UMT PRESS

Journal of Maritime Logistics
Journal Homepage: https://journal.umt.edu.my/index.php/jml
e-ISSN: 2805-5195
DOI: http://doi.org/10.46754/jml.2026.08.006

MARITIME SAFETY AND SUSTAINABILITY IN THE STRAITS OF MALACCA AND SINGAPORE: A REVIEW

LUTFI A RAHAMAN[1,2]*

[1]*Faculty of Built Environment, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, Malaysia*

[2]*Alami Technologies, Star Central, Lingkaran Cyber Point Timur, Cyber 12, 63000 Cyberjaya, Selangor, Malaysia*

Corresponding author: 2024556241@student.uitm.edu.my

ARTICLE INFO

Article History:
Received: 6 April 2026
Revised: 14 July 2026
Accepted: 15 July 2026
Published: 15 August 2026

Keywords:
Straits of Malacca and Singapore, maritime safety, environmental protection, S-100 standards, cooperative governance

ABSTRACT

The Straits of Malacca and Singapore (SOMS) are among the world's busiest and most vulnerable maritime corridors, carrying over 94,000 vessels annually and facing persistent risks from collisions, oil spills, and transnational threats. This review contributes by synthesising Malaysia's role in SOMS safety and sustainability through six themes linking governance, technology, and environmental protection: Navigation safety, environmental protection and oil spill response, sovereignty and security, regional and international cooperation, marine spatial planning, and socioeconomic significance. The review was conducted using the PSALSAR framework and PRISMA methodology: 2,800 records were identified; 81 remained after initial screening; 72 were retained after relevance screening; and 66 studies met the methodological evaluation criteria and were included in the final review. Findings highlight Malaysia's initiatives, including SISPELSAT and SBAS/DGNSS for navigation, the MyMarine GeoHub and S-100 transition for integrated maritime governance, and the National Oil Spill Contingency Plan for environmental response, with Malaysia's convening role reinforced at the 16th Cooperation Forum (2025). However, although cooperation exists through the Tripartite Technical Experts Group (TTEG) and the Cooperative Mechanism, funding contributions, data-sharing, and sovereignty sensitivities remain key limitations, alongside systemic challenges such as human factor risks, uninsured vessels, compensation gaps, and uncertainties from the global energy transition. By consolidating fragmented research and aligning it with emerging industrial practices and S-100 standards, this review advances academic discourse on maritime governance in congested chokepoints and offers policy insights for balancing global trade imperatives with safety, sovereignty, and environmental stewardship.

Introduction

Maritime transportation remains the backbone of international trade, with the Straits of Malacca and Singapore (SOMS) serving as one of the most vital and congested shipping lanes in the world (Assuad, 2025). Linking Europe, the Middle East, and East Asia, the SOMS handles an ever-increasing volume of global trade, with vessel traffic reaching a record 94,301 ships in 2024, based on STRAITREP mandatory ship reporting data published by the Marine Department Malaysia (Jabatan Laut Malaysia, 2025; Hand, 2026). Its strategic significance is matched by its vulnerability: Shallow waters, narrow channels, unpredictable tidal currents, and dense traffic combine to create one of the most complex and high-risk maritime corridors globally. Accidents such as collisions, groundings, and oil spills pose substantial risks to human life, fragile marine ecosystems, and coastal communities in Malaysia, Singapore, and Indonesia.

In response, regional and international stakeholders have developed cooperative frameworks to mitigate navigational and environmental risks. The Cooperative Mechanism for the SOMS, initiated in 2008, has facilitated collaboration among littoral and user states, with the Malacca Strait Council of Japan and the Nippon Foundation contributing significantly to hydrographic surveys, aids to navigation, and oil spill response capacity (Kono, 2025). At the national level, Malaysia has implemented multiple initiatives, including the Marine Department's Satellite-based Navigation Systems (SISPELSAT) and research on SBAS/DGNSS for safer navigation, the Royal Malaysian Navy's MyMarine GeoHub and Maritime Chart Service for enhanced situational awareness, and the strengthening of Straits Pilotage services to reduce incidents and improve operational safety (Anom, 2025; Ramli, 2025).

Despite these advances, systemic challenges persist. Human factors such as fatigue and stress remain significant contributors to maritime accidents in the SOMS (Harun, 2025). Emerging environmental pressures, particularly oil pollution from uninsured or unsafe ships, highlight gaps in compensation and enforcement mechanisms under international conventions. Furthermore, the global energy transition introduces uncertainty regarding alternative fuels, bunkering regulations, and greenhouse gas reduction targets, all of which affect the SOMS as a critical energy transport corridor (Friedmann, 2025). The urgency of these challenges was reinforced at the 16th Cooperation Forum on the Straits of Malacca and Singapore (2025), which gathered Malaysia, Indonesia, and Singapore alongside user states and industry partners to review the status of Straits projects, strengthen collaborative governance, and reaffirm commitments to navigational safety (Ahmad Shahrin, 2025), environmental stewardship, and cooperative burden-sharing. This underscores the continuing relevance of regional dialogue and institutional mechanisms in safeguarding the straits.

Although a substantial body of literature exists on the SOMS, previous studies have largely examined safety, security, environmental protection, and legal or institutional frameworks as separate issues; limited work integrates these dimensions from Malaysia's perspective using a systematic review approach. In particular, no prior review has consolidated Malaysia's national initiatives, its participation in cooperative governance mechanisms, and its adoption of emerging digital standards such as S-100 within a single, methodologically rigorous synthesis. This study therefore seeks to fill that gap by systematically reviewing the literature on Malaysia's contributions to maritime safety, environmental protection, technological innovations, and cooperative governance in the SOMS, and by aligning the consolidated findings with issues highlighted at the 16th Cooperation Forum on the Straits of Malacca and Singapore (2025).

Accordingly, this review is guided by three research questions: (1) What are Malaysia's key contributions to the safety and sustainability of the SOMS in terms of navigation, environmental protection, and governance? (2) What systemic and sustainability challenges remain despite these contributions? (3) How can maritime governance in the SOMS be improved through technology, regional cooperation, and burden-sharing? By addressing these questions, this review not only contributes to academic discourse but also aligns with the industrial way forward for the SOMS.

Methodology

Systematic Literature Review Method

This study uses Google Scholar as its database. The search was conducted in January 2026 using the keyword "SOMS" in combination with the terms "Straits of Malacca and Singapore", "maritime safety", "oil spill", "marine spatial planning", and "S-100", joined with Boolean operators (AND/OR). Keyword combinations were entered in Google Scholar's general search field, and the "allintitle" option was additionally used to identify records containing the search terms in the article title. The search was limited to peer-reviewed literature published in English between 2000 and 2025, a period chosen to capture the development of cooperative governance in the SOMS from the establishment of key regional mechanisms through to the 16th Cooperation Forum (2025) and the ongoing S-100 transition. Google Scholar was selected as the sole database because of its broad multi-disciplinary coverage, which spans the engineering, environmental science, legal, and policy literatures relevant to the SOMS, and because it indexes regional Southeast Asian journals and conference proceedings that are underrepresented in Scopus and Web of Science; prior methodological studies have shown that Google Scholar's coverage substantially subsumes that of these curated databases (Martín-Martín *et al*., 2018). Nevertheless, its use as a single source is acknowledged as a limitation in this review.

Figure 1 shows the methodology of this systematic literature review. The review followed the PSALSAR framework, which extends the Search, Appraisal, Synthesis, and Analysis (SALSA) model by adding Protocol and Reporting stages (Mengist *et al*., 2020). A clear protocol was established to ensure transparency, replicability, and rigour. The scope was defined using the Population, Intervention, Comparison, Outcome, and Context (PICOC) principle, with SOMS literature forming the population, methodological evaluation serving as the intervention, and methodological quality (MES assessment) as the eligibility criterion.

A comprehensive search was conducted in Google Scholar using keyword combinations entered in the general search field, supplemented by the "allintitle" option to identify records with search terms in the article title. Unlike curated databases such as Scopus or Web of Science, Google Scholar does not support structured field-based queries (e.g., Title/Abstract/Keywords filtering); screening for topical relevance was therefore performed manually during the subsequent stages. This initial search yielded 2,800 records. The broad query ensured maximal capture of potentially relevant works, aligning with PRISMA's emphasis on reducing selection bias. At this stage, records were assessed against the predefined inclusion and exclusion criteria summarised in Table 1.

