STUDIES IN NATIONAL GOVERNANCE AND EMERGING TECHNOLOGIES

Smart Ports and Robotic Systems

Navigating the Waves of Techno-Regulation and Governance

Edited by
Tafsir Matin Johansson · Dimitrios Dalaklis
Jonatan Echebarria Fernández
Aspasia Pastra · Mitchell Lennan

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Studies in National Governance and Emerging Technologies

From genome editing to deep learning, and from blockchain to quantum computing, the rise of emerging technologies poses a number of opportunities, threats and risks to society. Emerging technologies provide affordances to innovative products and services that can potentially revolutionize fields like medicine, transport and finance. They may also result, however, in unwelcome side-effects, unintended consequences and deliberate harms to particular groups and individuals, as well as entire systems and the environment. Questions about whether emerging technologies should be regulated at the national level, and how precisely governments should encourage and respond to them, are controversial. Precautionary approaches may discourage investment and make countries lose ground with respect to other economies. Permissive regimes may put consumers and natural environments at risk. Governments, business firms and the civil society are expected to play a role in (re-)designing how emerging technologies will be regulated, re-regulated and steered.

This series invites contributions on the intersection between technological development and the processes of promoting, steering and regulating the development and applications of emerging technologies. Books will address theoretical issues, such as what drives the development of new technologies, how new technologies reconfigure governance systems, and the effects of new technologies on democracy, accountability, efficiency, economic growth, justice, power, legitimacy, sustainability and inclusion. Empirically, the series welcomes contributions that address any area of emerging technologies, including Artificial Intelligence, control of sensor networks and Internet-of-Things, robotics, cryptocurrencies, renewable energy sources, nano-technologies, genetic therapies, smart cities, and the significance of space and technology to future development.

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Sweden
November 2022

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Yoss Leclerc (Captain) has over 35 years of experience in the maritime, logistics, transportation, and port industries. After a successful career at sea, Yoss spent over two decades working as Harbour Master and COO, leading the strategic development of several major Canadian ports, including the port of Vancouver. During his many years in the maritime sector, he used his experience to develop durable solutions in response to a multitude of complex and diverse problems related to governance, sustainability, safety, security, and emergency preparedness. As former President of the International Harbour Masters Association, Captain Yoss worked on various international maritime issues with international organizations such as IMO, IALA, ILO, OCIMF, IMPA, and PAINC. Presently as the President and CEO of Logistro Consulting International, Capt. Leclerc is involved in myriad maritime projects around the world including the development and implementation of strategies for digitalization, automation, and logistics & transportation's optimization.

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CHAPTER 1

Introduction to Smart Ports and Robotic Systems: Navigating the Waves of Techno-Regulation and Governance

Tafsir Matin Johansson, Mitchell Lennan, Jonatan Echebarria Fernández, Aspasia Pastra, and Dimitrios Dalaklis

Technology developed and corresponding benefits unravelled in the past is now continually constant and ergo, ubiquitous in all domains including the transport sector. As the maritime domain slowly progresses towards

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"autonomy" under the auspices of the fourth industrial revolution, port infrastructure and the likes are undergoing major transformations. Currently, ports are in the process of mitigating efficiency-related challenges. To tackle barbed challenges, they are progressively transforming into network developers. It is observed that a number of major international ports, e.g., port of Shanghai, port of Singapore, port of Rotterdam, port of Los Angeles and port of Hamburg are equipped with sensors and devices, and are fully connected to a network infrastructure for integrated communications system between "ship and port". In tandem, ship owners and classification societies are deploying remote inspection techniques (RIT) such as multi-aerial vehicles, hybrid crawlers, unmanned robotic arms, remotely operated vehicles—collectively known as maritime robotics and autonomous systems. In the not-so-distant future, RIT has the potential to replace the existing manual ways of conducting vessel survey and inspection that has been considered as being dull, dirty and dangerous. Whether through transformation towards smart ports or transition towards RIT-based operations, the intention behind going "digital" lies in the objective to conduct tasks with the help of machine learning systems capable of interacting with the environment to achieve pre-set goals while promoting safety, security and environmental protection facets.

This book is the second of two volumes which explore autonomy in ships and ports, with a special focus on ports and robotics from the context of "regulations governing technology" that editors' note as critical techno-regulatory aspects. In doing so, it examines a variety of complex technological, regulatory, legal, psychological and societal issues from experts across a wide range of fields. The key insights in this volume are spread across twenty chapters in 5 parts: (1) setting the scene; (2) vessel autonomy & autonomous systems redux; (3) smart ports; (4) remote inspection techniques; and (5) tying the threads.

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This volume on smart ports and robotic systems opens with a contribution by Andrei Polejack and Luis Fernando Corrêa da Silva Machado. The authors introduce "innovation diplomacy"—a concept at the intersection of international relations and technology development and is used in engagement and partnership between actors including government, academia, industry and society. With the help of concrete examples, the chapter showcases how innovation diplomacy is used successfully in the maritime sector to leverage the various moving parts involved in regulatory governance, or "innovation ecosystems" (Polejack & Machado, 2023). Noting that the chapter offers recommendations on how to leverage ocean diplomacy to benefit countries in the Global South and be used as a tool to support cross-boundary innovation (Polejack & Machado, 2023).

Part II of this volume concerns autonomous vessels and systems, the central theme of the first volume of this collection. Accordingly, the four chapters in this part are a redux on this topic, and seek to refresh the reader in their understanding of the pertinent issues concerning vessel system autonomy, crowdsourced bathymetry and ocean observation prior to diving into the subject of ports and robotic systems.

Chapter 3, authored by Mikael Hilden, opens this part with the discussion of human-generated errors, which make up no less than 80% of errors on board a vessel (Hilden, 2023). Captain Hilden tackles head-on the mostly notion that technological innovation in the maritime sector will reduce the likelihood of human error. Through an insightful discussion on the human nature of error and the flaws in human intelligence Hilden argues that it is too simplistic to assume that improvements in technology is the solution to human error. He then guides the reader through key concepts including artificial intelligence and machine learning, for example, with a projection that these developments may change (and is already changing) our world for the better in the context of autonomous ships. However, he warns us of the dangers of idealising a "Technological Utopia" since technology too can (and does) err (Hilden, 2023).

The next three chapters touch on various aspects of ocean observation. Michael B. Jones, insights the reader in Chapter 4 with a case study of how technological innovation in the sailing sector at the intersection of autonomy can save costs, and reduce emissions. We are guided through the benefits of wind-powered autonomous surface ships through the case study of groundbreaking SubSeaSail innovations, including in the ocean observation and in the global shipping market and beyond (Jones, 2023).

In Chapter 5, we are brought to the nexus of the oceanographer's staple of bathymetry and the relatively novel concept of crowdsourcing by Steven Geoffrey Keating. Keating provides a fascinating discussion on the unique status of crowdsourced bathymetry—where depth measurements form vessels engaged in regular maritime operations are shared cooperatively. This can advance knowledge on maritime depth and improve navigational safety, potentially on a massive scale (Keating, 2023).

Luciana Fernandes Coelho and Roland Rogers close this Part with a discussion on the international legal perspectives of Marine Autonomous Systems (MAS) in ocean observation in Chapter 6. Is the existing legal framework fit for purpose to accommodate the regulation of increased use of MAS? After examining no less than six forms of MAS, Coelho and Rogers turn to the international legal framework governing marine scientific research. They present various scenarios where challenges in the use of MAS arises (Coelho & Rogers, 2023).

Part III concerns itself with the pertinent topic of smart ports. We begin from a security perspective with a contribution from Adriana Ávila-Zúñiga-Nordfjeld, Hans Liwång and Dimitrios Dalaklis. Chapter 7 presents an analysis of the technological tools available to serve port and maritime security. They discuss the co-benefits of these developments including strengthening port and maritime security while simultaneously limiting the illegal trafficking of drugs (Ávila-Zúñiga-Nordfjeld et al., 2023). Importantly, the authors suggest changes to the International Ship and Port Facility Security (ISPS) Code to standardise such equipment on board vessels, arguing that its need and significance is similar to the Automatic Identification System (AIS), or the Long-Range Identification and Tracking (LRIT), to counter drug traffic by sea threats (Ávila-Zúñiga-Nordfjeld et al., 2023). Finally, the importance of continued, iterative adaptability to deter security threats is stressed (Ávila-Zúñiga-Nordfjeld et al., 2023).

Chapter 8 by Andrew Baskin and Mona Swoboda tackles the issue of the future of port governance. Baskin and Swoboda tackle this pertinent topic from the perspective of continued automation of port operations. This is an ever-growing trend which can reduce costs, increase productivity and reliability and improve inclusion, accessibility, safety and environmental performance (Baskin & Swoboda, 2023). In the face of this trend and the evolving governance landscape the authors make the strong case for port governance that is both collaborative and integrated (Baskin & Swoboda, 2023).

The third chapter i.e., Chapter 9 in focus on smart ports, provides us with incise perspectives from Canada from two prestigious contributors: Yoss Leclerc and Michael Ircha. The authors utilise their rich knowledge and navigate the reader through the various innovative approaches taken by major Canadian ports in the shift from “intelligent” to “smart” ports (Leclerc & Ircha, 2023). They highlight partnering with universities and research institutions on groundbreaking projects in transportation, logistics, big data, artificial intelligence and digitalization (Leclerc & Ircha, 2023). This has helped strengthen resilience and help ports across Canada adapt to the changing technological landscape (Leclerc & Ircha, 2023).

Jason Chuah raises crucial points surrounding the issue of project financing and investment for smart ports in Chapter 10. He focuses on developing countries, where lack of access to finance to implement smart port projects abound, and is a key challenge for emerging economies (Chuah, 2023). In particular smart ports as a concept within an emerging legal framework in developing countries causes ambiguity and uncertainty with regard to supporting private financing and awarding concessions in smart port to develop infrastructure, transportation and logistics in these projects (Chuah, 2023). Chuah makes key suggestions as to how emerging economies might change their legislative response to secure financing for smart ports, including specifying clear objectives regarding what aspect of the project the financing is for, and making the important case that all smart port implementation activities and milestones should reflect sustainability commitments (Chuah, 2023).

Chapter 11, penned by Gabriela Argüello takes us to the topic of smart port enforcement through unmanned aerial vehicles (UAVs). We understand UAVs to be cost-effective, labour reducing tools which can handle and process vast volumes of data with reduced human input—particularly in the case of surveillance and enforcement. In that context, Argüello begins with the perennial issue of port State jurisdiction for prevention of ship source pollution. The argument is made that both UAVs and other surveillance technology can assist in enforcement of pollution regulation and influence ship behaviour towards compliance as they come into port (Argüello, 2023). Despite being devices for data collection, UAVs are assimilated smoothly into legal systems as aircraft which simplifies their incorporation into existing frameworks (Argüello, 2023). However, she warns us that increased use of UAVs in smart port enforcement may lead to an expansion of Port State jurisdiction, which is fertile ground for further research in the law of the sea (Argüello, 2023).

We turn to the theme of smart port security. The multi-authored Chapter 12 by Iosif Progoulakis, Nikitas Nikitakos, Dimitrios Dalaklis, Anastasia Christodoulou, Angelos Dalaklis and Razali Yaacob tackles the aspects of digitalization and cyber physical security within maritime transportation and port infrastructure. This rich contribution stresses that cyber security systems should be re-evaluated as new applications of existing technical tools such as Information Technology (IT) and Operational Technology (OT) systems evolve, and new tools develop (Progoulakis et al., 2023). Well-known cyber threats are discussed and existing policies and guidelines that can be harnessed to tackle these are presented, and reviewed in an innovative fashion using bow-tie analysis. Despite the real threat of a cyber physical security incident in the maritime context, the authors conclude that the industry is unprepared despite proactive initiative from the International Maritime Organization—further guidance is needed for maritime owners and operators to avoid these threats (Progoulakis et al., 2023).

Continuing with the smart port security theme, Andrew Baskin contributes another chapter to this volume this time with Max Bobys in Chapter 13. This chapter complements the previous by appraising legislation and regulation on cybersecurity by governments and intergovernmental organisations. This regulatory landscape is growing in size and complexity. As a result, the number of port cybersecurity guidance documents are growing as is an emerging market of port cybersecurity insurance (Baskin & Bobys, 2023). After an assessment of policies and legislation by intergovernmental organisations, they conclude that while these are helpful, they must be taken into consideration with pre-existing frameworks for operational risk, and that implementation must be tailor-made for each individual port or port facility (Baskin & Bobys, 2023). They also highlight the need for coordination in policies and approaches in cybersecurity for the port sector (Baskin & Bobys, 2023).

In the final chapter of this part, i.e., Chapter 14, Dimitrios Dalaklis, Nikitas Nikitakos, Dimitrios Papachristos and Angelos Dalaklis take us through the opportunities and challenges those big data analytics presents for the shipping and port industries. The day-to-day running of the computer systems on a ship creates vast volumes of data, or “big data”. What do we do to manage all this information? Analysis of big data through the use of appropriate software tools to extract and process the key information is of course vital to facilitate transition towards smart shipping and smart ports. Dalaklis et al., follow an innovative

Strength, Weaknesses, Opportunities and Challenges (SWOC) analysis of the various tools and techniques of big data analysis to aid in decision-making and improve operational efficiency. However, they highlight that standards and performance of relevant algorithms vary significantly, and argue that regulatory interventions can ensure a uniform approach, and a discussion around best practices in industry is vital (Dalaklis et al., 2023).

