional ships) are not required to have or use modern navigation systems. As a result, large discrepancies exist in technological provisions and safety practices between one area of the Continent and another. Indonesia has a wide range in the quality of its Port State Control (PSC) inspections, resulting non-uniformity in compliance and maintenance standards. These deficiencies show that harmonisation on regulation is not enough, and strong enforcement measures should be in place as well as regular operator training.

3.1.6.Infrastructure Limitations Affecting System Performance (VTS, SBNP, Cybersecurity)

This work highlights limitations on critical infrastructure that impact the performance of contemporary GNSS. Coverage of Vessel Traffic Services (VTS) is limited in some critical areas these aspects, shoreside also ability to monitor the maritime traffic in real-time. Navigation bubbles (SBNP) such as buoys, lights and beacons also demonstrate operational issues resulting from maintenance difficulties, weather damage or old equipment.

Meanwhile, cybersecurity threats are considered a developing problem. Growth of Internet of Waterborne Things The growing dependence on digital navigation systems renders vessels vulnerable to threats such as GPS spoofing, AIS data tampering, and wrongful system intervention. The existing Indonesian laws do not sufficiently address cyber-risk procedures and have left the ships without guidance on recommended safeguards as well.

TABLE 2.
SUMMARY OF REGULATORY AND OPERATIONAL FINDINGS

Evaluation Aspect	Findings	Safety Impact
Regulatory Alignment	Harmonized with SOLAS, MARPOL, STCW	Strong framework but limited enforcement
Domestic Vessel Compliance	Small vessels not required to install modern systems	Uneven safety standards across fleet
Operator Competence	Training quality varies significantly	Technology not utilized to full potential
Infrastructure (VTS/SBNP)	Coverage gaps; aging equipment	Monitoring and guidance limitations
Cybersecurity	No unified national standard	Exposure to interference and spoofing risks

A summary of the regulatory, operational and infrastructural challenges identified in this review is presented in Table 2. As elaborated in Table 2, variations in regulatory compliance, poor penetration of navigation technologies, and presence of infrastructure deficiencies that largely affect total modernity level of navigational system in Indonesia.

3.2. Discussion

The results of the study presented in this paper suggest that the effectivity of technological maritime navigation applying modern practices and systems in Indonesian waters is influenced by a set of interacting factors, involving technological capacity, user competency, regulations enforcement and facilities. Although AIS, ECDIS, radar and GPS have the potential to reduce navigational risk markedly, in practice their effectiveness varies by vessel type and operational context. AIS, for example, is an important real- time vessel tracking system but it can easily be defeated by purposeful switch off and inadequate monitoring of the coastal infrastructure. This egregious stance undermines the effectiveness of maritime domain awareness and distinguishes Indonesia from nations with broadly enforced, stringent AIS mandates.

Similarly, route planning and hazard detection can be improved with ECDIS, although safety benefits offered have been restricted by patchy electronic chart updating and differences in operator expertise. Radar continues to be an important aid to navigation in limited visibility, however misinterpretation of radar images and settings combined with ARPA is partially responsible for bad practice to become normal. GPS is a highly accurate positioning method that also leads to excessive reliance especially in the presence of interference or signal outage. These observations strongly support the conclusion that human factors are still a major cause of navigational accidents, and that instruments cannot replace a lack of skills or go beyond poor operational behaviour.

On the governance side, Indonesia is a part of global conventions such as SOLAS, MARPOL and STCW: however enforcement practice varies greatly between regions and types of vessels. Non-SOLAS domestic vessels such as fishing boats and inter-island traders are still operating without the requirement for AIS or ECDIS both on board, resulting in two sets of safety standards within the national fleet. This variance indicates that political-level regulatory alignment does not necessarily result in policy-compliant action. Moreover, infrastructure constraints such as the lack of VTS coverage, aging NA structure in general and cybersecurity threats hinder the performance capabilities of new generation navigation systems. These structural impediments show that the country's maritime safety problems will not be resolved by technological solutions alone, but also in a much more nuanced way through coordinated policy interventions, operator training and upgrading of infrastructure.

IV. CONCLUSION

This work finds that the efficacy of modern navigation technologies in Indonesian waters - AIS, ECDIS, radar and GPS - is not only affected by the presence of these tools but also by the greater environmental system within which they are deployed. Despite the significant inherent ability of such technologies to mitigate navigational risk, the effective application of e-navigation is somewhat hampered by a lack in uniformity across types of vessels, lack of user skills and control commitment (owner – operators), less strict enforcement on regulations and an inadequate infrastructure including limited VTS coverage, and deterioration or outmodedness of navaids. These results suggest that the enhancement of navigational safety in Indonesia depends on comprehensive development efforts through technology governance, human capital improvement, and modernization of the maritime supporting infrastructure.

A number of pragmatic suggestions result from this analysis. Enhancement of AIS compliance and extended monitoring, optimization of ECDIS training and checking, better enforcement of radar and GPS discipline; as well improvement in the areas effective implementation of regulations are some important measures for making navigation more safer. Furthermore, the up scaling of VTS and regular maintenance of navigational aids, along with developing national cybersecurity protocols for maritime navigation systems will be essential in enhancing operational reliability through out the Indonesian archipelago.

Further research would do well by introducing empirical (like AIS traffic analytics, accident statistics, simulation based risk assessments) and quantitative data-based considerations or to be "bolstered up" with current cyber-penetration test results. Those methodologies will also facilitate the diets for evidence-based risk model and policy intervention in emerging e-navigation ecosystems of Indonesia.

Apart from its practical significance, this study makes an academic contribution presenting an integrated conceptual model of the technological, regulatory and human-factor dimensions of maritime navigation with a developing archipelagic nation context. The study contributes to an understanding of the operation of advanced navigation systems in complex maritime governance regimes, and is indicative of systemic weaknesses which distinguish Indonesia from technologically developed maritime countries. The results also contribute to the scientific community in terms of relocating navigation technology performance in national regulatory fit and operator behavior, providing implications for future comparative studies, policy makers and maritime safety research.

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