Table 1: Inclusion and exclusion criteria for the systematic review

Criteria	Included	Excluded
Publication type	Peer-reviewed journal articles and peer-reviewed conference papers	Grey literature, editorials, book chapters, theses, reports, and non-peer-reviewed conference presentations
Topical scope	Studies addressing the SOMS in relation to maritime safety, environmental protection, security and sovereignty, cooperation, marine spatial planning, or socioeconomic significance	Studies not substantively related to the SOMS or Malaysia's maritime domain
Language	English	Non-English publications
Publication period	2000–2025	Publications outside the defined period
Methodological quality	Studies applying a Methodologi cal Evaluation System (MES) with measurable, transparent assessment approaches	Studies lacking MES evaluation or substantive methodological content
Accessibility	Full text or sufficient metadata accessible	Fee-based articles with access limitations or insufficient metadata

Duplicates, grey literature, editorials, book chapters, and non-peer-reviewed materials were excluded, narrowing the dataset to 81 articles. Conference presentations from the 16th Cooperation Forum on the Straits of Malacca and Singapore (2025) and related technical meetings were not included in the systematic synthesis; they are cited separately in this review as contextual and policy-framing sources only. Articles were screened through a two-tier process:

i. Abstract Reading (Metadata, Fee-based Articles): Of the 81 articles, 79 were examined at the abstract level. Two articles were excluded because the full text was inaccessible behind a paywall and their abstracts and metadata did not provide sufficient methodological information to assess eligibility.

ii. Abstract and Main-Body Skimming (Relevance Check): 72 papers were retained after excluding 7 that did not align with the scope of SOMS or lacked substantive methodological content.

This iterative screening minimised irrelevant inclusions and maintained methodological precision. At the full-text appraisal stage, articles were scrutinised for methodological quality using a Methodological Evaluation System (MES). MES assessed each study against four criteria: (1) Clarity of the research method, (2) relevance to the SOMS context, (3) quality of evidence presented, and (4) reproducibility of the analysis. Each criterion was scored on a five-point scale (1 = very poor to 5 = excellent), giving a maximum score of 20. Studies scoring 12 or above, with no individual criterion scored below 2, were retained. Of the 72 articles appraised, six were excluded for failing to meet this threshold: These studies either did not describe their methods in sufficient detail to be assessed, presented conclusions without a transparent analytical approach, or could not be reproduced from the information reported. This process left 66 high-quality studies for synthesis. This stage reflects the quality assessment emphasis within PSALSAR, aligning with QA criteria such as relevance, methodological rigour, and reproducibility.

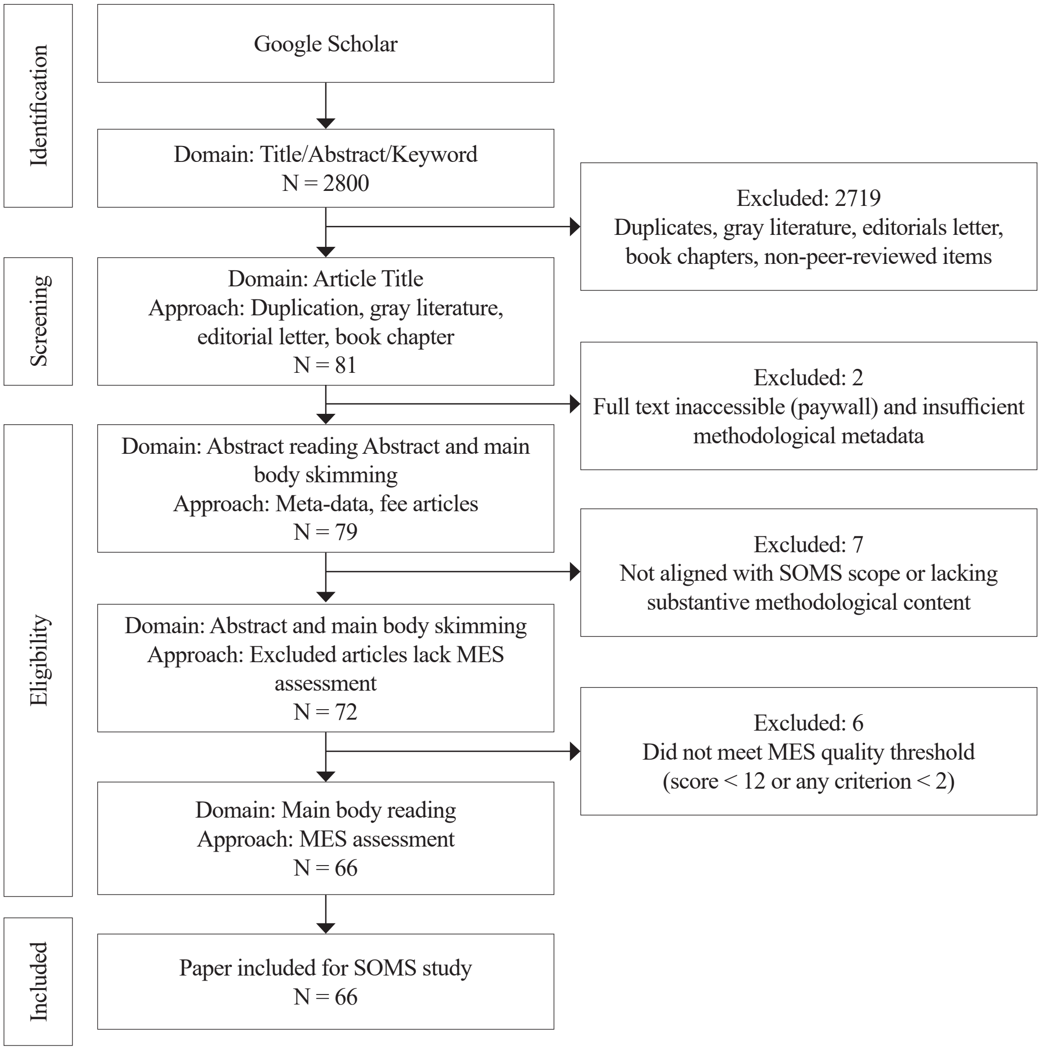

Figure 1: Methodology of systematic review

A final total of 66 studies were deemed eligible and included for systematic synthesis in the SOMS review. These works represent a curated evidence base filtered through rigorous PRISMA-guided selection, ensuring that the review's conclusions rest on validated and methodologically robust studies.

Data extraction was conducted using a structured template, categorising studies by scope, methods, assessment frameworks, and application contexts; Table 2 summarises the extraction fields. Both qualitative thematic synthesis and quantitative descriptive analyses were employed, consistent with the dual nature of SLR and meta-analysis approaches. This step enabled the identification of trends, research gaps, and the methodological robustness of SOMS applications. Finally, the SLR process and outcomes were reported following PRISMA guidelines, ensuring transparency in inclusion/exclusion decisions.

Table 2: Data extraction fields used in the structured template

Extraction Field	Description
Bibliographic details	Authors, year, publication venue, and publication type
Scope	Geographic and thematic focus of the study in relation to the SOMS
Methods	Research design, data sources, and analytical techniques employed
Assessment framework	Evaluation model, standard, or framework applied (e.g., QRA, MSP, S-100)
Application context	Policy, operational, or technological setting of the findings
Key findings and theme	Principal results and the review theme to which the study was assigned

Findings and Discussion

The findings of this study are organised into six themes. The themes were developed inductively through repeated reading and thematic coding of the 66 selected studies. They were subsequently refined and validated against the agenda and discussions of the 16th Cooperation Forum on the Straits of Malacca and Singapore (2025) to ensure alignment between the academic literature and current policy priorities. Figure 2 shows the six themes of this study, and Table 3 summarises the reviewed studies grouped by theme.

