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Improving Safety of Navigation and Sustainability of Shipping Through Innovative Autonomous Shipping Technologies in Asia Pacific: Case Study of Thailand

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Abstract

The concept of autonomous vehicle has also extent to maritime vessels due to the potential of minimizing operational cost, removing the difficulties to hire crew member on board, reducing the discharge of garbage and sewage, and lowering number of human error induced incidents during the voyage mainly due to human exhaustion. This article explored lessons from stakeholders in Thailand on how they prepare for adopting autonomous shipping by using the qualitative approach through documentary and field survey, interviews with experts and organizing a focus group comprising participants from relevant government authorities and business sectors, evaluated opportunities and threats and readiness of Thailand to engage in innovative autonomous shipping; and proposed guidelines for implementing autonomous shipping in Thailand. The result showed that Thailand should gradually promote autonomous shipping in the medium to long terms by raising awareness and opening mindset to us autonomous vessels in commercial shipping, innovating education, modernizing regulations through various stages ship construction and operations, creating government and port technical platforms to communicate with autonomous vessels, and conducting pilot testing in designated closed navigation system prior to commercializing it in national and international scale.

Keywords: Autonomous Shipping, Navigation, Safety, Sustainability

Introduction

The global industrial revolution has significantly influenced the development of vehicles across in all modes of transportation including road, rail, air, and shipping sector. Recently, a number of organizations in developed countries in Europe, North America, and selected countries in Asia such as Republic of Korea, China,

and Japan have conducted studies on the adoption of technologies for autonomous shipping as well as the preparation of regulations for governing future vessel operations. These efforts include a wide range of measures such as establishing regulations and technical standard to ensure navigation and operational safety, transforming conventional ports into smart ports equipped with digital technologies and advanced communication infrastructure, providing research and innovation funding, and conducting pilot testing in designated navigation areas. (GAO, 2024; Han, 2021; Jovanovic et al., 2024; Kang et al., 2025; Malmquist & Munim, 2025; Nakashima et al., 2025; Shao et al., 2024; SyndiGate Media, 2023; Wennersberg et al., 2026; Xing & Zhu, 2023; Xing, 2024). Autonomous vehicle across all transportation modes have also attracted increasing attention in many developing countries, including Thailand, especially in the areas of research and development prior to advancing toward commercial application in alignment with Thailand's 20-year National Strategy, which aims to develop the smart automotive and vehicle industry as one of the country's future industries. (Amiri et al., 2025; Chengcheng et al., 2024; Wenliang et al., 2024; Kiattikomol et al., 2025; NESDC, 2017).

Ideally, Society of Automotive Engineers (SAE) has classified autonomous vehicles into 0 to 5 levels based of the stages of development (McLeay et al., 2025). Level 0 is the level of traditional driving without autonomous driving and the driver is responsible for all operations. Level 1 is defined as the level which a vehicle contains driving assistance functions protecting the driver's driving. Level 2 refers to the level where the automation system performs part of the driving operations and the driver operates other functions such as monitoring driving circumstances. Level 3 is the scene which most entire driving is controlled but allowing driver to control the driving in some requested circumstance such as where the road condition and environment is unstable. Level 4 is the level where the automation performs the overall operation and monitors the driving environment. The driver is not required to control the drive but there is still room for the driver to intervene under certain circumstances. Level 5 is the unmanned vehicle and the using automation system to fully control and monitor all driving under all conditions.

Although the concept of autonomous vehicles have been extended to maritime vessels in developed countries in Europe and North America as well as in leading shipbuilding countries in Asia such as China, the Republic of Korea, and Japan due to their potential of minimize operational costs, address crew shortages, reduce the discharge of garbage and sewage, and lower the number of human error induced incidents during voyages, particularly those caused by crew fatigue and exhaustion (Ranjan et al., 2025; Yewen et al., 2021). The development of smart and autonomous vehicles in Thailand has been applied primarily to in-factory transportation and road transport. However, there has been very limited research concerning their application in commercial shipping. At the same time, the International Maritime Organization (IMO) has increasingly required member

countries to prepare regulatory frameworks related to the safe navigation of autonomous shipping, particularly in ASEAN countries which represents a key maritime shipping market in Asia Pacific (IMO, 2025). Singapore and Malaysia have already initiated preparation to support the adoption of autonomous ships (ESCAP, 2023), whereas Thailand has not yet undertaken studies on its readiness to govern and promote the adoption of autonomous shipping. Therefore, further study on this issue is necessary.