The chapters in Part IV of this volume are presented under the title of "Remote Inspection Techniques", which is, in its simple form, defined as a process of inspection/ means of survey for inspecting critical structures using specific "digital" techniques without requiring physical access on the part of the surveyor/inspector. Part IV, i.e., Chapter 15 opens with a pertinent contribution by Anastasios Kartsimadakis on remote inspection schemes on tanker vessels during the Covid-19 pandemic. The chapter discusses the fact that as a result of the pandemic, remote inspections have become more prevalent, despite being limited by technological and procedural frameworks (Kartsimadakis, 2023). The need for alternative remote inspection methods became vital due to Covid, and in this context Kartsimadakis discusses the Tokyo Memorandum of Understanding which established a remote inspection system with technical specifications at consent of the port Master, as well as the remote inspection policy launched by members of the Oil Companies International Marine Forum (OCIMF) Ship Inspection Report Programme (SIRE), concluding that there is a need for uniformity and coherency in remote inspection policy and guidance must be consensually agreed by stakeholders (Kartsimadakis, 2023).

We turn to the tecno-regulatory challenges presented by Remote Inspection Techniques in Chapter 16. Another prestigious multi-authored chapter, this time by Kin Hey Chu, Marina G. Papaioannou, Yanzhi Chen, Xiaoliang Gong and Imran H. Ibrahim of Maritime Advisory Research and Development, Region S.E.A., Pacific and India. Beginning from the fact that Covid-19 has resulted in an increase in remote inspections and assessments to ensure compliance and safety with the relevant regulations, they detail the techno-regulatory challenges that arise from remote inspections and surveys. They further clarify that there is a difference between remote inspection techniques and remote surveys and should be treated as such, highlight that classification societies offer guidance for the planning and execution of remote inspections as well as remote surveys, and conclude that regulations and technology will continue to evolve alongside the evolution and advancement of remote inspection techniques (Chu et al., 2023).

David Knukkel reminds us in Chapter 17 that while remote inspection techniques are not a necessarily new phenomenon, but today they exist at the nexus of autonomy and human interaction. Technology that will be familiar to the reader includes drones, UAVs and remotely operated underwater vehicles. To that end, Knukkel assesses the challenges related to inspection and certification, technological challenges, approval and briefly touches upon commercial discussions related to intellectual property and financing in remote inspection techniques (Knukkel, 2023).

Building on the human-autonomy point by Knukkel, Chapter 18 by Thomas Ellwart and Nathalie Schauffel brings a fresh perspective and informs us of the psychological perspectives of teamwork between humans and "self-governing" systems. They introduce us to the concept of the "human-autonomy team" (HAT), based on the premise that, like humans, autonomous systems possess a high degree of self-governance concerning adaptation, communication and decision-making (Ellwart & Schauffel, 2023). From a qualitative interview methodology, they enlighten us on three psychological perspectives of HAT (i) level of autonomy; (ii) system trust; and (iii) system knowledge/features, presenting us with opportunities and potential barriers to each (Ellwart & Schauffel, 2023). This important piece then outlines future trends within HAT, and the importance of an adaptive approach as technology and circumstances change (Ellwart & Schauffel, 2023).

The penultimate chapter in this Part on Remote Inspection Techniques provides us with lessons learned from key maritime nations leading in autonomous operations and remote inspection techniques. Chapter 19 is authored by Aspasia Pastra, Thomas Klenum, Tafsir Matin Johansson, Mitchell Lennan, Sean Pribyl, Cody Warner, Damoulis Xydous and Frode Rødølen. An assessment of AI national plans within the major maritime nations through a comparative study of the United States of America, the Netherlands, Canada, Norway, China and Singapore conducted through 60 interviews with maritime administrations, policy advisors, classification societies, service providers and subject matter experts on remote inspection techniques (Pastra et al., 2023a). They conclude that since no specific international guidance on remote inspection techniques exists, the adoption of an international regulatory framework could certainly lead to an increased uptake in the use of remote inspection techniques (Pastra et al., 2023a).

That brings us to the final chapter in this Part (Chapter 20), authored by Aspasia Pastra, Miguel Juan Núñez-Sánchez, Anastasios Kartsimadakis, Tafsir Matin Johansson, Thomas Klenum, Thomas Aschert, Mitchell Lennan, Marina G. Papaioannou and Maria Theodorou. This chapter presents the key findings arising from the BUGWRIGHT2 project which aims to alter the landscape of robotics for structure-inspection and maintenance in the EU. To that end, they present a blueprint that could serve as a foundation for the anticipated international guidelines on remote inspection techniques alluded to in the previous chapter, which should be developed in an inclusive, multi-stakeholder fashion (Pastra et al., 2023b). In any case, the guidelines should harmonise existing practices by flag States, and should be implemented on a case-by-case approach in line with the development of training and certification requirements of remote inspection techniques (Pastra et al., 2023b).

Finally, Paul Topping ties together in Chapter 21 the important threads discussed by authors of this volume in a strategic manner. His key conclusion is that development of technology is the limiting factor in the use of automation in smart ports and robotic systems. At present, most systems are still subject to some degree of human monitoring and/or control—things will become more complex as technology evolves and automated systems become more independent (Topping, 2023. From a regulatory point of view, Topping raises issues of liability, finance and safety standards, especially the fact that ship owners and port authorities are responsible for the automated systems they operate, which much be accounted for through human control or other methods (Topping, 2023).

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PART I

Setting the Scene

CHAPTER 2

The Possibilities of Ocean Innovation Diplomacy to Promote Transnational Innovation Ecosystems for the Maritime Sector

Andrei Polejack and Luis Fernando Corrêa da Silva Machado

1 Innovation Diplomacy

The idea of an innovation diplomacy, although conceptualized only at the turn of this century, gained momentum after the 1929 depression, gaining much attention with technology innovation as a core strategy to

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enhance profit and subsequently, leverage countries' economies (Griset, 2020). Innovation diplomacy, to date, remains a debated concept that has strong ties with both economic diplomacy and science diplomacy, i.e., it pertains to the interrelations between cooperative technology development, trade and international arrangements bridging communities from the public and private sectors (Carayannis & Papadopoulos, 2011). Works in innovation diplomacy include issues such as cooperative arrangements for joint technology development, matchmaking between entrepreneurs and financers, using innovation as a soft power of a country and attracting future investments, inter alia (Bound, 2016). As it builds from science diplomacy, where the international relationship between agents is motivated by the production and application of scientific knowledge (Turekian et al., 2015), innovation diplomacy embraces more comprehensively the interests of the private sector and the inherent market value of producing technological innovations (Leijten, 2017). In this regard, issues such as competition, national innovation ecosystems, intellectual property rights and even industrial espionage become fundamental in the study of innovation diplomacy as a field of research.

In reality, countries show a diversity of institutional frameworks and practices regarding international technology development, trade agreements and similar matters, seeking to promote themselves as innovators and the consequential use of this branding as a form of soft power (Machado, 2021). Soft power refers to the power exercised by a country in promoting its national assets to seduce other nations to cooperate and build ties, instead of using the traditional hard powers of coercion and force (Nye, 1990). Naturally, the differences between nations' capacities to produce knowledge and technology innovation are intrinsic parts of this soft power, whereas less privileged countries, having limited technological capabilities, can become subject to such a power, usually depending on the transfer of technology and capacity development (da Silva et al., 2021). Recognizant of the hard consequences of the technological gap between nations, the United Nations and other multilateral entities have established a diversity of international legal regimes

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responsible for balancing countries' capabilities, despite the incipient implementation of such provisions (Polejack & Coelho, 2021). In this scenario of unequal opportunities, innovation diplomacy is challenged by national socio-economic realities and the imperatives of the market, placing its actions somewhere in a scale between cooperation and competition, where there is often a nebulous line dividing the interests that drive either way (Brandenburger & Nalebuff, 1996).

2 Innovation Diplomacy in the Maritime Sector

The maritime and ocean industry are critical elements of international trade, which, in turn, witnesses, at regular intervals, an increased development of technology innovations through international cooperation, becoming an interesting venue for exploring innovation diplomacy. For example, the shipbuilding industry promotes innovation towards a greener energy efficiency, container shipping defends artificial intelligence as the future of trade by sea and unmanned vessels are increasingly becoming a reality. Despite the maritime industry representing only a portion of the investments among the major hundred ocean companies that exist worldwide—those are global companies that urge to innovate (Virdin et al., 2021). Finding technology-based solutions to overcome the private sector challenges could optimally drive international cooperation inasmuch as industrial competitiveness.

The ocean also places a challenge to innovation diplomacy. Due to our incipient understanding of the ocean's natural dynamics and its interlinkages with other natural systems, such as the climate, innovation diplomacy in the maritime sector is highly impacted by basic features that seek answers from ground research. For example, the shipping industry urges for better modeling of the oceanic conditions to forecast events that may affect the operation of autonomous vessels. In this case, international cooperation through the means of large-scale research projects can provide industry with sufficient information to organize security and safety plans. On the other hand, public–private cooperative research projects are often subject to confidentiality clauses regarding sensitive data with commercial value, highlighting the competitive market for new technologies. In the ocean, this could entail research on the seabed unveiling new areas for oil exploitation or the discovery of new molecules with pharmaceutical application found in marine organisms. A challenge in this regard is that a good portion of the ocean is still under-regulated, in particular the biodiversity that occurs beyond national jurisdictions. In such cases, the complex international legal regime can affect the business risk taking. Consequently, different from land, ocean innovations generally deal with international and cross-boundary spaces, which fall under the auspices of the United Nations Convention on the Law of the Sea (hereafter UNCLOS), and related instruments. Therefore, innovating in the ocean opens a Pandora's box of interests, stakes and legal regimes that many times require diplomatic negotiations to balance interests, to measure the stakes at play and find common grounds to work in the fine line between cooperation and competition, fuelling ocean innovation diplomacy practices.

In this chapter, we will briefly digress on the avenues that foster ocean innovation diplomacy. As the majority of nations on the planet lack the capabilities to develop and apply innovative marine technologies, our focus will be on less privileged countries, those seeking opportunities to both develop technology innovation through the means of international cooperation, as well as to open new markets and raise competitiveness of national products and services. Departing from this perspective, we provide insights on potential recommendations on how to improve ocean innovation diplomacy in South–North relationships.

3 Intergovernmental Frameworks

When we picture ocean diplomacy, our first thought usually goes to the UN system, mostly because of the role of UNCLOS and its related institutions in regulating marine activities. Indeed, under the UNCLOS framework, marine technology has been a core factor of negotiations (Robinson, 2020). Privileged countries generally have the necessary basic capabilities to develop and apply technology innovation in exploring the ocean. Ocean exploration often occurs in areas under other countries' jurisdictions or in international spaces, such as the high seas. Thus, navigating through UNCLOS becomes an important element of ocean innovation diplomacy. From the perspective of ocean science superpowers, such as those in Europe, North America and some parts of Asia, technological development and the application of marine technologies support negotiations to implement UNCLOS in international spaces. For less privileged countries, UNCLOS is a venue to access research infrastructure and promote technology development and transfer. However, private companies, the usual holders of intellectual property rights, are not bound to UNCLOS and their role in international negotiations can no longer be ignored. Thus, these companies and their shareholders need to see value in engaging in such negotiations, often seeking to influence the outcomes towards their interests while protecting their intellectual property rights.

Intellectual property is subject to a few provisions under the UN system and other intergovernmental frameworks. Although UNCLOS does not preclude specific regulations for this matter, other multilateral arrangements, such as the World Intellectual Property Organization (WIPO) and the World Trade Organization (WTO), the latter through the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), seek to regulate international intellectual property rights. Both organizations have stressed on the search for an equitable development and access to technology as a point of no return for modern global governance (Zhou, 2019). However, concrete outcomes of intergovernmental setups promoting the *de facto* transfer of technology are still insufficient.

In the ocean, the Intergovernmental Oceanographic Commission from UNESCO (IOC) has been a key factor in proposing means to progress with the transfer of marine technologies under the implementation of Part XIV of UNCLOS, namely Development and Transfer of Marine Technology. Despite all efforts undertaken by IOC in leveraging the transfer of such technologies, in reality, it has been inefficient in achieving its goals (IOC-UNESCO, 2020; Polejack & Coelho, 2021). Therefore, stakeholders from public, private and societal sectors have turned to schemes that are more agile by seeking cooperation directly between entities, relying less on traditional intergovernmental diplomacy.

This type of diplomacy that happens in spite of governments, but rather between non-State actors such as enterprises and research groups, is said to be more flexible, agile and efficient, sometimes referred to as Track 2 diplomacy (Jones, 2015). In the maritime sector, international relationships promoted by companies and innovators usually do not rely on States. Because of principles such as the Freedom of the High Seas and other provisions, technology to harvest data is deployed as marine scientific research and does not need formal diplomacy to interact. Thus, ocean innovation diplomacy is fluid, pragmatic, results-driven and comprised of a multitude of possible interactions between formal and informal diplomacy (please see Polejack, 2023).