Table 3: Summary of reviewed studies by theme

Theme	No. of Studies	Representative Studies	Focus Areas
Maritime safety and navigation	9	Ho (2009); Li *et al*. (2012); Virzo (2015); Rahmawati *et al*. (2025)	Navigation systems (SISPELSAT, SBAS/DGNSS), VTS/STRAITREP, quantitative risk assessment, AIS and simulator training, coastal state competences
Environmental protection and oil spill response	12	Ibarahim (1995); George *et al*. (2016); DasGupta and Shaw (2013); Rahman *et al*. (2024); Ismail and Taib (2025)	NOSCP, oil spill operations management, ship collision impacts, mangrove and ecosystem degradation
Security and sovereignty	10	Djalal (2001); Bateman (2009); Wongnakornsawang (2016); Muhammad and Wan Siti Adibah (2017); Omar *et al*. (2017); Zainol *et al*. (2019)	Littoral state primacy, joint patrols, border management, UNCLOS claims, marine space governance
Regional and international cooperation	9	Evers and Gerke (2006); Simon (2011)	Cooperative Mechanism, TTEG, Malacca Straits Patrols, user-state contributions, burden-sharing
Marine spatial planning and S-100 transition	16	IHO (2017); Nakabayashi (2022); Contarinis *et al*. (2022)	S-100 data model, ISO 19100 standards, MSDI, MyMarine GeoHub, EAHC harmonisation
Socioeconomic and strategic significance	10	Chong and Lam (2013); Sultan *et al*. (2016); Ahmad (2019); Ali (2020); Anwar *et al*. (2024)	Trade and energy flows, chokepoint geopolitics, coastal development impacts, marine renewables

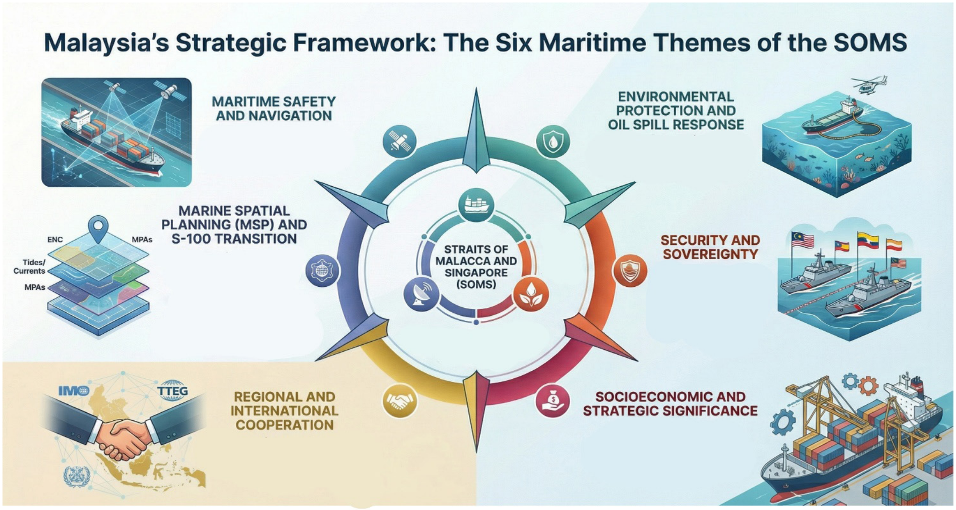

Figure 2: The six maritime themes of the SOMS

Maritime Safety and Navigation

Malaysia has consistently prioritised the safety of navigation in the Straits of Malacca and Singapore (SOMS), a waterway characterised by narrow channels, shallow depths, and intense vessel density that amplify the risks of collision, grounding, and oil spills. To mitigate these risks, the Marine Department of Malaysia has deployed satellite-based navigation systems such as SISPELSAT and advanced trials of Satellite-Based Augmentation Systems (SBAS) and Differential GNSS (DGNSS) to improve positional accuracy for vessels navigating constrained waters. These measures are complemented by the Vessel Traffic Services (VTS) in Port Klang and the IMO-mandated STRAITREP reporting system, both of which strengthen situational awareness, enhance traffic monitoring, and align Malaysia with international safety obligations (Ho, 2009). In parallel, Malaysia, with support from Japan's Nippon Foundation and the Malacca Strait Council, has modernised hydrographic surveys and invested in electronic navigational charts (ENCs) that comply with the emerging S-100 framework, while also enhancing Straits Pilotage services to ensure more reliable manoeuvring in high-risk segments of the straits.

Taken together, these initiatives indicate that Malaysia's safety strategy is predominantly technology-driven, prioritising positional accuracy, surveillance, and data infrastructure. The reviewed evidence, however, suggests that technology addresses only part of the risk equation. Quantitative risk assessment studies show that collision and grounding probability in confined waterways is a function of both geometric factors such as channel width, vessel size, speed and causation factors rooted in mariner skill, fatigue, and human error (Li *et al*., 2012). Improved positioning systems reduce geometric uncertainty but leave causation probabilities largely untouched: A vessel with centimetre-level positional accuracy can still collide if its officers are fatigued or make poor decisions under pressure. This helps explain why human factors remain a leading contributor to SOMS incidents despite two decades of navigational modernisation (Harun, 2025).

The literature points to AIS-integrated simulator training under the STCW framework as the complementary intervention, allowing officers to rehearse pilotage, berthing, and collision-avoidance decisions in the specific traffic conditions of the straits (Rahmawati *et al*., 2025). A further pattern emerging from the reviewed studies is institutional: Malaysia's safety architecture spans the Marine Department, the Royal Malaysian Navy, and port-level VTS authorities, and the effectiveness of technically sophisticated systems depends on how well data flows between these bodies — a coordination challenge that resurfaces in the environmental response literature discussed below. In short, the evidence indicates that Malaysia's navigational safety gains are real but asymmetric: Strongest where risk is technological and geometric, weakest where it is human and organisational.

At a technical level, safety of navigation in congested waterways like the SOMS requires robust Quantitative Risk Assessment (QRA), as shown in Table 4, to evaluate accident probability and consequences. Studies show that grounding and collision models must incorporate both geometric probabilities linked to channel width, vessel size, and speed and causation probabilities driven by mariner skills, fatigue, human error, and vessel manoeuvrability (Li *et al*., 2012). Advanced risk modelling using Bayesian networks and fault tree analysis now allows authorities to capture how weather, visibility, and vessel behaviour contribute to collision likelihood, offering predictive insight into accident hotspots. For Malaysia, integrating such probabilistic frameworks with real-time AIS and VTS data strengthens preventive risk management and informs the placement of traffic separation schemes, navigational aids, and pilotage services.

Table 4: Quantitative risk assessment (QRA) methods and their relevance to SOMS

QRA Method	What is Estimates	Relevance to SOMS
Traffic-based/event-frequency models	Expected number of collision or grounding candidates from traffic volume, encounter rates, and geometry	Suited to the SOMS' high transit density (over 100,000 transits annually); helps quantify baseline accident frequency in narrow, congested channels
Fault Tree Analysis (FTA)	Probability of an accident by decomposing it into contributing causal events and their logical combinations	Useful for tracing how equipment failure, pilot error, or procedural lapses combine in confined-water incidents; supports root-cause and barrier analysis
Event Tree Analysis (ETA)	Probability and severity of outcomes following an initiating event (e.g., escalation from contact to spill)	Links a collision or grounding to downstream consequences such as hull breach and oil outflow, connecting safety analysis to the spill-response theme
Bayesian Networks (BN)	Conditional accident probability integrating multiple interdependent factors, updatable with new evidence	Well-matched to the SOMS' multi-factor risk (weather, visibility, traffic, human factors); can ingest real-time AIS and VTS data for dynamic prediction
Causation-factor/ human-reliability models	Probability that an available evasive action fails owing to human or organisational error	Directly addresses the human-factor gap identified in the review, where positional accuracy alone does not reduce error-driven collision risk
AIS-based traffic density and encounter mapping	Spatial distribution of near-miss and high-encounter zones from vessel movement data	Identifies SOMS collision hotspots to inform Traffic Separation Scheme design, VTS coverage, and pilotage deployment

The international legal context reinforces these safety measures. As coastal and archipelagic states, Malaysia and its neighbours enjoy expanded competences under UNCLOS to regulate navigational safety in their territorial seas and exclusive economic zones. While historically such powers were dominated by flag states, there has been a progressive shift toward coastal state authority, supported by IMO conventions and regional agreements (Virzo, 2015). Malaysia's active exercise of these rights, ranging from mandating pilotage in specific straits to enforcing traffic schemes, illustrates its sovereign responsibility to balance freedom of navigation with navigational safety and environmental protection.