Objectives

1. Review concept of autonomous shipping.
2. Explore lessons learned from stakeholders in Thailand on how they prepare for adopting autonomous vehicle and autonomous shipping.
3. Evaluate opportunities and threats and readiness of Thailand to engage in innovative autonomous shipping and propose guidelines for implementing autonomous shipping in Thailand.

Research Methodology

In order to achieve the established objectives, this paper employed the qualitative approach and content analysis methodology. The study was conducted through the following processes:

1. Synthesis of existing knowledge through the collection and review of academic literature, concepts, previous studies related to the current situation of maritime transport, designated areas that are possible to conduct pilot test for autonomous shipping, application of autonomous vehicle and policy documents pertaining to the regulation and promotion of autonomous vehicle and shipping adoption in foreign countries.

2. Purposive interviews were conducted based on quota sampling method with five participants with relevant experiences and responsibility related to shipping operations from each stakeholder group totally 30 informants including (a) group of shipbuilding companies, (2) group of ship owners, (3) group of ship agents and brokerage, (4) group of ship classification societies, (5) group of port operators, and (6) groups of government officers directly responsible for ship inspection, certification, and standards. The interview was conducted by structured open-ended questionnaires covering topics related to technological adoption, financial cost and benefit, regulation of vessels, customs clearance, infrastructure, safety, sustainability, and human resource readiness as well as opportunities and challenges to their adoption in Thailand navigation.

3. Study of international practices and lesson learned in innovating autonomous shipping by purposively selected experts from authorities in countries that have already implemented or are preparing to adopt autonomous shipping namely China, the Republic of Korea, Japan, Russia, Malaysia, India, and Indonesia to extract lessons learned from their experiences.

4. Assessment of Thailand's Readiness by using content analysis based on the International Maritime Organization (IMO) framework. The assessment covered multiple dimensions, including vessel standards and regulations, shipbuilding capabilities, vessel inspection systems, communication systems between ships, ports, and government agencies, maritime safety requirements, cybersecurity preparedness, readiness of business operators and workforce, and economic justification.

5. Development of policy recommendations for regulating and promoting the adoption of autonomous shipping in Thailand were formulated through a stakeholder consultation workshop held in Chonburi Province. The workshop gathered representatives from the public and private sectors, as well as international experts from China, Japan, Korea, Indonesia, Malaysia, India, Russia, Thailand together with representatives from IMO and UNESCAP, totaling 30 participants. The study findings were validated by using triangulation methods to cross-checking information sources and assessing the relevance and credibility of informants. The findings were further verified against Thailand's existing regulatory context and international best practices to ensure their applicability for future policy implementation and practical adoption.