4 Multistakeholder Mechanisms

In a fast-growing knowledge economy, governments have come to realize that they cannot act alone in order to return public investments in research to the benefit of society. To spur innovation, the establishment of mechanisms that allow a dialogue among academia, private sector, governments and society, modeled on Quadruple Helix Innovation systems, and more 'human-centered' than 'institution-oriented', are of paramount importance (Carayannis & Campbell, 2014).

There are no ready-to-use formulas in setting up such mechanisms and their governance. There is evidence, however, that multistakeholder participation can lead to more effective and durable decisions, which tend to be better implemented by the parties involved (Reed, 2008). The establishment of institutionalized channels that allow all voices and demands to be heard increases the commitment of the parties towards a common vision and definition of goals and priorities, a result of the perception of stakeholders on the legitimacy of the mechanism. Multistakeholder environments tend to find a common understanding between the needs of the public and private sectors and strike a balance between technological pull and market push policies.

When it comes to innovation, different backgrounds and perspectives are a fertile ground to unleash solutions that would not be achieved otherwise. This is a strong driving force for the proliferation of multistakeholder mechanisms in the international sphere. Since 2007, the UN has created a multistakeholder forum on STI for the Sustainable Development Goals, within the structure of the Economic and Social Council of that organization. Apart from the UN system, the Brazil, Russia, India, China and South Africa group (BRICS) STI architecture has stimulated the participation of researchers, science parks, incubators, technological associations and representatives of civil society in all thematic working groups, including oceans. On the bilateral front, for example, Brazil and Sweden established, in 2009, a Steering Group on Innovative High Technological Industrial Cooperation based on a tripartite (government, academia, private sector) governance (Government Offices of Sweden, 2015). Such mechanisms have proven to achieve greater results exactly due to the participatory process by which stakeholders both voice concerns and desires, as well as subscribe to the collective decision-making.

5 Other Arrangements Boosting Ocean Innovation Diplomacy

The examples highlighted above have, in common, the leadership of governments that deploy diplomatic tactics, organize matchmaking exercises and identify relevant stakeholders to interact in such platforms. In this sense, governments seek to fulfill the goals of their foreign policies, in which industrial interests have a strong influence. Therefore, foreign policy objectives, influenced by the interests of the industry will trigger the search for the righteous partner countries, dependent on the target foreign assets that they may provide. It is natural to see these dynamic driving countries in the North, for their installed capacity. However, countries in the South bring interesting assets that can go beyond their national industry or technological capabilities. Southern nations are biodiversity hotspots, *ergo*, have privileged natural resources and are sources of most of the raw materials necessary for contemporary technological improvements. Consequently, profiting from such, countries in the Global South should have clarity on their domestic innovation gaps and opportunities to seek equalitarian international partnerships, using them to achieve stronger national STI structures. Thus, domestic coordination between ocean stakeholders is an imperative to find best international deals, those that will attend countries' aims and benefit from technological innovation to improve social wellbeing. This also becomes an inherent part of ocean innovation diplomacy.

We have so far described a few available mechanisms to foster international cooperation in applying ocean innovation diplomacy often led by government-related agents. Now, it is also important to stress that peer-to-peer collaborations and industry-led innovations play a vital role in ocean innovation diplomacy. In general, technological components are a mix of parts developed by companies abroad without which the assemblage of a given equipment would not be possible. Researchers in the Global South tend to collaborate with those companies to develop their full equipment, which also leads to an often-hidden aspect of ocean innovation diplomacy. By establishing these peer-to-peer arrangements, technology developers profit from less bureaucracy, enhanced freedom of negotiations and quicker results. This has been the case of many incubated enterprises working within high education institutions. In addition, companies themselves usually seek the assistance of other foreign companies to innovate. By applying business good practices mainly relying on the market holds, these companies combine expertise and innovate and this process may thus occur out of the sight of governments or intergovernmental frameworks. This market-led innovation diplomacy is mainly based on contractual binding regulations, informed by national policies on, for example, international trade, not always linked to a country's Foreign Affairs department. However, both the peer-to-peer collaboration and the industrial cooperation can result in an opportunity for governments to step in and facilitate dialogue and exchange. Therefore, ocean innovation diplomacy should consider all these aspects and the institutional dynamics therein to meet its goals.

Existing mechanisms of ocean innovation diplomacy could benefit from the multistakeholder approach of innovation diplomacy to foster technologies derived from international cooperation and enable transnational communities and ecosystems that would go beyond the national boundaries of States, with potential to produce more disruptive knowledge and innovation for the current challenges in relation to the blue economy.

6 Recommendations

In light of the perspectives provided in this chapter, and based on our experiences as government agents, we draw a few recommendations that, subject to consideration, could very well enhance the role of ocean innovation diplomacy among South–North enterprises.

6.1 Map and Assess Internal Market and Innovation Ecosystems (Identify Strengths, Weaknesses, Set Priorities)

In this chapter, we adopt the definition of innovation ecosystems provided by Granstrand and Holgersson (2020) as "the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations that are important for the innovative performance of an actor or a population of actors". Consequently, national innovation ecosystems involve the regulatory framework and public policies enacted by governments inasmuch as the actions of agents of innovation, such as entities, institutions, research centers, organized civil society, shareholders of a company, individuals, etc. Knowing which institution/agent plays what role in promoting innovation nationally is of utmost importance. In addition, it is necessary to map the network of actors engaged in ocean innovation, as well as the available innovative capabilities in a given context (infrastructure, field of research, financing capacities, companies, start-ups, incubators and so on). After such an exercise of mapping and networking, the natural next step is to define gaps and priorities to mobilize international partners, where ocean innovation diplomacy starts to play a more active role. With this data at hand, there is a higher chance that countries in the South will avoid engaging with international partners that are not fit for their purpose or view the seductive forces of innovation as a soft form of power—without foreseeing pragmatic benefits at the end of the process.

6.2 Defend Interests Multilaterally and Act Bi-trilaterally

Intergovernmental frameworks are important for the promotion of regulatory provisions that seek balance in research capabilities worldwide. Supporting diplomatic missions negotiating such provisions is necessary through providing information, advice and requesting further action towards equity in terms of marine technology capabilities. As diplomatic negotiations of this sort can take up years to finalize, we suggest engaging with relevant innovators on a bi or trilateral basis. Diplomacy can contribute by promoting national innovation ecosystems and matchmaking exercises that can culminate in formal agreements, if that is the objective of all parties. Therefore, after identifying the domestic assets and the international partnerships sought to leverage innovation, the mechanisms for this engagement and negotiation can be supported by chancelleries alongside with other relevant parties.

6.3 Public–Private Partnerships and Multistakeholder Engagement

Innovation diplomacy plays an important role in gathering the main national stakeholders that will contribute to the development of technological solutions to the benefit of society and the generation of wealth. The governments of the most innovative countries do not abdicate the lead in this process of connecting relevant players. They also bring about institutionalized mechanisms to allow peer-to-peer cooperation and encourage interaction and the establishment of synergies between innovation ecosystems. Leadership means that governments should act as brokers between private and public sectors of innovation, set priorities, highlight opportunities, as well as provide guidance and strategic advice to constituents of the national innovation ecosystems (Nygaard et al., 2021).

Track 2 diplomacy carried out by governments, a valuable tool of innovation diplomacy, should also be activated in showcasing the potentialities of the national STI systems as well as in moving the needle in terms of the image of the Global South abroad, particularly, concerning research and innovation. Trust is a key component in the equation that stimulate international cooperation. In this regard, innovation diplomacy builds bridges, connects dots and interweaves the main players of different countries.

In order to provide the necessary framework for cooperation in ocean innovation diplomacy, even though spontaneous peer-to-peer contacts, some degree of institutionalization of the channels of communications and the decision-making process is necessary. Governments should take the lead and engender these flexible mechanisms with multistakeholder engagement, while acting more as facilitators of this dialogue, rather than determining its multifaceted outcomes.

6.4 To Explore New Possibilities and Learn from Experience

Squarely, if risk transfers to technology innovation—governments are prone to being risk-averse. Innovation diplomacy navigates in these rough waters in an attempt to solve this puzzle. With the support of different stakeholders, governments should be more comfortable to delve into riskier areas and instruct their respective diplomatic corps accordingly. The challenges faced by ocean innovation diplomacy may benefit from resources and expertise coming from other entities apart from the government and NGOs. Bottom-up approaches not only identify pressing demands of society and the productive sector, but also prompt more creative approaches to the problems faced by national and global economies.

Learning from mistakes and good practices, as start-ups do, should, ideally, be the dynamics of innovation diplomacy. Initiatives should be driven by flexibility to pivot strategies, decisions and technological pathways. In this sense, some examples could be singled out in the Global South that could inspire the design of actions to be tailored to ocean technologies such as cross-incubation programs, the mobilization of the scientific and innovation diasporas and open innovation programs.

7 Conclusions

This chapter has presented, in brief, the importance of innovation diplomacy to the maritime sector by conceptualizing it along the lines of engagement and partnership between sectors. As it seems, ocean innovation diplomacy needs to account for a fragmented maritime regulatory international regime inasmuch as for public–private relationships. We provide a few examples of concrete cases in which ocean innovation diplomacy is used to leverage innovation ecosystems and progress with cooperative technological developments. Discussions, ranging from national competencies to international trade, act as a means to achieve a productive innovation diplomacy in the maritime sector. We advocate that creating platforms, both nationally as well as internationally, to give voice to stakeholders and build trust could provide the necessary venue for engaged commitments towards the implementation of agreements. We submit that countries from the Global South need to coordinate stakeholders and diagnose domestic potentialities and challenges, as a basis for beneficial international engagements, and to avoid being subject to innovation as a soft power or to the condition of mere consumers of outdated technologies. In conclusion, we recommend stakeholders to resort to governments as facilitators for matchmaking and to establish and further multistakeholder platforms.

The final takeaway is to be open. To be open to risk, to be open to welcome stakeholders' concerns and interests, and to be open minded to learn from experience. Ocean innovation diplomacy can be a tool to thrive cross-boundary innovation ecosystems in both hemispheres of the world.

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PART II

Vessel Autonomy & Autonomous Systems Redux

CHAPTER 3

"Utopia at Sea" from the Captain's Chair: Are Autonomous Ships the Real Solution to Human Error?

Mikael Hilden

1 Introduction

> For things will never be perfect, until human beings are perfect - which I don't expect them to be for quite a number of years!—Thomas More, *Utopia* (1992)

From Thomas More's quixotical vision of a utopia in 1516 to the Technological Utopia that is taking our world today, the idea of perfection has at its roots the concept of human flaws.

In this chapter, we will take a look at the role that human thinking and human errors play in the current state of the maritime industry, and

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consider the implications of technology in mitigating these human-driven errors and the vision of autonomous vessels as the answer to creating a Utopia at Sea.

2 Using Our Heads: New Technology Can Bring Safer Operations

It is estimated that about 80% of all errors that occur aboard a vessel are human-generated errors. Dell Technologies claims that 96% of shipping accidents are caused by human error (Dell Technologies, 2021).

Considering this, would it not be better if we could rely on technology that would allow for a shipping industry to sail serenely without the risk of humans causing accidents? Of course, it would—but is that realistic? And what implications would that technology truly have?

Personally, I have always been fascinated by all of the new advances that have been introduced into the industry that I have represented during the last four and a half decades. Naturally, some others have not been as enthusiastic and others still are simply against these newfound paths—some because of long-held beliefs that they are unwilling to part with, others out of fear, and still others because they see it as a sort of generational battle as they look on the younger officers and perceive them as having an easier career aided by so much technological intervention. In truth, these arguments have been around for generations, and I too heard similar commentary when I was first starting my career at sea.

The fact is, that when it comes to accidents, human error has always been and unfortunately will always be a part of our lives, everywhere, in every industry. And by accepting this, we understand that it is within our power to create tools that can help us to help ourselves. As our technology improves, whether assisted by Artificial Intelligence (AI) or not, and the less costly that this technology becomes, it will begin to outperform us humans. If properly managed and used as they are designed to be, the accuracy of these tools will mean that human error will account for the vast majority of incidents that happen. Still, we will not be the sole contributors to these errors because the machines that we create will fail as well sometimes.

I always remember an automotive journalist who tested a fantastic new car at the famous Nürburgring some 30 years ago. The car had four-wheel steering, four-wheel drive, and one of the best-built and best-performing engines. It was a regular car in many senses and built for driving on normal roads, but it managed to set new track records the moment it was tested. After driving it, the journalist said that it was the best-performing car that he had driven during his career, but at the same time, he said that it was also the most dangerous, not because of the way it was built, but because it drove so well that anyone could outperform him or herself, quickly going beyond their driving abilities and even the limits of the car—a situation that could lead to a loss of control.

The fact is that new technology is only better than previous technology as long as we continue to operate within proven parameters, following any precautions which may be required by the ordinary practice of good seamanship. As long as we do this, advances are still better than their previous versions—despite the words of any naysayers (Fig. 1).

Technology on its own is never inherently good or evil.