The role of Automatic Identification System (AIS) and simulator-based training has also become increasingly central. AIS provides real-time vessel positioning, course, and speed data, which not only supports traffic monitoring but also underpins risk modelling, collision avoidance systems, and maritime spatial planning. Recent reviews highlight how AIS data, combined with ship simulators, is being used for seafarer training under the STCW framework, allowing officers to gain virtual experience in complex pilotage, berthing, and collision-avoidance scenarios (Rahmawati *et al*., 2025). For Malaysia, integrating AIS analytics with simulator training ensures that human factors such as decision-making under stress and fatigue are addressed systematically, reducing the probability of error-driven accidents.

From a broader regional perspective, maritime safety in the SOMS cannot be divorced from maritime security and cooperative governance. As highlighted by Djalal (2001), the Asia-Pacific maritime domain faces intertwined safety and security issues, including piracy, unlawful acts, and smuggling, that directly affect navigation. Within this landscape, Malaysia's cooperation through the Tripartite Technical Experts Group (TTEG) with Indonesia and Singapore, as well as engagement with IMO-led initiatives, underscores its recognition that navigational safety is both a national responsibility and a collective obligation. Efforts to harmonise hydrographic data, expand Search and Rescue (SAR) cooperation, and integrate safety with broader security frameworks are central to sustaining confidence in the SOMS as a safe, reliable artery of world trade.

In summary, Malaysia's approach to maritime safety in the SOMS combines technological modernisation (SISPELSAT, DGNSS, S-100 ENCs), institutional reforms (pilotage, VTS, STRAITREP), advanced risk assessment models, and legal competences under UNCLOS with regional cooperation and training innovation (AIS-simulator integration). This layered framework not only enhances real-time safety but also positions Malaysia as a proactive littoral state in addressing the multi-dimensional risks of one of the world's busiest and most strategically significant maritime chokepoints.

Environmental Protection and Oil Spill Response

Given the ecological sensitivity of SOMS, Malaysia has treated environmental protection as a central concern, situating its national measures within the broader architecture of international sustainability frameworks. The National Oil Spill Contingency Plan (NOSCP), first approved in 1976 and updated multiple times, provides the framework for preparedness and response, integrating legal, institutional, and operational arrangements for oil spill management. In doing so, the NOSCP operationalises Malaysia's obligations under two complementary instruments: MARPOL, which targets prevention of operational and accidental pollution from ships, and Part XII of UNCLOS, which imposes a general duty on states to protect and preserve the marine environment (George *et al*., 2016). This framework is further complemented by regional cooperation through the Tripartite Technical Experts Group (TTEG) with Indonesia and Singapore (Ibarahim, 1995), as well as financial support from the Japan-backed Revolving Fund, established in 1981, which provides emergency financing for oil spill cleanup. While preventive measures remain the priority, Malaysia recognises persistent risks from deliberate discharges, unsafe vessels, and rising traffic density. It has aligned its domestic framework with UNCLOS and MARPOL conventions to strengthen enforcement (George *et al*., 2016).

Viewed through a sustainability lens, these arrangements connect directly to Sustainable Development Goal 14 (Life Below Water), particularly Target 14.1 on reducing marine pollution and Target 14.2 on sustainably managing and protecting marine and coastal ecosystems. The reviewed evidence suggests, however, that Malaysia's compliance architecture is stronger on paper than in operational resilience: Overlapping mandates among the DOE, MARDEP, and MMEA, together with financing and equipment constraints, weaken the rapid-response capacity that SDG 14 outcomes ultimately depend on (Ismail & Taib, 2025). The degradation of mangroves, coral reefs, and seagrass beds carries significance beyond conservation — these ecosystems underpin fisheries, aquaculture, and coastal livelihoods, meaning their loss erodes the natural capital on which Malaysia's blue economy rests (DasGupta & Shaw, 2013). This reframes environmental protection in the SOMS not as a regulatory cost but as an investment in blue economy resilience: Mangrove restoration, for instance, simultaneously serves shoreline protection, carbon sequestration, and spill buffering. Emerging green shipping pressures — alternative fuels, bunkering regulation, and greenhouse gas targets highlighted at the 16th Cooperation Forum (Friedmann, 2025) — will add a further compliance layer, suggesting that Malaysia's environmental governance in the straits must evolve from spill response toward an integrated pollution-prevention and decarbonisation agenda consistent with the IMO's revised GHG strategy.

Recent reviews highlight that effective operations management is vital for oil spill response. The success of the NOSCP depends on efficient logistics, distribution of Oil Spill Response Equipment (OSRE), and multi-disciplinary expertise across engineering, environmental science, and law. However, overlapping mandates between the Department of Environment (DOE), Marine Department Malaysia (MARDEP), and Malaysian Maritime Enforcement Agency (MMEA) can undermine efficiency, while limited financial resources and outdated equipment constrain rapid response (Ismail & Taib, 2025).

Malaysia's fragile marine ecosystems, including mangroves, coral reefs, and seagrass beds, face cumulative stress from oil pollution, ship collisions, and coastal development. Ship collision studies show that bulk carriers and oil tankers dominate accident statistics in Southeast Asia, with collisions and groundings being major contributors to large-scale oil spills (Rahman *et al*., 2024). These incidents amplify ecological risks, damaging fisheries, aquaculture, and coastal livelihoods. Moreover, the cumulative impacts of economic development, including port expansion, urbanisation, and aquaculture, accelerate habitat loss and pollution stress. For example, Malaysia has lost nearly 2% of mangrove cover since the 1980s, with degradation linked to shrimp farming, industrialisation, and climate-related hazards (DasGupta & Shaw, 2013). As mangroves provide shoreline protection, carbon sequestration, and biodiversity support, their degradation undermines natural resilience against oil spills and climate change.

These findings point to three evidence-based responses. First, spill trajectory modeling is recommended because early prediction of slick movement improves the pre-positioning of Oil Spill Response Equipment (OSRE) and response logistics, addressing the operational weaknesses identified in the reviewed literature (Ismail & Taib, 2025), and because collision-driven spills from tankers and bulk carriers, the dominant accident category in the region (Rahman *et al*., 2024), demand rapid, location-specific containment decisions. Such modelling could be operationalised through the S-100 data ecosystem discussed below, where surface current (S-111) and water level (S-104) products provide the real-time inputs trajectory models require. Second, a regional tiered response system and polluter-pays financing are warranted because the reviewed studies show that Malaysia's response capacity is constrained by limited financial resources and ageing equipment (Ismail & Taib, 2025), while liability gaps from uninsured and unsafe vessels leave cleanup costs inadequately compensated under existing conventions, which is a concern reaffirmed at the 16th Cooperation Forum (2025). Tiered arrangements distribute escalation costs across littoral and user states rather than concentrating them on the coastal state nearest the incident. Third, integrating mangrove restoration and climate adaptation into maritime governance is supported by evidence that mangroves provide shoreline protection, spill buffering, and carbon sequestration, and that Malaysia has already lost roughly 2% of mangrove cover since the 1980s (DasGupta & Shaw, 2013); restoring this natural infrastructure directly strengthens resilience against both acute spill events and long-term ecosystem decline. Underpinning all three responses is improved inter-agency coordination among the DOE, MARDEP, and MMEA, since the reviewed evidence identifies overlapping mandates as a persistent drag on response efficiency. Overall, Malaysia's approach illustrates the dual challenge of managing acute risks such as oil spills while addressing long-term ecosystem vulnerabilities in one of the world's busiest sea lanes.