Research Results

Current Maritime Transport Situation in Thailand

Maritime transportation plays a vital role in Thailand's international trade which accounts for more than 80 percent of the country's total international freight transportation. Thailand has a coastline of 3,219 kilometers which is divided into two main parts: Thai gulf and the Andaman coast. The coastline of Thai gulf extends 1,660 kilometers and covers the Eastern Region, Bangkok and its surrounding areas, the Lower Central Region, the Upper Southern Region, and the Lower Southern Region. There are approximately 220 ports along coastline which can be categorized into 4 clusters: (1) Inner Thai gulf covering Bangkok and its surrounding areas and includes major river ports such as Bangkok Port and other privately operated ports along Chao Phraya River, for example, Saha Thai Terminal, BMTP, and Bangkok Barge Terminals; The Inner Thai gulf has experienced heavy traffic congestion and high volume of passenger ferry services, which could create safety risks in navigation if commercial autonomous shipping are introduced into operation. (2) Eastern Thai gulf encompasses the Eastern region and serves as the center of Thailand's container and industrial deep seaport activities. Major ports in this area include Laem Chabang Port, Map Ta Phut Port, and Kerry Siam Seaport. Although ports in this area have been preparing to adopt advanced technologies to support vessel operations, the area cluster remains heavily congested by large vessels. In addition, a significant number of ships transporting dangerous goods regularly pass through the area. The factors could create safety risks in navigation if autonomous shipping are introduced into service; (3) Western Thai gulf combines parts of the Lower Central Region, the Upper Southern Region, and the Lower Southern Region, where maritime activities primarily focus

on fisheries and bulk cargo transportation. The main cargo ports in this region include Songkhla port and Prachub port. This cluster could be considered as another potential option for running autonomous shipping experience due to its relatively low to medium transport volume. However, there are still extensive coastal shipping service transporting fuel and gas which may cause safety concern for the deployment of autonomous shipping; and (4) the Andaman coast which mainly supports passenger ferries, offshore supply services, and short voyage connecting Thailand and neighboring countries. The number of cargo ports in this region is relatively limited, with most located in Ranong and Trang province. Compared with other maritime clusters, this cluster is rated as the most suitable for establishing the experiment of running autonomous shipping as it has relatively low traffic density and is supported by coast guard organization that are readily available to provide assistance.

Approximately 10 to 12 percent of Thailand's merchandise trade from 2000 to 2025 was transported by Thai - flagged vessels. Restrictions on foreign ownership remain a significant regulatory measure within Thailand's maritime sector. To register a vessel under the Thai flag for international shipping services, the operator must maintain at least 51 percent Thai ownership and at least 50 percent of the crew must be Thai nationals. For vessels operating in domestic routes, the ownership requirement increases to a minimum of 70 percent Thai ownership, while all crew members must be Thai nationals. In addition, foreign vessels are prohibited from to engaging in domestic waterborne transportation under the provision of the Thai vessel Act. In order to implement autonomous shipping in Thailand, the registration of ship and requirement of employing ship crew must comply with this existing law. Several public and private organizations play important roles in promoting Thailand's shipping industry. Key stakeholders include Ministry of Transport, Marine Department, Customs Department, Revenue Department, Ministry of Commerce, Port Authorities of Thailand, Thailand National Shipper Council, Thai Chamber of Commerce, Thai Federation of Industries, Thai Ship Owner Association, Bangkok Ship owners and Agents Association, Thailand International Freight Forwarders Association, and Thai International Cargo and Container Association. The survey findings indicate that only a limited number of organizations, particularly the Marine Department, has demonstrated substantial awareness of autonomous vessels development initiatives promoted by IMO. Most public and private organizations remain relatively unfamiliar with autonomous shipping concepts and have not yet established adequate preparedness measures to support future implementation. Nevertheless, in the short term, most stakeholders agreed that Thailand should place greater emphasis on the adoption of energy – efficient or electric vessels rather than prioritizing the development of systems and infrastructure to support autonomous shipping operations.

Thailand's shipbuilding and ship repair industry remains less developed than those of Singapore, Malaysia, Indonesia, the Philippines, and Vietnam. Approximately two-thirds of the dockyards in Thailand are small scale facilities with capabilities limited to the construction and repair of vessels smaller than 500 gross registered tons (GRT). Most

of these dockyards are not equipped with advanced machinery, automation and digitalization systems, or modern shipbuilding technologies, and primarily serve local demand, particularly for wooden fishing boats. At present, the industry is more heavily focus on ship repair services rather than new ship construction and currently lacks the technological capability required to construct autonomous vessels.