Fig. 1 A Viking looking at an approaching Viking sister, passing another sister from a previous life. Ships of two sister ships I worked on as captain (*Source* Author [© AMH])

3 The Human Error Factor

> I cannot conceive of any vital disaster happening to this vessel. Modern shipbuilding has gone beyond that.—Edward J. Smith, Captain RMS Titanic

In the book Noise, Daniel Kahneman, Olivier Sibony, and Cass R. Sunstein show the detrimental effects of what they refer to as "noise" in many areas and fields, including medicine, law, economic forecasting, forensic science, child protection services, strategy, performance reviews, personnel selection, and of course shipping (Kahneman et al., 2021). Wherever there is judgment, there is noise. Yet, most of the time, individuals and organizations alike are unaware of it.

Imagine that two doctors in the same city give different diagnoses to identical patients, or that two judges in the same courthouse give markedly different sentences to people who have committed the same crime. Suppose that different interviewers at the same firm make different decisions about indistinguishable job applicants, or that when a company is handling customer complaints, the resolution depends on who happens to answer the phone. Now imagine that the same doctor, the same judge, the same interviewer, or the same customer service agent makes different decisions depending on whether it is morning or afternoon, or Monday rather than Wednesday. These are examples of noise: variability in judgments that should otherwise be identical.

Now, some statements might be or probably are an exaggeration of fact, but they are plausible. The range between one decision and another is pending on so many factors. My point here is more toward the results and effects of the noise in our decision-making. Experts in any field can get their education from a recognized university, following a curriculum similar to any other university, but how do the professors and students interpret the information taught and how do they use it when working, how are they influenced, and by what? I would even consider their upbringing and the society in which they were raised.

This same noise in judgments happens on our ships as well. How do we know that the crew on one ship will interpret the rules of Collision Regulation the same way as the crew on another ship will when there is the risk of an accident? And how is the judgment of when we "may" take actions rather than when we "shall" take actions interpreted from one ship to another?

Noise deciphers why humans are so susceptible to these variations in judgment and considers the point that organizations can leverage this information to improve decision-making practices for all of their personnel, thereby reducing the chances of human-driven errors.

3.1 The Flaws in Human Intelligence

> To err is human; to recover, is angelical; to persevere is diabolical.—Thomas Jones, Welsh clergyman, 1678

To err is human, and so is our ability to adapt—an ability that has indisputably contributed to the survival of our species. Indeed, Professor Sidney Dekker, author of "Drift into Failure" (2011), "Just Culture: Balancing Safety and Accountability" (2012), "Safety Differently: Human Factors for a New Era" (2015), and "The Field Guide to Understanding Human Error" (2014) has studied the subject over several years and has given us good insights into what constitutes *human errors* and the possible reasons for why they occur.

Sailors, in particular, have a great understanding of the need to adapt and adjust to the world around them. It seems to be part of our DNA. Being far away from family and working in sometimes extremely harsh conditions where plans are suddenly changed, from vacations to passage plans, adapting quickly is a necessary survival tactic. However, as we adapt and adjust our ways, we are also leaving ourselves open to failures in judgments. We might do something without thinking it through simply because we have done it so many times before—without considering if the rules have changed, or without investigating a latent or dormant problem within the system. This is where failures happen, opening the gateway for mistakes to occur.

In the maritime industry, we talk about various types of failures: latent, active, intentional, and unintentional. We classify latent failures as those caused by ineffective operational procedures and active failures as those violations resulting from errors made by frontline personnel. Lapses, slips, and mistakes are those errors that are considered to be unintentional, while violations regarding routines, situations, optimization, and exceptions are placed in the category of intentional actions. Naturally, when circumstances are such that a violation becomes unavoidable then we have what is known as an exceptional violation. Nevertheless, whether intentional, unintentional, latent, or active, these errors are the result of variables in the human mind and in how we relate to the environment around us. It is a human flaw.

3.2 The Human Label

If we return for a moment to that percentage sighted by Dell Technologies in a post on LinkedIn in December 2021 that claimed that up to 96% of shipping accidents are the result of errors of human judgment, then it would make sense to fall behind the company's solution to this problem by integrating more AI and by better leveraging data analytics (Dell Technologies, 2021). Yet, is that the best or principal way forward? Is the answer to human errors simply one of replacing as many humans aboard our ships with more advanced technology? Or is that turning a blind eye? We need to dig deeper. Author, professor, and pilot Sydney Dekker says that using the term "human error" is no more than just slapping a label onto the problem (Dekker, 2014). He refers to it as a judgment in itself, an attribution that we make after an event has already happened—a belief about the behavior of a person, including ourselves. Even so, if we see human errors as judgments, we might easily fall into the trap of proving our point, in this case, a need for autonomous ships and more AI, instead of also trying to find the root cause of an incident.

Take, for instance, the *Ever Given* accident in the Suez Canal in 2021. The incident has been cited as an example where a greater level of automation could have helped to avoid the situation in which control of the ship was lost, ultimately causing it to crash into the bank where it remained blocked. Better equipment might have warned of the high wind and its change of direction and what effect that would have had on the ship's steerability. Maybe it could have suggested a different engine setting. Either way, the accident happened although the Ever Given had two pilots on the bridge responsible for making decisions. How did they arrive at their choice to keep going even as several other ships remained at anchor because they had determined that passage at that time wouldn't have been safe?

The point of the *Ever Given* in this case, is that if safety is the only reason for striving toward fully autonomous ships, then perhaps a primary solution that is both easier and more cost-efficient would be to better educate those who are already on board these ships.

Truthfully, the industry has tools that will reduce these errors. There is BRM which is paramount in preventing or minimizing the risk of an error—working like slices of Swiss cheese creating enough safety layers so that we are protected from allowing weak points, such as poor judgment, to align and thus reducing a single point of error.

We also have equipment on the market that can think, warn us, and even take some actions automatically. Dynamic Positioning is just one example, where a system takes care of keeping the position, which then, in turn, releases the officers to monitor other functions thereby increasing their situational awareness. However, it is of no matter if we have the best equipment on ships but don't have good training programs to help the crew learn to use it to its utmost potential. We must ensure that they can use the equipment that is installed while also being able to detect any errors within that system that could hamper safe navigation or endanger those aboard.

4 Enter Artificial Intelligence

Artificial Intelligence is a topic that has been getting a lot of attention, mostly because of the rapid improvements that this field has seen since the turn of the twenty-first century. Amazing innovations are laying the foundation for ongoing breakthroughs capable of transforming almost every area of our personal and professional lives.

We have become accustomed to it, wittingly or unwittingly, most likely more than we believe. Do you need a rideshare? AI to the rescue. Perhaps you need to get some online banking done. AI is there to help. Happy that some junk email landed in your spam folder? Say thank you to AI. Maybe your place needs a tidying up before guests arrive, so you run your robotic vacuum … take a guess who is helping you. From facial recognition, navigation, and the short videos on our entertainment or music streaming services, to autocorrect and text editors, social media feeds, and online search recommendations—AI is with us all the time.

But, before we can consider AI's reach specifically within the shipping industry, it is helpful to know exactly what it is and what it is not.

4.1 What Is Artificial Intelligence?

In the 1950s, AI pioneers John McCarthy, Marvin Minsky, Claude Shannon, and Ray Solomonoff described artificial intelligence as any task performed by a program or a machine that if it were performed by a human would require the human to apply intelligence to accomplish the task.

Today, all tasks associated with human intelligence are described as AI when performed by a computer. This includes planning, learning, reasoning, problem-solving, knowledge representation, perception, motion, manipulation, and, to a much lesser extent, social intelligence, and creativity.

It is essentially, the method by which a computer can act on data through statistical analysis, enabling it to understand, analyze, and learn from data through specifically designed algorithms. This is an automated process. Artificially intelligent machines can remember behavior patterns and adapt their responses to conform to those behaviors or encourage changes to them. On ships, TrackPilot and DP are examples of technology that can recognize patterns.

4.2 What Is Machine Learning?

Machine learning is a big part of AI, and it might be the key reason for this field's meteoric rise. It's based on the principle of trial and error. That information is stored as data, and each time an AI goes down a specific path, it will reference the data from prior trials to see which one will work best this time.

4.3 What Artificial Intelligence Is Not?

It is not thus far capable of many complexities that the human mind, as underrated as we sometimes perceive it to be, does on a fairly, constant basis. For example, AI has not mastered empathy-based social skills and emotional intelligence, thought leadership, creativity, conflict resolution, and negotiation.

5 How Will Artificial Intelligence Change Our World Within Twenty Years?

In the eyes of Kai-Fu Lee, the New York Times bestselling author and former senior executive at Microsoft as well as president of Google China, it is most likely that AI will be considered one of the most impactful developments of the twenty-first century (Lee & Qiufan, 2021). Our daily lives will be forever changed. It can generate unprecedented wealth, transform medicine and education, and foster fresh new forms of communication and entertainment. It will be able to liberate us from our work routines, and a new human–machine symbiosis will become standard in our lives. However, it is also sure to upend the organizational principles of our economic and social order, creating some hardships as well. Left unregulated AI can also pose new risks in the form of autonomous weapons and smart technology that inherits human bias.

In his book *AI 2041: Ten Visions for Our Future*, Kai-Fu Lee notes, "We are the masters of our fate, and no technological innovation will ever change that." For him, AI is a sort of forewarning that requires humanity to wake up to both AI's rosy prospects as well as its threats to life as we know it. He urges us to remember that for all of the possibilities that AI offers, it is the human race that holds the keys to its own fate.

6 A Technological Utopia: The Next Industrial Revolution

A technological utopia is a vision of living in which advances in the tech arena would improve how humans live to the point that our lives would become quasi-idealistic—where increasingly sophisticated AI would be able to resolve some of society's most complicated problems and perils. However, the concept that we are on the verge of some new utopian world is not a new one.

6.1 The Next Industrial Revolution

What we are experiencing is the fourth industrial revolution, following those created in the seventeenth century by the invention of the steam engine, in the eighteenth century by the introduction of electricity, and the more recent revolution of the twentieth century ushered in by the digital age. The fourth industrial revolution of today is the result of what is called Disruptive Technologies. We have AI, VR, and IoT. We live in the world of Blockchain, the Cloud, and 3D printing.

And like the revolutions that have come before, a Technological Utopia will cause disruptions. It will lead to some job losses, stagnant wages in certain fields, and an overhaul of the education system. Indeed, a report by the World Economic Forum noted that about 65% of today's elementary school children will occupy jobs that don't currently exist (WEF, 2016).

6.2 *Masters of Our Fate*

> The real problem is not whether machines think, but whether men do!
> —B. F. Skinner

In short, this is not a technology to simply embrace or to let others worry about. The machines are coming, and they won't stop, and each of us needs to know what that means if we are to thrive in the twenty-first century.

There cannot be a void where much of humanity rests comfortably on its laurels. Industries, academia, science, and corporations need to work together to integrate and adapt, to educate and build new and transformative ways of thinking in order to prosper in this human–machine symbiosis.

Instead of wondering whether to trust AI or not, we must learn to see it as a tool—one that we humans are in charge of shaping and using to our advantage as a bridge between previously unsolvable problems and a future of new possibilities.

7 The Move Toward Autonomous Ships Has Begun, but Are We Prepared?

These technological advances are what are paving the way for autonomous ships. These ships already exist to a greater or lesser degree. We can therefore talk about Maritime Autonomous Surface Ships (MASS), which are currently divided into six different classifications depending on the extent to which humans must intervene. These levels can range from the most basic of classifications which still require officers and crew to run the ship

Fig. 2 From Aboa Mare—remote pilotage center (*Source* Author)

all of the way to a more futuristic fully autonomous ship capable of functioning without human interference at all, where the system can cope with unforeseen situations and anomalies without the need of human oversight. To this, I dare to say that the future will judge us on how well we handle this Disruptive Technology in shipping and how the maritime industry maneuvers its way through this fourth industrial revolution (Fig. 2).

8 History from Forty-Some-Odd Years Ago

When I started my career at the end of the 1970s we did not talk too much about human error, psychological safety, Bridge Resource Management (BRM), Risk Assessment (RA), and Threat and Error Management (TEM). We spoke about good seamanship, or sometimes about the lack of it. By "we" I mean a Finnish liquid energy company that from the beginning had procedures that were close to what ISM brought us some 35 years later.

The ships had, compared to today, plenty of crew. My first ship, a 16,000 DWT tanker built in 1962, had already reduced its crew to 42 when I started to work on it, and with fewer sailors, we thought that this might pose a challenge to completing all of our tasks properly, but we had high morale and worked well together, giving great importance to maintaining very high levels of standards and procedures.

Was this one of the reasons that we, as far as I remember, didn't have too many near-miss situations, or was it because we simply had manpower enough to have two or three sailors helping each other? Perhaps it was because the technology in those days, although we had the latest models imaginable, still wasn't as sophisticated as it is now and we simply knew that all readings and such had to be double-checked, assuring that all high-risk jobs were done with special caution?

Well, I doubt that we make more mistakes today than we did in the past. We were still humans. Frankly, if you count the number of errors per ship/sailor we are not making more errors today; however, if you consider the percent of events when compared to the machines that we have today, then more errors are surely happening now—something to truly think about considering that there is no doubt that the equipment is far superior nowadays than what we had when I began my career.

Is there an over-reliance on what technology can do for us? Are we overestimating ourselves or the machines we use?