Security and Sovereignty

Malaysia's maritime governance approach underscores both sovereignty and national security in the Straits of Malacca and Singapore (SOMS). While piracy incidents have significantly declined since the early 2000s, the region continues to face transnational threats including smuggling, trafficking, and potential maritime terrorism. Malaysia, often in coordination with Indonesia, has consistently stressed that the primary responsibility for straits security rests with the littoral states, maintaining a cautious stance toward external naval interventions by non-littoral powers (Bateman, 2009). This sovereignty-minded posture is exemplified by joint patrols such as MALSINDO, which balance regional cooperation with an emphasis on national control, contrasting with Singapore's greater openness to outside involvement (Wongnakornsawang, 2016).

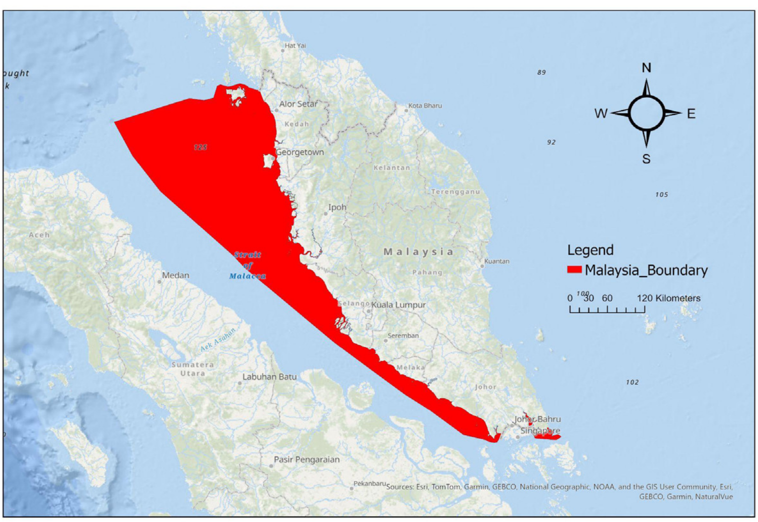

Figure 3: Malaysia's boundary in the Straits of Malacca and Singapore (SOMS)
Source: Flanders Marine Institute (2023)

Malaysia's ability to sustain this littoral-primacy posture in the SOMS is, however, conditioned by security demands elsewhere in its maritime domain. Enforcement assets and inter-agency attention are shared across extensive boundaries with five neighbouring states, and persistent pressures in Sabah and the Sulu Sea, as well as overlapping claims in the South China Sea under UNCLOS (Muhammad & Wan Siti Adibah, 2017), compete for the same naval, police, and Malaysian Maritime Enforcement Agency (MMEA) resources that patrol the straits (Zainol *et al*., 2019). The relevance to SOMS governance is direct: A littoral state that insists on excluding external navies must be able to resource straits security itself, and Malaysia's dispersed security commitments make burden-sharing arrangements with Singapore, Indonesia, and user states more consequential. As illustrated in Figure 3, Malaysia's declared maritime boundary in the SOMS defines the jurisdictional space within which this enforcement responsibility must be discharged.

Within the straits themselves, sovereignty intersects with sustainability. Malaysia's SOMS coastline concentrates ports, oil and gas activity, fisheries, aquaculture, and tourism, and competition among these uses creates overlapping jurisdictions and federal–state–private conflicts (Omar *et al*., 2017). These governance complexities bear directly on security: Fragmented authority weakens enforcement in the straits, creates loopholes for illegal activities, and complicates Malaysia's ability to assert sovereignty over its busiest waters. Institutionally, enforcement rests on the Territorial Sea Act 2012, the Exclusive Economic Zone Act 1984, and the MMEA Act 2004, while internationally Malaysia aligns with UNCLOS and selectively adopts IMO conventions that enhance navigational safety without undermining sovereign control. Nevertheless, overlapping ministerial jurisdictions and the absence of a unified marine space policy remain obstacles to seamless enforcement in the SOMS (Omar *et al*., 2017), with the same institutional fragmentation identified in the safety and environmental themes above. At the regional level, ASEAN-led mechanisms such as the AMF, ADMM, and ARF provide dialogue platforms. However, Malaysia's emphasis on non-interference and consensus reflects its enduring prioritisation of sovereignty, complementing its stance that external naval intervention in the SOMS should be minimised.

In sum, Malaysia's approach to SOMS security balances littoral state responsibility with resource constraints imposed by wider maritime commitments, and anchors enforcement in domestic law and selective internationalisation. The evidence suggests that the principal vulnerability is not external encroachment but internal governance fragmentation, a finding consistent across the reviewed themes and central to the policy implications of this study.

Regional and International Cooperation

SOMS embody both a critical maritime artery and a global chokepoint, carrying one-third of world trade and half of Asia's energy supplies, making cooperative governance indispensable (Evers & Gerke, 2006). Littoral states Malaysia, Indonesia, Singapore, and later Thailand have institutionalised initiatives such as the Malacca Straits Patrols (MSP) and the Eyes in the Sky (EiS) aerial surveillance, which reduced piracy incidents after 2005, though sovereignty sensitivities continue to limit deeper integration, with Malaysia and Indonesia resisting the "internationalisation" of security while Singapore remains more open to external involvement. Under the 1982 UNCLOS framework, the littoral states assume primary responsibility for safety, while platforms like the Tripartite Technical Experts Group (TTEG) and the IMO-led Cooperative Mechanism since 2007 provide dialogue and project funding on navigation and environmental protection, deliberately excluding direct security enforcement. Among user states, Japan has been the most consistent partner, contributing over US$130 million through the Malacca Strait Council and the Nippon Foundation since 1969 for hydrographic surveys, dredging, wreck removal, navigational aids, and training, exemplifying long-term assistance without sovereignty intrusion.

Other powers, including the United States and India through CARAT and SEACAT exercises, and more recently China and South Korea, have expanded capacity-building efforts, reflecting their strategic stakes in uninterrupted trade flows. Malaysia has played a central coordinating role, hosting platforms such as the 16th Cooperation Forum (2025), which brought together littoral states, user states, and industry to review ongoing projects, reaffirm commitments to safety and environmental stewardship, and highlight new challenges such as the global energy transition, uninsured ships, and compensation mechanisms. Yet challenges remain, as Malaysia and Indonesia reject foreign patrols while welcoming technical and financial aid, and shipping industries resist mandatory fees, leaving burden-sharing unresolved (Simon, 2011). Overall, the SOMS demonstrates both the opportunities and constraints of cooperative security: While sovereignty concerns restrict multilateral enforcement, confidence-building, information sharing, and Malaysia's leadership in convening cooperative platforms have ensured tangible safety improvements, with the Cooperative Mechanism offering a pragmatic model that balances littoral sovereignty with user-state responsibility.

Marine Spatial Planning and S-100 Transition

Malaysia has increasingly recognised Marine Spatial Planning (MSP) as a cornerstone of maritime governance in the SOMS. The straits accommodate diverse and often competing activities such as international shipping, fisheries, offshore hydrocarbons, submarine cables, and marine conservation. Without a structured governance framework, overlapping claims increase the likelihood of navigational conflicts, ecological stress, and inefficient use of maritime space. MSP provides a science-based mechanism to allocate space, harmonise multi-sectoral interests, and reduce jurisdictional overlaps between federal and state agencies, while alignment with UNCLOS ensures MSP functions as a compliance mechanism within the international legal framework (Contarinis *et al*., 2022).

The adoption of the IHO S-100 Universal Hydrographic Data Model represents a transformational shift from the legacy S-57 ENC standard. Unlike S-57, which was almost exclusively constrained to Electronic Navigational Charts (ENCs), S-100 supports a much broader suite of interoperable marine data products, such as bathymetry (S-102), surface currents (S-111), dynamic water levels (S-104, S-112), under-keel clearance (S-129), marine protected areas (S-122), and nautical product catalogues (S-128). This makes it a core enabler for MSP, as it integrates safety, environmental, and economic datasets into a common operating picture (International Hydrographic Organisation, 2017).