The principal legislations governing the maritime and waterborne transportation sector encompass the Navigation in Thai Waters Act, Thai Vessels Act, Mercantile Marine Promotion Act, Carriage of Goods by Sea Act, General Average in Maritime Adventure Act, Preventing Ship Collision Act, Ship Mortgage and Maritime Lien Act, Arrest of Ship Act, Multimodal Transportation Act, Port Authorities Act, Immigration Act, and Customs Act. The Marine Department under the Ministry of Transport continues to serve as the primary regulatory authority for the maritime transport sector. Its responsibilities include law enforcement, navigation safety, ship registration and inspection, certifying ship's equipment and facilities, maintenance of navigation channels, provision of pilotage services for seagoing vessels, supervision of port construction and expansion, and mitigation of environment impact arising from maritime transportation and port operations. In addition, the Marine Department is responsible for promoting and developing the maritime transport including infrastructure development. The study findings indicate that several existing laws and regulations, including customs regulations, immigration laws, and ship collision prevention regulations, are not yet fully supportive of the operation and implementation of autonomous shipping. These legal frameworks were originally designed for conventional manned shipping operations and may therefore require significant amendments to accommodate autonomous navigation technologies and remote vessel operations.

As of 2024, Thailand has approximately 220 international ports nationwide, the majority of which are small and medium sized ports owned and operated by private companies. Thailand's main ports are those owned by Port Authorities of Thailand namely Laem Chabang Port, and Bangkok Port. Laem Chabang Port, the largest and highest maritime liner connectivity port, is owned by Port Authority of Thailand while container terminal operations are managed by private operators under concession agreement. The private sector participation in port operation generally takes the form of either a leasehold agreement or Built – Operate – Transfer (BOT) agreements. Concession periods granted to private terminal operators typically range from 25 to 30 years for the management of container terminals and other port facilities. Other main government - owned ports are Map Ta Phut Port in the east of Thailand, which is operated by Industrial Estate of Thailand under Ministry of Industry and Songkhla Port in the south of Thailand, where port operations have been granted to the private company under concession. In addition, other container ports and ports used for serving liner shipping in Thailand are operated by private sector. These include Kerry Siam Seaport and Siam Commercial Seaport nearby Laem Chabang Area and BMTP, Sahathai Terminal, Bangkok Barge Terminal, Suksawat Terminal, Thai Connectivity Terminal, and Unithai port which are located along the Chao Phraya River. The study

findings revealed that only Laem Chabang Port and Bangkok Port, both under the responsibility of Port Authority of Thailand, have initiated preparations to upgrade equipment and digital systems to accommodate modern vessels and future maritime technologies. In contract, most other ports have primarily focused on improving cargo-handling equipment at berth areas, while limited progress has been made in developing communication systems, digital infrastructure, and integrated smart port technologies necessary to modernize port operations and support autonomous shipping in the future.

Thailand's logistics and maritime transport policy is formulated within the broader framework of 20 Year National Strategy (2018-2037) and National Social and Economic Development Plan which are periodically revised while conventionally emphasizing several key priorities. These priorities include (a) the utilization of trade cooperation and trade liberalization agreements to increase export volume and investment; especially agreements involving ASEAN countries and their dialogue partners; (b) the development of transport infrastructure, especially rail and water transport systems to facilitate modal shifts from road transport to reduce traffic congestion and environmental pollution; (c) the enhancement of trade and transport facilitation systems, especially national single window to increase speed and accuracy of information exchange among organizations involved in international trade; (d) the promotion of utilization of existing river ports and regional coastal ports, including the improvement of road access to such ports; (e) the strengthening of connectivity between international ports and coastal ports; (f) the monitoring of operations and concession payments of private container terminal operators at Laem Chabang Port to ensure compliance with concession agreements; (g) the expansion of service capacity of Laem Chabang port; (h) the enhancement of capacity of logistics service providers and Thai maritime transport operators through tax incentives, financial support measures, quality standards development, and business network expansion with domestic and international partners; (i) the amendment of laws and regulation that may hinder business efficiency, taking into account of international standards and accepted practices; and (j) the promotion of environmental friendly transportation services. Overall, the study findings indicate that Thailand's logistics and transportation strategies have not yet explicitly emphasized the commercial adoption of autonomous shipping. In contrast, Thailand's industrial development strategies place greater importance on the promotion and development of autonomous vehicles and next-generation vehicles aimed at improving energy efficiency and supporting the transition toward clean and renewable energy technologies.