As my years passed aboard the ships, we witnessed the continuous growth spurred on by the digital revolution, and I was fortunate because my employer maintained the most advanced technology available. We had a satellite navigation system called Transit that had been developed by the US Navy in 1964, with six satellites in a nearly polar orbit that already, by the end of the 70s, could give us a rudimental fix with intervals between once an hour to a few times a day depending on where you were, with a less frequent position fix around the equator. From there, we got GPS and later on dGPS. Digital maps emerged and then became ENCs. For me, one of the most fascinating advances of the time was by far the unbelievable accuracy, mainly for position keeping, introduced by Dynamic Positioning.

I had my first opportunity to work with DP at the beginning of the 1990s, and it revolutionized the way I saw the future. We suddenly had something that could think and make some decisions on how to use the power needed. It was amazing. Impressive. Of course, it required a specialized supervising DP officer and plenty of training.

Soon after this, it seems that the bridges on the ships I sailed on had a rudimental AI that if not capable of making decisions on its own, could warn us of dangers so that we could take appropriate actions.

8.1 Dynamic Positioning: Shipping's First Step Toward Autonomy

First introduced to the maritime world in 1961, DP, with its automated system controlled by computers capable of enabling a vessel to maintain its heading and position offshore with fair accuracy, was the true first introduction of autonomy into the industry.

It is often used on ships, offshore semi-submersible drilling units, cruise ships, cable laying ships, and dive support vessels during oceanographic research. It can be installed for use when precision position maintenance is required or for when it is either impossible or not ideal to moor or anchor.

Information regarding the vessel's position and any environmental forces which might affect it is constantly fed to an onboard computer system via position reference sensors, motion sensors, wind sensors, and a gyrocompass. This information coupled with a program containing a mathematical model of the vessel, the location of its thrusters, and its drag permits the DP system to calculate thruster output and steering angle, helping to control the ship's surge, sway, and yaw.

The DP is also capable of measuring the waves and period, by calculating the vertical movement.

What was most fascinating for me was the entire process during the building, set-up, testing, and implementation of DP—in my case for loading offshore. It gave me a great insight into how all of the many parameters of the ship needed to be input into the computer system with a very high sense of accuracy after which all tests were verified with a stopwatch. And this in turn gave me a great understanding of how future ships must be built if we want to succeed with autonomous ships and the rigorous global standards that it requires so that they can navigate safely around the seven seas, without misunderstandings that could lead to severe accidents.

As I see it, the next phase will be to have a more sophisticated AI that can step in as "the navigator" with a trained officer as a supervisor, a little like in the offshore field where they use DP. And from there the step toward autonomous ships is not that long anymore. However, for this to work, ships need to be tested properly so that all data fed into the system is accurate. Without that accuracy, it will not work properly. This will depend on how sophisticated the AI is and how well it will learn from its previous errors, as well as its ability to reprogram itself and the ship's system. These are factors that will prove to be of the utmost importance for the whole operation. But as always, not all shipping operators will invest in the best and highest quality equipment.

8.2 An Overestimation?

> We tend to overestimate the effect of a technology in the short run and underestimate it in the long run.—The Law of Amara, Roy Charles Amara, American futurist, scientist, and researcher (Amara, date unknown)

It is easy to assume that the sooner we can get better equipment to aid the sailors onboard, then the sooner we could help these sailors to avoid making so many mistakes, and we would have a safer maritime community. Of course, the logic holds that the better the equipment is or will be, the greater percentage of the mistakes that still occur will be due to human error, and the limits of human competency will be questioned even further. Moreover, it is sure that there are parts of the community that will immediately see autonomous ships as an opportunity to save some money by reducing the crew on board. It is true that every ship has a minimum manning certificate, and therefore, the logic could hold that we should be safe enough if we reduce the crew to those numbers.

Why would we keep more crewmembers than is necessary? Furthermore, as soon as we have fully autonomous ships in service, there really would not be a need to have a crew at all. Nevertheless, we have to remember that ships are built to rigorous standards and expected to sail for several decades, so it will take a while before we can even imagine having all ships sailing without crew. We also must consider that autonomous doesn't necessarily mean unmanned—at least at the beginning. Neither can we forget that when we talk about human error, that error isn't necessarily due to the incompetence of the captain, the officers, and the crew. We must remember that these people are professionals who have studied and worked for years in their respective positions. Additionally, there are numerous procedures involved as well as several people working within the chain of actions, both aboard and ashore, and any mistakes made along the way by any of these people would be an example of human error even if it doesn't occur directly on the bridge.

9 AI: Friend or Foe?

9.1 Introduction

> Don't base decisions on the advice of those who won't have to deal with the consequences.—Paulo Coelho

Autonomy is key to removing ocean trade's infrastructural bottlenecks and achieving. Be it automating operations for optimum energy efficiency to cut CO_2 emissions, decision-support technology that reduces human error, or autonomous vessels that safely resolve congestion issues at the busiest ports—intelligent operation is the only way forward, the question is how we go about doing this.

The automation of maritime transportation brings savings in time and money, while at the same time enhancing safety. However, development does not happen all at once: automation is approached one step at a time. For example, we still have a long way to go before we can attain remote piloting, and it is not yet possible to steer vessels along the smart fairways without the crew.

9.2 Challenges Ahead

Shipping is still based on the crew observing the environment and getting an understanding of the whole picture so that they can then anticipate what will happen next, make their choices, and finally navigate the ship in the right direction. Technology and data act to support this process. Yet, the industry at times designs equipment that is not user-friendly. It is based on the ideas and designs that engineers believe are necessary for ships and crew.

According to a 2020 ECDIS study (Electronic Chart Display and Information System), an investigation made by MAIB and DMAIB showed that while the standardization and allocation of simple and repetitive tasks, like plotting the ship's position and chart updates, has brought about tangible benefits, it has also introduced new challenges that affect system design, training, and good practices by requiring user interaction with ECDIS (MAIB, 2021). For instance, the number and types of alarms and alerts generated during automatic route checks, pose a distraction that can lead to the crew either ignoring them or can increase the risk that they will miss critical safety alerts among the numerous more trivial ones.

ECDIS requires significant cognitive resources to use its functions, which has contributed to a minimalist approach by users, who learn to distrust the ECDIS and continuously verify the ship's position by alternative means—despite the fact that the 2020 study found that significant discrepancies are rarely encountered.

Even the authorities responsible for establishing the rules oftentimes work with a somewhat old-fashioned vision for tackling the use of ECDIS, continuing to frame and audit within the context of paper chart practices with Flag State, PSC, and SIRE inspections that commonly do not recognize new ways of operating, such as the use of Radar Image Overlay (RIO) (Fig. 3). Moreover, the complexity of the interfaces and menu increases cognitive workload, particularly in busy environments.

In other words, we have this fantastic tool that has been created to decrease the workload, which it does but only to a certain extent because it simultaneously increases the load by augmenting the number of alarms—and if you have been on a bridge during departures and sailings then you know what this feels like. This is my point of a design by non-users, based on an imaginary need for reminders and alarms that instead of being productive and improving safety does the opposite.

I know what you are thinking, isn't it a matter of education and training? Yes, it certainly is, but when land organizations comment about ECDIS that it is a good tool mostly for younger generations, they are missing the point of the equipment altogether. New equipment means new training for all. It's a matter of keeping the crew constantly updated on the use of onboard technologies.

It is only half of a success story if the crew aren't properly trained and then blamed for accidents while the land organizations, work to plan their way toward increasingly high-tech ships, installing new tools and equipment that sound so good without ensuring that their sailors, who are the ones using these tools, have acquired the new skills necessary.

A clear example of the devastation that this race to implement the latest smart technology without properly training crew occurred in the aviation industry with the failure of the Boeing 737 MAX resulting in the deaths of 346 people in two crashes in 2018 and 2019. The cause of the disasters was found to have stemmed from a systematic breakdown in Boeing's

Fig. 3 Like Merle Haggard sang—too many bridges to cross over (*Source* Author [© AMH])

company culture, management oversight, and airplane safety regulations. Pilots were not informed of the existence of a Maneuvering Characteristic Augmentation System sensor installed on the planes, the cause of the crashes, until two weeks after the first accident. Boeing had not disclosed information regarding it in either the pilot manuals or in the training material. A decision that turned out to be deadly.

10 Why Airplanes Might Soon Have Just One Pilot—Adapted from the Article "Moving Towards One Pilot" (Prisco, 2022)

The skies are in fact one of the areas where advances in technology have made stunning changes to those who work in the industry and to society and globalization itself. As catastrophic as some failures like that of the 737 MAX have been, the aviation industry has always remained at the forefront of equipment innovation, and it continues to do so, especially as it seeks to produce aircraft that help to reduce the number of personnel needed on board.

An article published by CNN in January 2022 began by noting that it took five men to man a cockpit in 1950—two pilots, a flight engineer, a navigator, and a radio operator (Prisco, 2022). Advances in navigation systems, onboard monitoring, and radio communications removed three of these figures over time, leaving the captain and first officer. Something we've become comfortable with. But personally, would you trust AI to replace another one of your pilots on your next flight, taking you from your departure gate safely to your arrival gate? Well, this is exactly where the aviation industry is going—if advanced automation can allow them to save money and deal with impending pilot shortages by keeping only one, or on some long-haul flights that currently require three, two pilots onboard. Several airlines have already begun testing their long-range flights in conjunction with Airbus and regulatory authorities.

How is this feasible? Airlines will need to delegate more tasks to computers while creating a "distributed crew" offloading some of the work normally done in the cockpit to the ground crew.

A study of single-pilot programs conducted by NASA in 2014 noted: "They provide operating cost savings while maintaining a level of safety no less than conventional two-pilot operations" (Bilimoria et al., 2014; Lachter et al., 2014). However, further tests on simulators of the single-pilot system, also run by NASA, found that although all of the pilots safely landed their planes, their workload grew notably and the lack of visual cues from the other pilot at times created a level of uncertainty or confusion with regards to particular tasks, resulting in subjective assessments of safety and degrading performance.

The fact remains that the importance of interactive and even intuitive teamwork between humans cannot be underestimated. And the topic of an increased workload begs the question—what do we have to give up in return for relinquishing work to systems of AI?

A 2019 paper by the Airline Pilots Association International referred to these advances as "premature." They highlighted the fact that no AI can make up for a pilot that has become incapacitated for some reason. It also cited the example of the teamwork and decision-making skills of Captain Chesley Sullenberger and First Officer Jeff Skiles who landed their damaged plane on the Hudson in 2009, while also reminding us of the tragedy that ensued in 2015 when a Germanwings pilot locked himself alone in the cockpit and intentionally slammed the flight with 150 souls on board straight into the side of a mountain.

10.1 Aviation Is Just Blame Culture

Needless to say, all of this is happening within an industry that has had an error-positive trust culture since the 1990s. Personnel is encouraged to report incidents with less fear of prosecution or of being fired. Aviation has moved away from a blame culture to the fair blame culture that it has now, differentiating between intentional and unintentional errors.

10.2 A Captain's Responsibility

For the maritime industry, it will be interesting to see what direction aviation takes in terms of using AI to decrease the number of pilots on its flights. Shipping is still a long way away from the just blame culture, an aspect of the maritime world that could impede its progress.

A quick look at the role of the captain aboard a ship underscores this aspect of the maritime blame culture. The captain is the captain and as such is responsible for the ship and the safety of the environment, crew, guests, and property. The role has indeed diminished a great deal over the years—for various reasons. Although a fair amount of the organization, controls, and procedures are land-based these days, in the case of an accident the responsibility is usually given to the captain and officers aboard.

Wouldn't it be time for the maritime industry to copy the aviation industry, making it clear that when there is an accident, they honestly want to understand what happened and want personnel to dare to speak up without fear of being prosecuted so that they can improve for the future? In the maritime industry this level of communication has not been achieved so far, and as such the whole truth might not be spoken and real improvements might not be made. Professionals may see the root cause of an incident and then adjust their procedures, but how can we be absolutely sure?

When the captain and crew don't feel safe giving their opinions or speaking up about what they need and what is going wrong, the industry risks the formation of a schism between the people it employs in whose hands safety truly lies and the sweeping technology that is quickly changing the way we sail. Incorporating a fair blame culture would help to sort out the root cause of maritime incidents, a fact that will become especially important when we reach the point where ships are either controlled by personnel from a remote station or are, indeed fully autonomous.

10.3 No Such Thing as an Accident

In the book entitled *There Are No Accidents* (Singer, 2022): The Deadly Rise of Injury and Disaster—Who Profits and Who Pays the Price, author Jessie Singer claims that there is no such thing as an accident, noting that the majority of occurrences are predictable and preventable—a thought that every industry should be keeping in mind, whether we are talking about human or artificial intelligence.

The book further suggests that throughout history organizations have used the excuse of the word accident to avoid consequences for their own delinquencies, sighting cases of traffic accidents, accidental opioid overdoses, and accidental oil spills, resulting in the prevention of investigations that could truly uncover what needs to change to save lives in the future.

The author raises the ever-important question of the cause of accidents and lays bare the question of what can be done—a discussion that is well-needed within the maritime sphere as well.

10.4 The Chain of Consequences

Let's take the case of car accidents and vehicle safety. An article published in The Atlantic in November 2021 reported that the number of driving fatalities in the United States rose by more than 10% between the years 2010 and 2020; while the same data from the European Union marked a 36% reduction in such deaths during the same period (Zipper, 2021).