S-100's design is fully aligned with the ISO 19100 series of geographic information standards, ensuring consistency in data quality (ISO 19113, ISO 19114, ISO 19138), metadata (ISO 19115), and data product specifications (ISO 19131) (International Organisation for Standardisation, 2014). The combination of ISO 19100 principles and S-100 modularity ensures that Malaysia can achieve data interoperability across agencies, improve international data exchange, and build a Marine Spatial Data Infrastructure (MSDI) that is scalable to future technologies such as IoT-enabled buoys, digital twins, and AI-driven risk modelling. Malaysia has taken concrete steps toward implementing S-100 compliant systems through initiatives such as:

i. MyMarine GeoHub – an integrated marine geospatial platform combining hydrography, environment, and port data for real-time decision support (National Hydrographic Centre, 2025).

ii. Maritime Chart Service (MCS) – modernised chart services designed to support S-100 product dissemination, ensuring compliance with IHO and IMO mandates (Esri Malaysia, 2021).

iii. Integration with Port Klang and Penang smart port ecosystems – linking AIS, ECDIS, and environmental monitoring sensors to optimise logistics, navigational safety, and climate resilience (Harizah Hanim Mohamed, 2025).

By embedding S-100 within these platforms, Malaysia is moving toward dynamic risk management, where vessel movements, tides, and currents can be simulated in real time to help anticipate collisions, oil spill dispersion, or shallow-water risks.

The transition also complements advances in intelligent ship supervision and quantitative maritime risk analysis. For example, tools such as AIS-based traffic density mapping, under-keel clearance models (S-129), and risk overlays enable authorities to proactively identify high-collision zones and propose optimised Traffic Separation Schemes (TSS). The incorporation of real-time weather overlays (S-412) and surface currents (S-111) supports not only navigation safety but also climate resilience planning for ports and coastal zones.

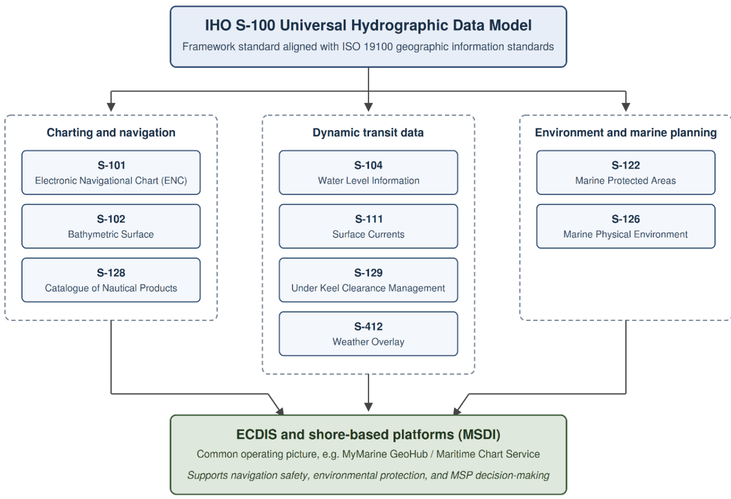

Figure 4: S-100 product ecosystem and its convergence into a common operating picture
Source: Authors' illustration, adapted from (Fisheries and Oceans Canada, 2021)

Table 5: S-100 product specifications as shown in Figure 4

Code	Product Specification	Description
S-100	Universal Hydrographic Data Model	IHO framework standard under which individual product specifications are defined
S-101	Electronic Navigational Chart (ENC)	Next-generation navigational chart replacing the legacy S-57 ENC
S-102	Bathymetric Surface	High-resolution gridded depth data
S-104	Water Level Information for Surface Navigation	Dynamic tide and water level data
S-111	Surface Currents	Real-time and predicted current data
S-122	Marine Protected Areas	Boundaries and attributes of designated protected areas
S-126	Marine Physical Environment	Physical environmental conditions of the marine domain
S-128	Catalogue of Nautical Products	Metadata catalogue of available nautical publications and products

S-129	Under Keel Clearance Management (UKCM)	Supports safe transit of deep-draught vessels in shallow waters
S-412	Weather Overlay	Meteorological data for route planning
ECDIS	Electronic Chart Display and Information System	Shipboard system on which S-100 products are displayed

Table 5 shows the abbreviations used for the S-100 ecosystem in Figure 4, while Figure 4 itself visually demonstrates how modular S-100 products interconnect:

i. S-101 ENC and S-102 bathymetry feed into ECDIS for safe navigation.

ii. S-104 water levels, S-111 currents, and S-129 UKCM enable dynamic decision-making for large vessels in shallow or congested waters.

iii. S-122 Marine Protected Areas and S-126 Physical Environment directly support MSP by embedding environmental safeguards.

This interoperability illustrates how MSP can be operationalised through S-100, transforming policy frameworks into real-time, data-driven governance. At the regional level, Malaysia has actively contributed to the East Asia Hydrographic Commission (EAHC), working on ENC harmonisation and cross-border S-100 product rollouts. Since the 1970s, efforts such as NAVTEX station deployment under NAVAREA XI and ENC standardisation have reinforced cooperative safety mechanisms (Nakabayashi, 2022). These efforts are critical because S-100 product effectiveness depends on cross-jurisdictional consistency, a vessel transiting from Singaporean to Malaysian to Indonesian waters must encounter seamless data continuity. Comparatively, Malaysia's approach to S-100 adoption differs from its neighbours:

Singapore focuses heavily on smart port logistics (e.g., Tuas Mega Port), where digitalisation enhances hub competitiveness, with MSP playing a secondary, though still active, role (Maritime and Port Authority of Singapore, 2025; Ministry of Transport Singapore, 2026).

Indonesia has advanced MSP legislation at the national policy level, but operationalisation of S-100 remains fragmented due to its archipelagic complexity (Wen *et al*., 2022).

Malaysia combines both dimensions of hydrographic digitalisation and MSP integration, thus bridging safety, environmental, and governance objectives in a single framework (National Hydrographic Centre, 2025).

In sum, Malaysia's integration of MSP with the S-100 digital transition represents a holistic, forward-looking model of maritime governance. MSP provides the institutional and legal mechanism to reconcile competing maritime uses, while S-100 supplies the technical infrastructure to ensure interoperable, high-resolution, and quality-controlled geospatial data. By aligning national platforms like MyMarine GeoHub with international ISO 19100 quality principles and IHO S-100 standards, Malaysia is positioning itself as an active contributor to safe navigation, sustainable ocean use, and digital maritime transformation in the region.

Socioeconomic and Strategic Significance

Malaysia treats the SOMS as both an economic lifeline and a strategic chokepoint whose stability underwrites national growth and regional connectivity. Empirically, the straits carry vast oil and cargo flows: Vessel transits reached a record 94,301 in 2024 (Jabatan Laut Malaysia, 2025), very large crude carriers prefer the Malacca route for distance and time savings, and two-thirds of tonnage through the straits consists of Persian Gulf crude bound for Northeast Asia, underscoring why uninterrupted passage matters to Malaysia and user states alike. The economic dependence is direct: Approximately 98% of Malaysia's trade by volume is carried by sea

(Malaysian Investment Development Authority, 2021), with the main container ports along the straits, led by Port Klang, ranked among the world's top ten container ports (Harizah Hanim Mohamed, 2025), and Tanjung Pelepas, handling the bulk of national throughput. Beyond national metrics, the Indian Ocean Region literature situates the SOMS within a network of strategic chokepoints (Suez–Hormuz–Malacca) central to one-third of global trade and energy movement, where major and middle powers increasingly project influence (Anwar *et al*., 2024).

The maritime logistics implications of this dependence are substantial. Any disruption to the SOMS, such as a major collision, grounding, oil spill, or security incident, would propagate through regional and global supply chains via several channels: Vessel delays and port congestion at Port Klang, Singapore, and Tanjung Pelepas as daily transits queue or divert; rerouting costs, since the Sunda and Lombok–Makassar alternatives add days of steaming time, raising fuel, charter, and emissions costs, an effect analogous to the Red Sea disruptions of 2024–2025, which measurably lengthened average global shipping routes (Ministry of Transport Malaysia, 2026); insurance repricing, as elevated chokepoint risk triggers war-risk and hull premium increases passed on to shippers; and degraded supply chain resilience, because just-in-time manufacturing networks across East and Southeast Asia depend on predictable transit times through the straits. Malaysia's investments in navigational safety, spill preparedness, and digital governance reviewed in the preceding themes are therefore not merely regulatory obligations but direct protections of national logistics competitiveness.