Compendium of Initiatives Related to Autonomous Vehicle and Vessel in Thailand

Thailand' s interest in developing the autonomous vehicle industry originated in 2015 when the automation industry including robot, automation system, and autonomous vehicle was identified as one of top ten targeted next generation industries under the Thailand 4.0 policy. This policy was introduced as a strategic initiative to support Thailand's transition from a middle-income economy to a high high-income economy in the future (TDRI, 2021). Robot

and automation systems have increasingly played vital roles in both daily life and industrial operations. The adoption of robot and automation technologies has contributed to improvements in operating efficiency across various sectors including manufacturing, agriculture, services, transportation and logistics services. In August, 2017, Thailand government approved three main mechanisms aimed at creating favorable ecosystem to propel the development of robot and automation system industry. These mechanism consisted of (1) accelerating the adoption of robotic and automation systems across manufacturing and service industries in order to enhance operational efficiency by stimulate domestic demand for automation technologies.; (2) promoting the production of system integrators (SI) to ensure the supply of qualified SI providers would adequately meet growing market demand; and (3) instituting the Center of Robotics Excellence (CORE) to provide technological support, research collaboration, and advisory services for existing robot and automation system enterprises, enabling them to expand into advanced application and future – oriented products such as elderly care robot, police robot, hospitality robot, autonomous vehicle, autonomous bus, robot taxi, autonomous ship, and autonomous aerospace (BOI, 2019).

To achieve the government's objective of positioning Thailand as a regional leader in ASEAN in developing and using robot and automation in various fields by 2026, Thailand government introduced several policy measures. These measures include: (a) the implementation of marketing promotion strategies aimed at encouraging manufacturing and service industries to gradually transition from conventional operating system to robotic and autonomous system; (b) the development of system integrators (SI) to accommodate growing investment in robot and automation industries; (c) the strengthening of supply generation capabilities to raise the quality of robotic and autonomous technology products; and (d) forming center of excellence by CORE to support the advancement of robot and autonomous technologies by fostering strategic collaboration among technical institutes and universities. The main organization responsible for driving policy initiatives related to robot, autonomous vehicle, automation system industry in Thailand is Ministry of Industry and its affiliated agencies, Office of Industry Economy, Office of Industrial Standard, Department of Industrial Promotion, and Electrical and Electronics Institute. working in cooperation with relevant organizations such as National Science and Technology Development Agency, Board of Investment (BOI), and Thai- German Institute. However, the study found that that collaboration among these organizations has primarily remained within agencies under the Ministry of Industry and Ministry of Higher Education, Science, Research and Innovation (MHESI) with limited involvement from transport related authorities, particularly the Ministry of Transportation. As a result, the absence of an integrated coordination mechanism involving transport related authorities may hinder or delay the development, regulatory preparation, and commercialization of autonomous vehicles and autonomous vessels within Thailand's transportation and maritime sectors.

In terms of advancing the government policy on the promotion of the robotic and automation system industry

toward industrialization and commercialization, the period of 2017 to 2025 witnessed increasing participation by Thai business enterprises in automation related activities. Most investments were concentrated in the production of drones used for agricultural applications and automated guide vehicles (AGVs) used within factories, warehouses or other closed operational environments. However, up until end of 2025, no enterprise had applied for investment promotion privileges for the manufacture of autonomous vehicle intended for commercial operation in public spaces such as roads and waterways.