What is happening here? If the vehicles on our roads are becoming more and more sophisticated by the year, shouldn't the safety on all roads be increasing too? Well, there are several factors to take into consideration.

In Europe, regulators have increased pressure on car manufacturers to create automobiles that are safer for pedestrians and cyclists. National and local authorities make regular alterations to road engineering after an accident occurs. This means that the cause of an accident involving a car and a pedestrian or cyclist is the responsibility of more than just the person behind the wheel, the pedestrian, or the cyclist.

Let's cross the ocean for a minute. In the United States, in over 94% of similar accidents, driver error is considered to be the sole cause of the incident. Too often, neither those who create the roadways we drive nor those who create the vehicles we ride in are considered responsible. This can get too comfortable for the automotive industry and traffic engineers.

A 2015 memo by the National Highway Traffic Safety Administration noted that: "The critical reason, which is the last event in the crash causal chain, was assigned to the driver in 94% of the crashes." But did someone say chain? What if a cautionary road sign is partially obstructed by an overgrown branch or was left damaged and slightly turned away from the driver's line of vision? What if a pedestrian crossing has been left unpainted and faded? What if the driver has a huge SUV whose massive weight can create far greater force upon impact with a cyclist or a pedestrian than a smaller car would? What if the dashboard is poorly planned out, or there was no bicycle path for a cyclist to use, or the car didn't come equipped with a couple of onboard safety features like pedestrian-detection technology—because manufacturers can sell that for an extra cost to buyers and earn millions more every year? What if…

The "if" in question is this: if culpability in an accident is solely that of the driver or pedestrian or cyclist, then it is easy to disregard the importance of reviewing the engineering of roads and the necessity of putting more pressure on carmakers to value safety before profit. Similarly, in the maritime world, International Collision regulations require, with regards to Rule 6, what is referred to as safe speed—a speed at which the vessel can take proper and effective actions to avoid collision and stop within a distance appropriate to the situation. However, despite the rule, accidents still occur. Is it simply because the officers ignored the rule or didn't understand what to do? Could anything else that is preventable in the future have happened to lead to the accident? How can we fix it? Or, should we, instead of trying to figure out and fix what happened, simply build autonomous and unmanned ships so that the onboard human element would disappear and with it, the risk of human error? Eventually, we may have these ships, but even then, there will still be humans monitoring these autonomous ships remotely—and then we will find ourselves again asking the question of how well trained and prepared they are, especially if they don't know how the ship is behaving while at sea.

10.5 Bridging the Gap

Of course, several well-known shipping companies are doing a very good job at constantly training and updating their already well-educated officers and crew. These companies understand the value of the human intelligence that guides their ships, while also keeping up with cutting-edge technology that can increase safety for all involved. Many have company-owned training academies, while others use renowned universities and privately owned academies to continuously give their crew all of the tools, they need to do their best work.

They share a common belief that you must train your teams so that they can safely bring the ships over the oceans.

11 The Secret to Success

As the American author of personal finance George S. Clason wrote almost 100 years ago, "Opportunity is a haughty goddess who wastes no time with those who are unprepared."

Are we in the maritime industry prepared to capture the opportunity that advanced technologies are offering us now and in the future? Carefully critiquing the weak points in our systems today will set us up for success in the decades to come.

11.1 Connectivity—The Most Important Link

For the safety of shipping, it is imperative to get relevant information as quickly as possible (Fig. 4). It is so important that a request has been made to add internet access to the Maritime Labour Convention (MLC, 2006), and it was even deemed a human right in a UN report back in 2011—though as of 2022, only about 82% of officers and crew had access to the internet while aboard.

To have a faultless connection becomes a matter of survivability as soon as we talk about autonomous ships and remote pilotage or assistance of vessels. Without good connectivity, these smart functions cannot perform as they should, or they may not be able to perform at all. And then what?

It is true that sailors have been braving the seas long before the internet existed, however, these sailors also had skills that we don't learn today because we have technology that performs them for us.

Fig. 4 5G connectivity (*Source* Author [© AMH])

We have become so used to having instant access to information that it seems as if we are living up to the words of Einstein, "Never memorize something that you can look up." But what if we forget something but cannot look it up?

Connectivity aboard ships is also a matter of quality and that can, at times, depend on how much a company is willing to invest in it. Lamentably, these vessels with their inferior technology sail among us every day—a scary truth that we must contend with.

Of course, technology, just like its human counterpart, is not immune to other phenomena that can cause problems. Storms, like snow and sand storms, and even solar storms can all affect the reliability of electronic devices.

We also must keep in mind that even the most sophisticated GNSS positioning system can be manipulated. Intentional harassment of our systems through jamming, phishing, and malware also exists. Spoofing, for example, is currently considered to be a growing threat to GNSS-enabled equipment.

11.2 Eyes Wide Open

Besides looking at the weaknesses in our systems, we must also contend with the many opinions and fears of our fellow humans as we enter the age of Disruptive Technologies. While some want to plunge ahead regardless of warnings or inconsistencies, others want to halt progress out of fear of the risks this new technology may pose.

11.3 The Concerns of "Modern" Technology

> They cause momentary insanity. Their noise may produce heightened cases of anxiety. The vibrations could have a disastrous effect on the human nervous system. A newspaper story tells of a man who, as a result of exposure, began flailing about erratically, trying to climb out of a window, swearing, shouting, and struggling with everyone. Fortunately, the police were able to subdue him.
>
> Swiss scientist warns of the dangers of information overload. He explains that it is simply too much information for the public to handle. The outstanding scholar, along with other scholars and some in power believe that laws should be enacted to regulate sales and distribution. He refers to this overwhelming amount of available data as "confusing and harmful" for our brains.
>
> A group of scientists and doctors have submitted a written request calling for a halt to the rollout of technology that could endanger humans. The media reports fears of potential long-term health risks and those who predict that it will create widespread cases of electromagnetic sensitivity that could potentially manifest as a headache or eventually instigate a series of immunodeficiencies.

Do you know what each of these concerns is referring to? The first refers to media reports that date back to 1860s England and the "they" in question was the newest technological creation, the steam engine train. At the time, these cases of "railway madmen" were attributed to the speed and motion of the trains. And thus, many Victorians decided that steam trains were very dangerous.

As for the scientist's raised alarm, well, his name was Conrad Gessner. He died in 1565 and he was warning of the overwhelming amount of information unleashed by the printing press.

The final concern is far more recent and references the current move toward 5G technology. Much fear has been evoked by protests and reports describing worries regarding this new unknown frontier.

11.4 The Uproar over 5G

Technology changes rapidly. Just a few years ago it was considered incredible that gsm mobile signals could extend 10 miles from the coast. Today, 5G can reach a staggering 30 miles out, an important fact since it is 5G-based platforms that are expected to enhance the safety of ships. However, this vital aspect of technology has run into plenty of pushback.

Just like earlier versions of cellular technology, 5G uses signals carried by radio waves that are part of the electromagnetic spectrum. The difference is that this particular technology relies on higher frequency waves to run its networks compared to earlier versions. Because the waves travel shorter distances, more transmitter masts are required to run it. And these electromagnetic waves have long been a concern to some people who fear they could increase health risks such as cancer. Although the WHO and International Agency for Research on cancer do classify all types of radiofrequency radiation as possible carcinogens, the radio waves used for cellular technology are placed in this category due to inconclusive evidence supporting their link to increased cases of cancer in humans. In 2014 the WHO declared that "no adverse health effects have been established as being caused by mobile phone use," according to a report by the BBC (BBC News, 2019).

What about fears regarding the increased number of transmitters? The fact that there are more of them means that they each require lower power levels to run compared to 4G networks, meaning that 5G antennas will create lower levels of radiation exposure.

As with all advances in technology, there are concerns and possible fears of the unknown. But do we give up on making possible advances, and fly our white flag to the what-ifs? Or do we harness our ability to make adjustments and improve our creations as we go, remembering not to let our thirst for the next big invention blind us to our ability to carefully monitor our progress? We as humans have free will, therefore we remain in charge of our technological advances … at least for now "I am the master of my fate; I am the captain of my soul."—William Ernest Henley, Invictus.

12 United We Stand, Divided We Fall: Hardware, Software, and Liveware

12.1 AI v HI

Inevitably, as Artificial Intelligence grows a certain sense of confrontation between it and our own Human Intelligence has sprung up. Through Machine Learning and Deep Learning, machines can acquire knowledge on their own and can even make some decisions, just as a human would. This has led some to posit that AI could take over, throwing Human Intelligence into a sort of existential crisis. However, Human Intelligence is based on adaptive learning and experience. It does not always depend on pre-fed data the way AI does. Human memory, its computing power, and the human body may seem insignificant compared to the hardware and software of a machine; but the depths and layers present in our brains are far more complex and sophisticated—at least for the time being.

As Nick Burns, an SQL Services Data Scientist, put it, “No matter how good your models are, they are only as good as your data.”

12.2 Bridge Resource Management: A True Model for Mitigating Human Error

Crew Resource Management (CRM) is a concept that is widely used in the aviation industry to improve the operation of its flight crews. Introduced in 1979, in response to a NASA workshop aimed at examining the role that human error plays in air-traffic accidents, it was the result of a commitment by the industry to improve safety after the deadly crash of two Boeing 747s, KLM 4805 and Pan Am 1736, on the runway of Los Rodeos Airport in Tenerife.

CRM focuses on the human factor in high-risk and high-stress situations. Its goal is to use all available resources, including information, people, and equipment, to ensure the safest and most efficient flight operations. It makes use of team training, simulations, interactive group debriefings, and measurements of the improvement of crew performance. By the early ’90s the shipping industry began introducing the same concept to its bridge teams, creating what is now known as BRM—a tool determinant for the success of maritime operations that demonstrates how human error can be minimized and safety maximized in a maritime environment where the risk of a single point of error is reduced.

BRM stresses the vital importance of teamwork in reducing human error and ensuring that all teams utilize every available resource from liveware to software to hardware—including those resources offered by AI—in such a way that adequate situational awareness is maintained at all times. On the bridges of today, and to a much greater extent on those of tomorrow, this teamwork also includes the contributions of AI. It is effectively another member of the team, and together this combination mitigates the risks of human error.

12.3 Some Errors Are Fatal

Unfortunately, no matter the number of preparations, procedures, and sophisticated tools, accidents occur and sadly some are fatal. Such was the story of the Costa Concordia's grounding in January 2012, in which 32 people died (STT, 2017). There were clearly errors made both before and during the fatal accident, and disputes followed regarding what was done, how it was done, how much of the blame lay on the captain's shoulders, and whether the shore organization should have taken more responsibility. The errors committed on that fateful day raised some much-needed voices of concern.

The ship already had good enough equipment and sophisticated technology that had passed all inspections, the company implemented BRM practices and the officers were trained, but how well did they monitor the equipment and how well did they follow proper BRM while on the bridge? During the investigation, how close to the truth were the stories told? Were the officers and crew involved afraid for their jobs and hence rather than recount what had really happened, did they say what they knew should have happened instead? Is there more advanced technology that could have helped to prevent this tragic error? Were there any discrepancies with the data regarding seabed obstacles on the ECDIS and what was the accuracy of the chart in use? Will we ever really learn from the story of the Concordia?

This is a good example of my belief that the maritime industry should learn from the aviation industry. This tragedy underscores how essential it is for the maritime industry to adopt the fair blame culture of the aviation industry. It is also a neon sign invoking the need to ensure that the crew can use all of the new sophisticated technology at their fingertips. It is a cry for inquiring beyond the labels of human judgment and figuring out the noise of bad decision-making. It is the reason why

BRM must be properly taught and re-taught. The Concordia gave us new enhanced stability rules in 2015 with the Probabilistic Damage Stability for Passenger Ships but only after the fact. It could even be a rallying cry for higher-level autonomous ships.

12.4 A Final Human Thought

Let's take an incident in the financial sector that happened in May of 2022 in which a mistake made by a Citigroup trader caused a flash crash of shares, especially in the Nordic area. The dip only lasted for a few minutes, but one minor error created a machine-led crash since the system itself calculated a worst-case scenario. That said, there were no problems with the software being used. The incident was rectified very quickly, in large part because the humans operating the system understood that there was no apparent reason for it to be behaving the way that it was.

Now, let's take rules 15, 16, and 17 of Collision Regulation as an imaginary but parallel example at sea. There is a crossing situation where one ship is the "give-way" vessel and the other is the stand-on vessel. They follow the rules to some extent and the onboard automation is pre-programmed to follow the rules as stated. Now, if the "give-way" ship doesn't respond as it should, for one reason or the other, the stand-on vessel shall, when in doubt of the intentions of the "give-way" vessel, give at least five short blasts on the whistle—assuming that there would be someone on the bridge of the other ship. Then when the distance between them closes and it becomes apparent that the "give-way" vessel isn't following the set rules, the stand-on vessel may take action to avoid a collision, however, it is not required to act quite yet. If the situation continues and the distance, later, becomes so close that actions by the "give-way" vessel alone cannot avoid a collision, then the stand-on ship shall also take actions to avoid an accident. With the mass that modern ships have and their potential speed, it is at this point very unlikely that a collision could be avoided—especially if a minor mistake, latent or not, happens just as in the Citigroup example.

Human minds sometimes fail, and it is human minds that will create the AI and other equipment designed to make our lives easier and safer (Fig. 5).