At the same time, coastal development linked to maritime growth produces uneven local impacts. In Iskandar Malaysia, large-scale waterfront regeneration (e.g., Danga Bay) promises jobs, public spaces, and catalytic investment. However, it has also triggered environmental and social concerns from mangrove reclamation to gentrification and transboundary ecological effects, highlighting the need to balance port-led urbanisation with community resilience (Sultan *et al*., 2016).

Strategically, the straits' centrality to Asian energy security has intensified great-power attention, with India, China, the US, and Japan each seeking reliable sea lines and mitigation of chokepoint risk; China's development of overland alternatives such as CPEC/Gwadar in response to its "Malacca dilemma" illustrates the stakes (Ahmad, 2019; Ali, 2020). For SOMS governance, this geopolitical salience has three direct consequences. It reinforces freedom of navigation as a shared interest that user states are willing to fund, strengthening the case for burden-sharing through the Cooperative Mechanism; it heightens the sensitivity of security cooperation, sustaining the littoral-primacy posture discussed under the sovereignty theme; and it channels external investment into straits infrastructure especially from Japanese-funded aids to navigation to hydrographic capacity-building, making the SOMS one of the few chokepoints where geopolitical competition has, so far, been converted into cooperative safety financing rather than militarised rivalry. Even as alternative corridors develop, the straits' throughput dominance means this dynamic will continue to shape Malaysia's maritime diplomacy.

Looking forward, Malaysia can align the straits' trade function with an energy-transition opportunity. Technical assessments identify the SOMS as one of the country's most promising corridors for marine renewables, especially tidal current energy supported by national policy frameworks (Renewable Energy Act 2011; SEDA 2011). Preliminary studies report suitable current regimes (often ~2 m/s, up to ~4 m/s in places) and estimate meaningful generation potential, while also cautioning that localised ecological impacts require careful siting and monitoring (Chong & Lam, 2013).

In sum, for Malaysia the SOMS is simultaneously a GDP engine and a locus of strategic exposure. Its ports and coastal cities benefit from dense maritime throughput even as local communities and ecosystems absorb development externalities; meanwhile, regional actors' search for redundancy (e.g., CPEC) underscores how Malacca remains pivotal to Indo-Pacific energy and trade geometries. Sustaining advantage will therefore hinge on three parallel tracks: Keeping the waterway safe and efficient for global commerce; managing coastal transformation with stronger social and environmental safeguards; and investing in data-driven, low-carbon maritime innovations to future-proof the straits' role in national and regional prosperity.

Conclusion

Main Findings

This review systematically examined Malaysia's role in safeguarding the Straits of Malacca and Singapore (SOMS) through six interrelated themes: Navigation safety, environmental protection, sovereignty and security, regional and international cooperation, marine spatial planning, and socioeconomic significance. The synthesis of 66 studies shows that Malaysia has emerged as both a littoral guardian and a key beneficiary of the straits, advancing initiatives such as SISPELSAT and SBAS/DGNSS for safer navigation, the National Oil Spill Contingency Plan for environmental preparedness, and the MyMarine GeoHub and S-100 transition for integrated maritime governance. At the same time, persistent challenges remain human factor risks, institutional overlaps, uninsured vessels and compensation gaps, constraints on funding and data-sharing within cooperative mechanisms, and uncertainty from the global energy transition.

Contributions

By consolidating fragmented literature across safety, security, environmental, and governance research, previously examined largely in isolation, and aligning it with insights from the 16th Cooperation Forum (2025), this review offers the first integrated, systematic synthesis of Malaysia's role in the SOMS. It demonstrates how a littoral state can operationalise international conventions, harness digital standards such as S-100, and navigate sovereignty sensitivities, providing transferable lessons for other congested sea lanes.

Policy Implications

Malaysia should consolidate its multi-agency governance framework by strengthening coordination among the Marine Department, the Malaysian Maritime Enforcement Agency, and environmental regulators to reduce institutional overlap. Regionally, advancing cost-sharing and burden-sharing arrangements under the Cooperative Mechanism would ensure that user states contribute equitably. Investment in S-100-compliant platforms and digital twins should be scaled up as policy tools to anticipate navigational risks and embed environmental protection in operational planning, with Malaysia leveraging its leadership in ASEAN and the East Asia Hydrographic Commission to champion this model.

Limitations

This review relied on Google Scholar as the sole database, which maximised multi-disciplinary and regional coverage but may have introduced indexing inconsistencies; restricting inclusion to English-language, peer-reviewed studies may have excluded relevant work in Bahasa Melayu or Bahasa Indonesia. Screening and MES appraisal were conducted by a single reviewer, which may introduce selection subjectivity despite the structured protocol.

Future Research

Future studies should deepen empirical analysis of digital twin applications, AI-enabled risk modelling, and climate resilience in maritime chokepoints; examine decarbonisation, marine renewable energy, and blue economy linkages in the SOMS; and undertake comparative analyses with corridors such as Hormuz and Panama to test the generalizability of Malaysia's governance approach.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interest Statement

The author declares no conflict of interest.

Author's Contributions Statement

The author confirms sole responsibility for the conception, design, analysis, and manuscript preparation.

References

Ahmad Shahrin, A. B. (2025, September 22–26). *Maritime safety information and S-100 product applications using ArcGIS* [Conference presentation]. 10th Meeting of the S-100 Working Group, Bali, Indonesia.

Ahmad, M. (2019). Strategic importance of CPEC: Prospects and challenges. *Journal of Politics and International Studies*, *5*(2), 127–145. https://jpis.pu.edu.pk/45/article/view/59

Ali, M. (2020). China–Pakistan economic corridor: Prospects and challenges. *Contemporary South Asia, 28*(1), 100–112. https://doi.org/10.1080/09584935.2019.1667302

Anom, W. (2025, September 29–30). *Satellite-based augmentation system (SBAS) for marine navigation in Malaysia* [Conference presentation]. 16th Co-operation Forum on the Straits of Malacca and Singapore, Penang, Malaysia.

Anwar, U., Yousaf, D. M. R., & Hussain, Z. (2024). Evolving geopolitics and security dynamics in the Indian Ocean Region: An analytical overview. *Journal of Nautical Eye and Strategic Studies*, *4*(1), 144–167. https://doi.org/10.58932/MULG0037

Assuad, M. (2025, September 29–30). *The important role of Straits Pilots in ensuring safety of navigation in the Straits of Malacca and Singapore* [Conference presentation]. 16th Co-operation Forum on the Straits of Malacca and Singapore, Penang, Malaysia.

Bateman, S. (2009). Regime building in the Malacca and Singapore straits: Two steps forward, one step back. *The Economics of Peace and Security Journal*, *4*(2). https://doi.org/10.15355/epsj.4.2.45

Chong, H. Y., & Lam, W. H. (2013). Ocean renewable energy in Malaysia: The potential of the Straits of Malacca. *Renewable and Sustainable Energy Reviews*, *23*, 169–178. https://doi.org/10.1016/j.rser.2013.02.021

Contarinis, S., Nakos, B., & Pallikaris, A. (2022). Introducing smart marine ecosystem-based planning (SMEP)—How SMEP can drive marine spatial planning strategy and its implementation in Greece. *Geomatics*, *2*(2), 197–220. https://doi.org/10.3390/geomatics2020012

DasGupta, R., & Shaw, R. (2013). Cumulative impacts of human interventions and climate change on mangrove ecosystems of South and Southeast Asia: An overview. *Journal of Ecosystems*, *2013*(1), Article 379429. https://doi.org/10.1155/2013/379429

Djalal, H. (2001, December). *International framework for maritime security: Current situation and problems* [Paper presentation]. IIPS Meeting, Tokyo, Japan.

Esri Malaysia. (2021). *MyMarine GeoHub – Supporting operations with MCS* [Webinar]. https://youtu.be/Ul3DclPQPdI?si=v1vALtQcDHOvJB9e

Evers, H. D., & Gerke, S. (2006). *The strategic importance of the Straits of Malacca for world trade and regional development* (ZEF Working Paper No. 17). Center for Development Research, University of Bonn.