Although limited progress has been achieved in commercial investment related to autonomous vehicle and autonomous shipping for transportation purpose, some advancements have been made in research and development (R&D) projects in small scale through government funded pilot projects. These projects primarily focus on the development of small scale remotely controlled autonomous ships for specific applications such as water quality monitoring, marine resource surveying, and environmental data collection, with the objectives of minimizing human operational risks. In addition, unmanned surface boats have been developed for inspection and survey operations in canals and rivers. Overall, the implementation of automation technologies within Thailand's maritime and shipping sector remains limited and is still largely confined to experimental research and small-scale pilot applications.

Challenges of Developing Innovative Autonomous Shipping

At the present, the research discovered that the demand for autonomous shipping for commercial maritime transportation in Thailand remains limited, in contrast to the growing demand for environmentally friendly and clean energy vessels, as well as the increasing adoption of internet-based and digital communication technologies within the maritime shipping and port sectors. To facilitate the commercialization of the autonomous vessel in maritime transportation sector in Thailand, it is necessary to examine the associated challenges across multiple dimensions as follow.

1. Legal Concerns

1.1 Prevention of Collision of Ship Act

The convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs) was established to ensure safety in ocean navigation. Thailand subsequently adopted the Prevention of Collision of Ships Act, 1979, following its accession as a member state to COLREGs. One of the fundamental principles of maritime navigations is the duty of good seamanship, which is explicitly stipulated under Rule 2 of COLREGs. In addition, Rule 5 of COLREGs requires that every vessel maintain a proper lookout by sight and hearing, and all available means at all times, implying the continuous use of both radar systems and direct human observation. Rule 6 of COLREGs further requires vessels to proceed at a safe speed appropriate to prevailing circumstances and conditions. With the advancement of autonomous shipping technologies, significant legal and operational questions have emerged

regarding the applicability of these regulations to autonomous ships, particularly in situations where human perception, judgment, or decision making are traditionally required to respond to complex navigation circumstances. Nevertheless, it may be argued that autonomous ships equipped with sufficiently advanced technologies could comply with the intent and objectives of COLREGs framework for several reasons. (1) properly qualified shore-based controllers would be capable of responding promptly and effectively to navigational situations; (2) autonomous ships equipped with remote control function, cameras, audio systems, radar and satellite communication technologies may satisfy the requirement of Rule 5 as lookout functions traditionally performed onboard can potentially be conducted remotely by shore-based controllers.; and (3) autonomous ships equipped with satellite communication, spatial sensors, artificial intelligence systems, and advanced control algorithms may be able to obtain more precise navigational data in real time, thereby improving the accuracy of safe speed determination and navigational decision making. Accordingly, the COLREGs framework may still be appliable to t autonomous ship operations, notwithstanding the fact that the regulations were originally designed for conventional human – operated ships. This issue is particularly significant given that current studies estimate that approximately 75 – 96 percent of marine accidents and casualties are caused by human error. Therefore, autonomous shipping technologies may offer potential opportunities to substantially reduce human error related maritime incidents in the future.

1.2 Navigation in Thai Waters Act

Different levels of autonomous shipping reflect varying degrees of human participation in monitoring, intervening in, or controlling ship operations during a voyage. The introduction autonomous ships into Thai water territory will therefore require a series of substantial amendments of existing legislation and regulatory frameworks in several key areas. These issues include (a) the duties and responsibilities of ship masters and remote operators in relation to collision prevention, navigational control, and incident reporting to relevant authorities; (b) the mechanism and procedures for notifying relevant authorities such as the Marine Department and port operators, regarding the ship arrival and departure information; (c) the establishment of measures to prevent an autonomous ships from entering into the restricted or prohibited navigation areas; (d) the legal framework governing the suspension, withdrawal or confiscation of license of ship master or remote operators responsible for an autonomous ship that violate navigational restriction or enter into prohibited navigation areas; and (e) the authority or regulatory agencies to require autonomous ships to navigate only within designated routes and to anchorage only in approved anchorage areas.