Fig. 5 The world's first autonomous ferry "Falco." Finferries road ferry Falco in the Finnish SW Archipelago—the first fully autonomous ship, test done in co-operations with Kongsberg, December 2018 (*Source* Picture courtesy of Finferries [collected by Author])

13 Conclusions

Thomas More published Utopia in 1516 and over 500 years later humans, although we have evolved, continue to be imperfect. Perhaps this was More's point, after all his story revolves around a traveler by the name of Raphael Hythloday who spent five years on an island named Utopia—Hythloday is translated as "expert of nonsense" in Greek, and Utopia means "nowhere." This was a work aimed more at ridiculing existing conditions rather than offering any real solutions to problems—something that we must always keep in mind as we debate and invent our way toward the benefits and uses of more and more advanced technology in shipping.

Now, whether any sort of utopia exists—be it social, technological, or maritime—I leave that up to you. I'm not going to argue if an ideal world of autonomous shipping is either doomed to fail or destined to be a defining success. I guess that depends on the plan and how much you believe in it. As so often noted, a goal needs a good plan if it is ever to become a reality, and a simple wish that technology will save us will not navigate a ship safely from one port to another.

Although it might seem as if I am against the inevitable development of shipping toward autonomous and eventually unmanned vessels, I am not. And, neither am I suggesting that unmanned autonomous ships are nonsense, by any measure, I actually believe the opposite—not necessarily to save costs on manpower, but instead because it makes sense. Technology makes huge leaps forward and AI will, when it is a little more developed, revolutionize the world of shipping and beyond. However, I strongly believe that it needs to be well planned, prepared, and executed. What I do not believe is that it will be a salvation with regard to human error, for that we must wait for a future generation of AI that can start to program itself and correct its errors.

I was once asked if I knew the difference between being smart and being intelligent. I replied that I did not and was told that the main difference is that smartness is an acquired trait whereas intelligence is a trait that people are naturally born with. Being smart is about using the knowledge obtained and applying it to practical situations. Intelligence is about gaining knowledge easily and swiftly.

In the chapter, I have offered a critical view and hence it might have seemed that I even pointed a finger toward those who can make a difference shoreside. But I have only done this with the most honest of intentions—to raise questions. Perhaps, I have even made a few of you dear readers slightly upset. Well, if I have, then I have reached my goal, but only if you look in the mirror and ask yourself: What can I do to make our industry safer? Only then have I truly succeeded because it is, after all, in the common interest of everyone to make the maritime industry as safe as possible, using all the tools we have at our disposal at any given time.

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CHAPTER 4

Changing Ocean Observation and Cargo Carrying with Disruptively Affordable, Long Duration Autonomous Vessels—Case Study: SubSeaSail LLC

Michael B. Jones

1 Introduction

Maritime "decarbonization" requires a sense of urgency combined with an "all-hands-on-deck" approach. Autonomy is a critical element to help provide needed efficiency and cost savings. At the same time, every kind of propulsion system needs to be analyzed, improved, and employed to its maximum advantage. Sailing technologies of all kinds from sail assist to primary power as well as different hulls must be considered to understand and maximize this potential. "*Ships produce 3% of greenhouse-gas emissions. Burning maritime bunker fuel…contributes to acid rain. None of this was*

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a problem in the age of sail-which is why sails are making a comeback, in high-tech form, to costs and emissions" (*The Economist*, 2021).

Great empires from the Egyptians and Phoenicians forward rose and fell over the centuries partially based on ocean innovation and the resultant ability to "rule the waves." Sailing vessel improvements were a critical part of this progression. In the nineteenth century—following two wars with England—American shipbuilders developed larger and faster ships to be able to access and trade with Asia. Larger ships meant that they could carry more sails, which facilitated speed and carry capacity (Vance, 2020).

The advent of the Industrial Age on land in the eighteenth century began to revolutionize ocean-going vessels in the nineteenth century. The introduction of precision in delivery was a crucial advancement alongside an ability to reduce needed crew to work vessels. But the downside was reliance on hydrocarbon that has increased dramatically over time in price while creating meaningful pollution. "*The maritime share of 3% of global emissions risks growing as other sectors decarbonize if nothing is done*" (Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2021).

The time has come for a new era of sailing based on advancements from centuries past. The International Windship Association (IWSA) is a UK-based, not-for-profit that has played an important role in this regard by promoting innovation and collaboration related to wind propulsion for global shipping. IWSA brings together all parties to shape the industry, policy, and a public understanding of the potential of windsail for shipping. "*International Windship Association and it's 150+ members have declared the period 2021–2030 as the "Decade of Wind Propulsion", a decade of delivering wind propulsion installations, optimising the technology solutions and helping to facilitate a quicker, deeper and ultimately cheaper transition to a fully decarbonised fleet*" (IWSA, 2021a).

Wind energy is an abundant, clean, renewable source of power. It is delivered "free of charge" to the vessel without expensive shoreside infrastructure, which means that operations have fewer power-related restrictions. Wind Propulsion Technology (WPT) can be used as an auxiliary source of power, particularly in retrofit situations with hydrocarbon-based propulsion vessel, and gains are expected in the range of 5–30% depending on technology, geographic area of operations (i.e., more or less wind) and other factors. All the major class societies—ABS, Bureau Veritas, ClassNK, DNV GL, and Lloyds Register—have published or are in the process of preparing wind-assist guidelines. Major shipping companies are getting involved including Cargill, Louis Dreyfus, K-Lines, Mærsk, and others (IWSA, 2021b).

With new builds focused on WPT and vessel design, the savings can be much larger. Shipping company Wallenius Wilhelmsen announced plans in early 2021 to build a full-size wind-powered car and truck carrier expected to achieve up to 90% reduced emissions compared to traditional vessels (Ship Technology, 2021; Wilhelmsen).

Direct (i.e., primary) wind energy usage is extremely efficient compared to renewable wind energy that is transported and converted into fuel sources useable by traditional vessels (Fig. 1).

To date there are a limited number of companies developing crewed vessels utilizing WPT as the primary source of power combined with other clean technologies including hydrogen and solar. Combining WPT vessels with weather routing can save additional time and money. More and more industry leaders and media influencers are convinced that the time is now to promote wind energy. "*Windship Technology is promoting its design concept as the "Tesla of the Seas", able to present a viable and economical solution for ocean-going bulk carriers and oil tankers*" (Maritime Executive, 2021a). "*Believe it or not — and I do believe — the economics of sail power is looking pretty compelling*" (Milken Institute Review, 2022). And the European Commission is promoting and funding sailing innovation trials (EC, 2021; European Parliament, 2009).

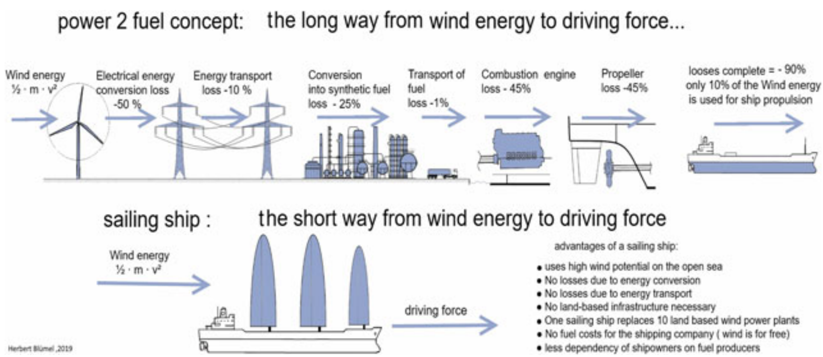

Fig. 1 Comparison of primary v. secondary renewable energy (*Source* Herbert Bluemel, 2019)

2 Wind-Powered Autonomous Surface Vessels (WASV)

It was estimated that there were over 1,000 Maritime Autonomous Surface Ships (MASS) operated by more than 53 organizations globally in September 2021. These powered MASS vessels typically work alongside manned vessels "with minimal autonomous-specific regulation" (The Maritime Executive, September 2021b). However, Wind-powered Autonomous Surface Vessels (WASVs) is a whole new area of endeavor.

3 SubSeaSail[R] LLC

SubSeaSail LLC (SubSeaSail) is a San Diego, CA-based BlueTech company with a mission to develop 100% autonomous, disruptively affordable, energy harvesting, long-duration (1+ month) sailing vessels and unique sensors. SubSeaSail is developing vessels that do not employ traditional monohull technology. The company has an aggressive Intellectual Property strategy and as of September 2022 had 5 issued U.S. patents and a number of additional U.S. and international patents pending.

SubSeaSail is positioned at the intersection of multiple megatrends: *Autonomy, Blue Economy/BlueTech, Clean/GreenTech, Communications, Decarbonization, Price/Performance, Robotics, Sailing and Weather Change*. *Autonomy* is critical to reduce the cost and risk of vessels for observation and cargo. *Blue (Ocean) Economy/BlueTech* have only recently been recognized as a massive, growing market with BlueTech as the fast-growth innovation sector critical for sustainable economic growth. *Clean/GreenTech* is inherent in vessels that are 100% energy harvesting. Satellite *Communications* costs for vessels on the ocean will decrease rapidly with the proliferation of smallsats allowing real-time reporting globally. *Decarbonization* is critical for shipping and SubSeaSail vessels are 100% Clean. SubSeaSail vessels will excel in *Price/Performance* since they will require less Capital Expenditure to build (CAPEX) and minimal Operating Expenses (OPEX). *Robotics* is a growth field as are uncrewed surface vessels. *Sailing* cargo vessels are seeing a resurgence—wind energy is an abundant, clean, renewable source of power delivered "free of charge" to the vessel without expensive shoreside infrastructure. *Weather Change* is expected to result in more frequent, intense storms that endanger traditional monohull vessels… but SubSeaSail vessel submerging capabilities will allow them to "hide" underwater from bad actors and bad weather and continue their missions when conditions permit.

SubSeaSail is developing three lines of business products: (1) monohull, semi-submersible *observation* vessels based on multiple issued U.S. patents; (2) multihull, surface *cargo* vessels protected by several issued and pending patents; and (3) unique sensors ideally suited for the observation vessels including rigid and semi-rigid Passive Acoustic Monitoring (PAM) Arrays and a weather station. The vessels are highly scalable and variable as to design depending on customer needs. They will be well suited for distributed maritime operations and fleets/swarms.

HORUS™: There is a critical need to better understand the ocean. The company's first offering is a monohull, semi-submersible observation vessel. It is called HORUS after the powerful Egyptian god. The Eye of HORUS stands for protection and knowledge, which is fitting for a long-duration observation vessel. Just as affordable "Smallsats" at a fraction of the price of traditional satellites are revolutionizing the way humans work with space, HORUS observation vessels will act as smallsats for the ocean (Fig. 2).

The HORUS 7th generation product (Gen7) is affordable and easy-to-transport/deploy/retrieve. It is 1.65 meters long (the hull), 3+ meters high (50% below water structure/50% wing sail), weighs (depending on

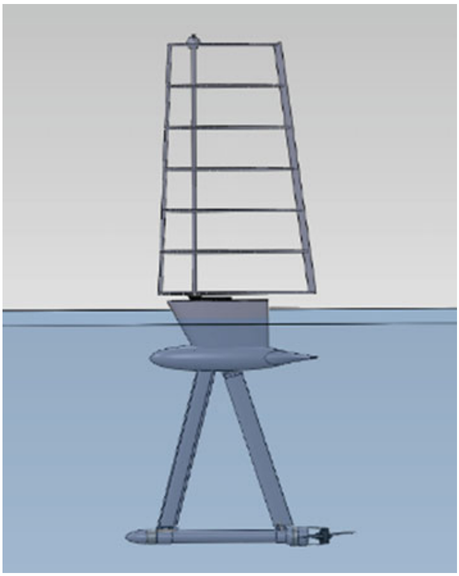

Fig. 2 HORUS profile (*Source* SubSeaSail LLC)

sensors) approximately 34 kilos (75 lbs.), is wind propelled (0.5–2.5 knots), and solar powered. It was developed to have an ultra-low signature (acoustic, IR, radar, and visual) in the ocean but can be made visible when desired. The design is scalable as to form and size to fit client needs.

HORUS represents a strong value proposition: ability to submerge, disruptively affordable (i.e., low CAPEX/OPEX), easy-to-deploy (32 kg), flexible design that permits sizes/shapes to suit users' needs, long-duration/long-residence capability, low detection signature (acoustic, IR, radar and visual), and 100% energy harvesting eliminating a need to re-fuel (Fig. 3).

HORUS is very affordable compared with other long-duration observation vessels. A company goal is to make the vessel price accessible to marine institutes in developed and developing countries alike around the world. Sensors developed by SubSeaSail and 3rd parties can be added on the top of the mast (e.g., a 360° light, camera with classifiers, anemometer, etc., and weather station), in the cone and above/below the lower tube. Communications are subsurface to surface via acoustic

Fig. 3 HORUS Gen7 offshore with 360° light + anemometer (*Source* SubSeaSail LLC)

link and surface-to-surface/surface-to-command-center via cellular, WiFi and satellite. A factory-installed option will permit submergence initially to 30 meters—and later to 100 meters—to avoid bad actors/weather and to measure/listen at various levels. A unique, multi-function observation vessel is the base, but sensors are essential to address information needs of customers. The two biggest areas of interest expressed by potential users are underwater acoustics and weather.