Fisheries and Oceans Canada. (2021). Navigating the S-100 world [Infographic]. Government of Canada. https://www.dfo-mpo.gc.ca/about-notre-sujet/publications/infographics-infographies/chs-s100-shc-eng.html

Flanders Marine Institute. (2023). Maritime boundaries geodatabase: Maritime boundaries and exclusive economic zones (200 NM), version 12 [Data set]. https://doi.org/10.14284/632

Friedmann, J. (2025, September 29–30). *Navigating the future of energy: Technology, policy and market forces shaping maritime's energy transition* [Conference presentation]. 16th Co-operation Forum on the Straits of Malacca and Singapore, Penang, Malaysia.

George, M., Sabaruddin, J. S. H., & Chong, V. C. (2016). Marine spatial planning: What does it have to offer Malaysia? *The International Journal of Marine and Coastal Law*, *31*(2), 242–278. https://doi.org/10.1163/15718085-12341397

Hand, M. (2026, April 20). Malacca Strait vessel traffic at record levels in 2025. Seatrade Maritime News. https://www.seatrade-maritime.com/tankers/malacca-strait-vessel-traffic-at-record-levels-in-2025

Harun, E. (2025, September 29–30). *Enhancing safety and sustainability: INTERTANKO's perspectives on the Straits of Malacca and Singapore* [Conference presentation]. 16th Co-operation Forum on the Straits of Malacca and Singapore, Penang, Malaysia.

Ho, J. (2009). *The Straits of Malacca and Singapore: Ensuring safe and efficient shipping* (RSIS Commentaries No. 119/2009). S. Rajaratnam School of International Studies.

Ibarahim, R. (1995). *International/regional cooperation to oil spill response in the Straits of Malacca: An overview* [Paper presentation]. Oil Spill Symposium.

International Hydrographic Organization. (2017). *S-100: Universal hydrographic data model* (Edition 3.0.0). International Hydrographic Bureau.

International Organization for Standardization. (2014). *Guidelines for ISO 19100 geographic information quality standards*. ISO/TC 211.

Ismail, M. B., & Taib, C. A. (2025). A current review on operations management in managing major oil spills from ships (tankers) in the Straits of Malacca, Malaysia. *Journal of Technology and Operations Management, 20*(1), 45–57. https://doi.org/10.32890/jtom2025.20.1.4

Jabatan Laut Malaysia. (2025). *Statistik laman web: Disember 2025* [Website statistics: December 2025]. https://www.marine.gov.my/wp-content/uploads/2026/04/01-STATISTIK-LAMAN-WEB-DIS-2025.pdf

Kono, H. (2025, September 29–30). *Contributions to the Straits of Malacca and Singapore* [Conference presentation]. 16th Co-operation Forum on the Straits of Malacca and Singapore, Penang, Malaysia.

Li, S., Meng, Q., & Qu, X. (2012). An overview of maritime waterway quantitative risk assessment models. *Risk Analysis, 32*(3), 496–512. https://doi.org/10.1111/j.1539-6924.2011.01697.x

Malaysian Investment Development Authority. (2021). *Maritime transport: Accelerating international trade*. https://www.mida.gov.my/maritime-transport-accelerating-international-trade/

Maritime and Port Authority of Singapore. (2025). *Driving growth and innovation to strengthen maritime competitiveness and resilience* [Media release]. https://www.mpa.gov.sg/media-centre/details/driving-growth-and-innovation-to-strengthen-maritime-competitiveness-and-resilence

Martín-Martín, A., Orduna-Malea, E., Thelwall, M., & Delgado López-Cózar, E. (2018). Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories. *Journal of Informetrics, 12*(4), 1160–1177. https://doi.org/10.1016/j.joi.2018.09.002

Mengist, W., Soromessa, T., & Legese, G. (2020). Method for conducting systematic literature review and meta-analysis for environmental science research. *MethodsX, 7*, 100777. https://doi.org/10.1016/j.mex.2019.100777

Ministry of Transport Malaysia. (2026). *Malaysia must build future-ready maritime economy, says Loke* [Keynote address at the Global Maritime Economics Conference 2026, reported by The Edge Malaysia]. https://theedgemalaysia.com/node/807880

Ministry of Transport Singapore. (2026). *Shaping the future of Maritime Singapore*. https://www.mot.gov.sg/what-we-do/maritime/shaping-the-future-of-maritime-singapore/

Mohamed, H. H. (2025). Port Klang joins global port elite, officially ranked 10th among the world's top container ports. *BERNAMA*. https://www.bernama.com/en/news.php?id=2494379

Muhammad, N., & Wan Siti Adibah, W. D. (2017). The islands claimed by Malaysia in the Spratly Islands: A review based on the United Nations Convention on the Law of the Sea 1982. *IOSR Journal of Humanities and Social Science, 22*(9), 7–17. https://www.iosrjournals.org/iosr-jhss.html

Nakabayashi, S. (2022). East Asia Hydrographic Commission: Fifty years of progress. *The International Hydrographic Review*, (27), 99–112. https://journals.lib.unb.ca/index.php/ihr/article/view/33135

National Hydrographic Centre. (2025). *MyMarine GeoHub: Marine geospatial data portal*. Royal Malaysian Navy. https://geohub.hydro.gov.my

Omar, A. H., Abdullah, N. M., Rambat, S., Yahaya, N. A. Z., Rahibulsadri, R., Abdullah, A., Yahya, R., Jamil, H., Hua, T. C., & Lim, C. K. (2017). Sustainable marine space managements: Malaysian perspective. In Yomralioglu, T., & McLaughlin, J. (Eds.), *Cadastre: Geo-information innovations in land administration* (pp. 309–332). Springer International Publishing. https://doi.org/10.1007/978-3-319-51216-7_23

Rahman, R. A., Suryanto, S., Prabowo, A. R., Yaningsih, I., Ehlers, S., & Braun, M. (2024). Assessment of ship collision risk based on the recorded accident cases: Structural damage and environmental recovery. *E3S Web of Conferences, 563*, 03087. EDP Sciences. https://doi.org/10.1051/e3sconf/202456303087

Rahmawati, M., Pitana, T., Handani, D. W., & Siswantoro, N. (2025). Utilization of AIS data and ship simulator integration in maritime safety: A systematic literature review. *IOP Conference Series: Earth and Environmental Science, 1461*(1), 012049. IOP Publishing. https://doi.org/10.1088/1755-1315/1461/1/012049

Simon, S. W. (2011). Safety and security in the Malacca straits: The limits of collaboration. *Asian Security, 7*(1), 27–43. https://doi.org/10.1080/14799855.2011.548208

Sultan, Z., Norizan, N. Z. A., & Tahira, M. (2016). Between land and people: A review of socioeconomic issues within the context of rapid development in Iskandar Malaysia. *International Journal of Built Environment and Sustainability, 3*(3). https://doi.org/10.11113/ijbes.v3.n3.143

Virzo, R. (2015). Coastal state competences regarding safety of maritime navigation: Recent trends. *Sequência (Florianópolis)*, 19–42. https://doi.org/10.5007/2177-7055.2015v36n71p19

Wen, W., Samudera, K., Adrianto, L., Johnson, G. L., Brancato, M. S., & White, A. (2022). Towards marine spatial planning implementation in Indonesia: Progress and hindering factors. *Coastal Management, 50*(6), 469–489. https://doi.org/10.1080/08920753.2022.2126262

Wongnakornsawang, W. (2016). *Maritime security cooperation in ASEAN: Challenges and prospects*. Royal Thai Navy. https://www.thai-mecc.go.th/wp-content/uploads/2021/06/maritime-security-cooperation-asean.pdf

Zainol, N. A. M., Jusop, A. Z., Ridzuan, A. A., & Kamaruddin, S. (2019). Managing Malaysian border: The challenges and prospects in maintaining security. *International Journal of Politics, Public Policy and Social Works, 1*(3), 1–13. https://doi.org/10.35631/ijppsw.13001