1.3 Thai Customs Act

The introduction autonomous ship into Thai territorial water will require amendments to several aspects of existing customs related legislation and procedures. Key issues include (a) the duties and responsibilities of ship

masters or remote operators in facilitating customs inspections, including accommodating customs officers onboard and responding to inquiries to the ships, crew members and cargoes; (b) the authority of customs officer to detain or control the autonomous ships in situations where cargo handling operations are not completed within the prescribed timeframe or where there is a risk of evasion from customs control; and (c) the development of appropriate mechanism and procedures for notifying customs authorities of ship the arrivals and departures, including the adoption of digital communication and automated reporting systems suitable for autonomous ship operations.

2. Human Resource

Current education and training programs and facilities offered by universities, vocational schools, and training institutes in Thailand have not yet been adequately adapted to support the adoption of autonomous shipping technologies. This situation places Thailand in a challenging position with respect to preparing human resources in both public and private sectors to accommodate the implementation of autonomous shipping in the short and medium term. At present, the academic courses offered in universities and colleges specializing in maritime transportation continue to focus primarily on conventional subjects such as cargo handling and stowage, ship communication systems, International Maritime Organization (IMO) conventions and maritime laws, oceanographic, prevention of marine pollution, advanced ship passage planning, electronic navigation, celestial navigation, navigational watch keeping, ship stability, ship construction, seamanship, and cargo ship operations training. Furthermore, many educational and training institutes have not yet substantially revised their courses or modernized teaching methods to address emerging technological mega trends and disruptive innovations affecting the maritime industry. Areas such as robotics, digitalization, artificial intelligence, autonomous systems, future mobility technologies, and smart maritime operations remain insufficiently integrated into existing maritime education and training frameworks. As a result, Thailand may face constraints in developing a future maritime workforce capable of supporting autonomous shipping operations and related technological transformations.

3. Cybersecurity

Cybersecurity concerns have emerged alongside the increasing adoption of digital and computer - based systems in maritime operations. Autonomous ships are especially vulnerable to cyber threats due to their heavy reliance on complicated computerized system, large scale data transfer through satellite communication networks, and satellite – based navigation technologies. Without accurate and continuous navigational information, autonomous ships may be unable to safely continue their voyage. Unmanned vessels controlled through shore based remote – control systems, as well as fully autonomous vessels that rely on remote intervention when necessary, depend extensively on the continuous exchange of large amounts of information via a satellite communication network. Consequently, any disruption to communication systems, unauthorized

system intrusion, or transmission of false or manipulated information may result in a significant loss of navigational control and operational safety. These cybersecurity risks therefore represent one of the critical challenges associated with the development and implementation of autonomous shipping technologies.

4. Protection of Marine Environment

The operation of autonomous ships with reduced crew is reckoned to contribute to reduce environmental impacts, particularly through reductions in the discharge of garbage and sewage. Nevertheless, significant concerns remain regarding the ability of unmanned vessels to effectively respond to pollution incidents originating from their own fuel tanks and cargo. For the time being, there are limited practical solutions in the form of equipment capable of independently containing and cleaning up spillage or hazardous cargo leakage without a crew. In the absence of effective pollution response mechanism, it might be difficult to demonstrate that autonomous ships can provide an equivalent level of environmental protection to that achieved by conventionally manned ships. In addition, the obligation to report pollution – related incidents present another important regulatory challenge. Under the International Convention for the Prevention of Pollution from Ships (MARPOL), the ship master or the person in charge of a vessel is required to report on all incidents that may result in marine pollution. While conventionally manned vessels and remotely controlled autonomous ships may still be capable of complying with such requirements through onboard personnel or shore-based operators, fully autonomous vessels operating without human supervision onboard may face difficulties in meeting these reporting obligations under the existing legal framework.

Conclusions and Recommendations

Based on recent development of autonomous shipping in developed countries outlining that the adoption of autonomous shipping requires a considerable period of time to revising regulation and establishing mechanisms to support technologies and human resource readiness (Dhaneswara, 2024; Malmquist & Munim, 2025; Sotiropoulos, 2024), together with Thailand's policy initiatives aimed at positioning the country as a regional leader in automation system industry, as well as existing constraints related to regulatory frameworks and human resource readiness. This paper proposes several pragmatic medium to long term measures to promote autonomous shipping in Thailand, as follows:

1. Establishment of a National Forum on Autonomous Ships is necessary to enhance awareness, facilitate knowledge exchange, and formulate strategies to promote the progressive adoption of autonomous shipping in both domestic and international waters Such a forum should include representatives from the maritime transportation sector as part of the national work group responsible for driving of the development of robotics, autonomous vehicle, and automation system industries. At present, policy coordination mechanisms in these

areas are primarily led and administered by agencies under Ministry of Industry. Therefore, the inclusion of maritime transport authorities and stakeholders would help reduce existing development gaps, improve inter-agency coordination, and accelerate progress in the research, development, commercialization, and practical application of autonomous vehicles and autonomous vessels within Thailand's transportation and maritime sectors.

2. **Promoting an Open Mindset toward Autonomous Shipping**: the introduction of autonomous ships into commercial maritime services should not focus solely on cost reduction and energy efficiency, but should place primary emphasis on operational safety management of operations, ship design and construction standards, and the allocation of responsibilities and liabilities among relevant stakeholders. At the same time, both public and private sector stakeholders should adopt a more open mindset toward technological advancement and innovation in order to facilitate the gradual acceptance and implementation of autonomous shipping technologies in the maritime sector.

3. **Enhancing Education and Human Resource Development**: the current educational programs offered by universities, colleges, and training institute in Thailand continue to focus primarily on convention maritime transport subjects and have not yet been sufficiently modernized to accommodate rapid technological advancements. There is therefore a need to revise curricula and training programs to incorporate emerging fields such as robotics, digitalization, artificial intelligence, future mobility technologies, autonomous systems, and other disruptive innovations. Strengthening education and human resource development in these areas will be essential for preparing a future workforce capable of supporting the adoption and operation of autonomous shipping technologies.

4. **Implementation of Pilot Projects through Regulatory Sandboxes**. Experimental testing within controlled or closed system environments (regulatory sandbox) should be undertaken to facilitate the future commercialization of autonomous shipping. This approach should include (a) the designation of specific sandbox areas within controlled water territories for conducting pilot experiment in both domestic and international navigation context. Initial pilot projects should be implemented along low traffic density route to ensure that the operational safety during the testing phases, such as routes linking between foreign ports and coastal port and Ranong Port, a regional port operated by Port Authority of Thailand located on the Andaman coast; and (b) the development of technical and operational standard of autonomous ships in accordance with international standard and guideline recognized by IMO or internationally accepted professional engineering societies.

5. **Modernization of Regulatory Frameworks**: the government should prepare to modernize existing laws and introduce new regulatory frameworks related of autonomous shipping. These regulations should cover areas

including ship design and construction, ship licensing, ship owner and ship controller licensing and qualification requirements, safety management, operational safety assurance, cybersecurity protection, ship registration procedures, and navigation control in water territory. Regulatory development should be informed, where applicable, by empirical findings and operational experiences obtained from sandbox experiments and pilot projects in order to ensure that future legal frameworks are practical, adaptive, and aligned with international standards and technological developments.

6. **Development of a Technological Platform:** the government should consider establishing an integrated technological platform to support the monitoring, communicate, and management of autonomous shipping operations. Such a platform should facilitate real time communication between autonomous ships, shipowners, remote controllers, port, and relevant authorities. In addition, the platform should incorporate mechanisms for emergency reporting, collision notification, vessel arrival and departure reporting, and information exchange among relevant stakeholders. The system should also support regulatory oversight and clarify responsibilities and liabilities of shipowners and remote vessel controllers in relation to autonomous vessel operations. The development of such digital infrastructure would be essential for ensuring operational safety, regulatory compliance, and efficient coordination within the autonomous shipping ecosystem.

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