SubSeaSail is constantly on the search for small sensors from 3rd parties. However, SubSeaSail has developed unique sensors for these two primary areas of interest because there have not been sensors available that fit the needs of HORUS—low SWaP (Size, Weight, and Power) and ability to submerge. There is broad, global interest to understand ocean soundscapes. Reasons range from understanding marine life to monitoring anthropogenic noise (i.e., human created) that can be detrimental to aquatic life and industry and military uses. Acoustics is how marine life and humans communicate underwater. The speed of sound changes with salinity and temperature, so it must be measured in different areas and at different times over extended periods to have accurate measurements. SubSeaSail vessels can be deployed in multiple locations and over extended periods facilitating high quality measurements, which are important to track and classify sources on and below water including fast vessels, marine life, semi-submersible drug vessels, and much more.

SubSeaSail monohull vessels can be equipped with a powerful onboard Data Acquisition system (DAQ) inside the hull and one of several affordable, rigid or semi-rigid Passive Acoustic Monitoring (PAM) arrays. The DAQ will facilitate the easy integration of hydrophone arrays and digital inputs from other sensors and a tie-in to the vessel's communications system. One rigid PAM array developed named X2(4) includes 4 hydrophones in an "L" shaped array extending down from the vessel cone. By virtue of HORUS being a hyper-quiet vessel plus knowing where the hydrophones are (due to it being a semi-submersible with GPS above water), it will permit on-board processing including beam forming and sound classifiers with an ability for real-time, exception-based data exfiltration. This will be Ideal for detecting surface vessels, underwater vehicles, marine mammals, and more.

HERMES™: The second line of business will be autonomous, multihull surface cargo-carrying vessels that can cost-effectively deliver goods point-to-point globally. The traditional problem with multihull vessels—and the reason that they have been little used for long-distance cargo vessels—is the risk of catastrophic capsizing in high wind. The creation of stable, cargo-carrying, multihulled vessels will change the economics of cargo vessel production and operation for some applications and destinations. It will be well suited for small high-value-add loads of liquids and some other traditional cargos as well as to carry and deploy special assets. Potential cargo applications include expeditionary forces supply, humanitarian aid (60–80% of cost is delivery), inter-island and remote island delivery, and time critical research supplies.

SubSeaSail received a grant from the U.S. National Science Foundation (NSF) to design a performance, 100% clean, multihull, surface sailing cargo vessel that addresses the risk of catastrophic capsizing of multihull vessels. SubSeaSail has named this vessel HERMES after the winged messenger of the Greek gods who was also considered the God of Commerce. This unique technology will be protected by several issued and Patents Pending. When developed, this will likely be licensed to ship builders globally to permit the creation of affordable fleets of smaller vessels that can deliver point-to-point to an array of locations including small to medium-sized ports, remote islands, and other destinations.

Sensors: As a third line of business, SubSeaSail is developing sensors that take advantage of the patented, ultra-quiet, semi-submersible observation HORUS vessel, which in the future will offer the option to submerge. The company will incorporate sensors from 3rd party providers when they present the attributes needed on the monohull—lightweight, low profile, low-power draw and, in the future for properly outfitted vessels, the ability to submerge to 100 meters and continue to function above and/or below water, as the case may be.

4 Semi-Submersible HORUS Vessels

Affordable, autonomous, long-duration observation vessels are essential to allow the deployment of thousands of sensor-carrying vehicles across the globe at the air/water interface in places not previously accessible and for uses to help us understand the ocean in ways not previously affordable.

Background: Sailing vessels have been around for thousands of years. They universally comprise a vessel that is propelled by the wind on the surface of water. The propelling force on a vessel is provided by a wind-catching mechanism in the form of a sail, wing, rotating device, etc. This wind can propel the vessel downwind by virtue of the drag of the wind-catching mechanism. However, if it is desired to proceed in a direction at least partially into the wind, then the wind-catching mechanism must have the hydrodynamic property of lift, which generates a force perpendicular to the direction of the apparent wind. This lift can be utilized to make the vessel go forward partially into the wind, however this lift also generates a sideways force on the vessel, as well as a rolling moment along a longitudinal axis of the vessel. If the vessel is not to slip sideways under the influence of the side force, it must resist this force. This can be accomplished in a rudimentary manner by virtue of some advantageous shaping of the vessel itself. Alternately, and more efficiently, this is done with the use of a keel, which is typically an appendage to the vessel, that has its own hydrodynamic property of lift and thus when the vessel is moving, will generate an equal and opposite side force to the wind, thus enabling the vessel to go upwind instead of slipping sideways.

The wind also generates a rolling moment which attempts to roll the boat about its longitudinal axis from bow to stern. This is due to the fact that there is the aerodynamic lift force generated by the wind on the wind-catching mechanism, and it is located above the water, so the force becomes a moment which must also be resisted or the vessel will roll over and capsize. This roll resistance is accomplished in traditional sailing vessels by virtue of the fact that there is a center of gravity of the vessel which is displaced laterally from the center of buoyancy when the vessel rolls, and this displacement provides a counter rolling moment, known as a righting moment. Typically, this approach is manifested in a vessel which has a center of gravity lower in the water than its center of buoyancy, and therefore when it is rolled somewhat, the center of buoyancy moves laterally and then provides a restoring moment when coupled with the center of gravity. This can be seen in a myriad of forms of current sailing vessels. Alternately, in a multihull vessel, the righting moment is provided by virtue of the fact that the center of gravity of the vessel is raised above the water by the force of the wind, and therefore there is a restoring righting moment between the center of gravity and the center of buoyancy in the outboard hull.

There are several disadvantages of traditional vessels.

- First, because vessels float on top of the water, a drag is induced on the vessel due to the hull form being driven through the water and thus creating waves on the surface (a wake). Energy of propulsion is lost to wave-making.

- Second, surface vessels experience instability as waves, swells, and wind act upon their hulls.
- Third, the shape of surface vessels must generally be chosen to minimize the wave-making drag described above. Typically, this results in vessels that are necessarily slender and somewhat cylindrical in its wetted sectional shape. It is inefficient to stray from this design.
- Fourth, the side force generated by a keel increases the rolling moment caused by the lift effect of the wind on the wind-catching mechanism, because the method of generating the side force necessarily lies below the vessel's hull.

SubSeaSail designed and patented a new type of sailing vessel—a semi-submersible sailing vessel—to overcome the disadvantages noted above. The U.S. Patent Number 10,029,773 entitled "*Submerged Sailing Vessel*" was issued on July 24, 2018 (Google Patent Search, 2018). It describes a series of embodiments with the hull and keel submerged below the water with a wind-catching assembly above the water. This results in a semi-submersible form that is highly scalable and variable in shape to the needs of the user. It can be lightweight, 2-person deployable over the side of a RIB (rigid inflatable boat) or scaled up in size with a larger sail, more batteries, and solar production to accommodate more power-hungry sensors and to function in harsher ocean conditions. It could look like the current A-frame (Fig. 2) or like a whale for pre-positioning of goods or flat like a stingray.

The vessel is designed to be positively buoyant with several inches of "freeboard" before the wingsail begins. A factory-installed option will be a buoyancy engine that allows the vessel to submerge to specific depths. The ability to submerge will have multiple advantages including the ability to "hide" from bad storms, which—due to climate change—are expected to become more frequent and more violent. Other uses of this capability to dive and hold position will be to listen and monitor above and below water, to avoid "bad" actors, to deploy, and/or retrieve scientific instruments and/or unmanned underwater vehicles (UUVs). It will have advantages when deployed in contested/hazardous zones, when trying to detect vessels engaging in Illegal, Unreported and Unregulated (IUU) fishing, and much more.

SubSeaSail vessels are engineered to be durable, practical, reusable platforms, which is evident in a second patent designed to protect a novel, simple way to manage a wingsail without lines, pulleys, or motors.

The U.S. Patent Number 10,625,841 entitled "*Passive, Automatic Wing Control Mechanism*" was issued in April 2020 (Google Patent Search, 2020a). This describes a passive, automatic wing-control mechanism for sailing based on a cam attached to one end of a rotatable mast with a tensioner configured to exert a constant force perpendicular against the cam. When a wing is in a no-go sailing angle with respect to an apparent wind, the cam does not exert a torque on the mast. When the wing is outside the no-go sailing angle, the cam exerts a counter-torque to a torque caused by the apparent wind acting on the rotatable wing, causing the wing to remain at a predetermined angle with respect to the apparent wind. Other autonomous sailing vessels utilize an anemometer to measure the speed and direction of the wind combined with a motor to move/hold the wingsail, all of which happens passively, real-time on the HORUS vessel.

A third issued patent relates to solar power developed inside a solar wing formed by transparent material that allows panels to be on the parallel, space apart wing ribs or in some other configuration inside the wing. This solar wingsail is envisioned to work in conjunction with deck mounted solar panels to provide additional power to charge batteries to operate on-board electronics. The U.S. Patent Number 10,526,096 entitled "*Solar Wind Sail and Apparatus*" was issued on January 7, 2020 (Google Patent Search, 2020b).

5 Multihull HERMES Cargo Vessels

Autonomous cargo vessels will be important in the evolving global shipping market. However, it will be critical to address a series of issues related to fully autonomous vessels (versus partially autonomous) including cargo oversight, collision avoidance, cyberattacks, malfunctions, and navigation system failure.

Some issues that fully autonomous vessels will be able to help address include:

- Reduce ship handling and maneuvering accidents caused by human errors;
- Reduce the number of people at risk at sea (less accidents, health issues, etc.)
- Allow crew to focus on short voyages versus long-distance voyages;

- Reduce the need for crew at a time it is increasingly difficult to recruit;
- Eliminate suicides and crime among crews;
- Reduce the cost of voyages by reducing/eliminating crew cost on certain routes.

The greatest opportunities may be on small cargo vessels to enhance delivery opportunities to more locations and to reduce ship losses. A focus on smaller vessels could help enhance voyages in/out of smaller ports that have suffered during a period of every larger vessel and increasingly fewer ports that can handle them. That would have the added benefit of increasing maritime transport while reducing port congestion.

The SubSeaSail approach is to develop multihull, small load cargo sailing vessels that are dramatically reduced CAPEX cost and minimize OPEX by eliminating on-going costs of crew and fuel. By reducing both CAPEX and OPEX, smaller vessels can be deployed to provide more service to more locations. The ability to submerge will reduce risks such as those related to piracy and climate change, which is expected to result in increasingly frequent and severe storms, thereby reducing delivery and insurance risks.

Multihull vessels are inherently fast and have good load carrying ability but suffer from a risk of catastrophic capsizing. SubSeaSail has patents issued and pending to mitigate this risk for autonomous multihull vessels. The creation of stable, performance, cargo-carrying, multihulled vessels will change the economics of cargo vessel production and operation for some applications and destinations. It will be well suited for certain uses including expeditionary forces supply, humanitarian aid, inter-island and remote island delivery, and research.

SubSeaSail small, multihull vessel design attributes compared to traditional monohull cargo vessels include:

- Low CAPEX and OPEX permit fleets to help de-risk the supply chain;
- Low signature (acoustic, IR, radar, visual);
- Ability to submerge to hide from bad actors/weather;
- If vehicle capsizes, ability to right itself, re-surface, and sail again;
- Given smaller vessel sizes, less likely to create a catastrophic accident situation;

- With low draft, the ability to sail into smaller (i.e., less dredged) and/or damaged ports;
- Ability to act as secure, offshore storage when vessels arrive (critical if port facilities have been damaged);
- Ability to deliver to the beach (when needed);
- Can be utilized outside of normal traffic lanes to reduce likelihood of collisions—more point-to-point deliveries;
- Multi-use platforms including:
  - Cargo delivery
  - Communications gateway
  - Data gathering sensor packages
  - UAV/quadcopter landing & UUV delivery/docking with re-charging

Background: Modern vessels that have been designed to a low wake specification tend to be multihulls only partly in order to utilize interference wave suppression. The principal wave resistance advantage of catamarans is due to the very slender waterplane area of each hull. This has been proven by evolution of designs where propulsive efficiency is the ultimate criteria, for example, kayaks and rowing shells.

In late 2021 SubSeaSail applied for two patents on unique technologies relevant to its multihull design and direction. These are patents pending and, therefore, are described below without reference.

The first patent pending elates to a *method and apparatus for reducing a heeling moment of a sailing vessel*. It includes a series of claims related to a method to reduce a heeling moment as the wind acts on the sail of a sailing vessel. Generally, it will allow the mast to lean leeward, thus reducing the heeling moment.

Sailing vessels universally have a heeling, or roll, moment applied to their hulls by virtue of an aerodynamic force generated by the vessels' sails, mast, or wing (collectively, the "rig") during the normal generation of thrust used to propel the vessel. This heeling moment must be resisted by the vessel or the vessel will simply roll over to the horizontal. The action of a monohull sailing vessel to resist a rolling moment is inherently self-restoring because more roll moment (caused by stronger wind) generally generates a greater righting moment. Rolling the vessel and particularly the mast, sails, and/or wing actually reduces the rolling moment. If the wind increases, the vessel may roll further, but the equilibrium angle is always less than fully horizontal, thus ensuring the vessel will right itself with lessening wind speed, providing that the vessel doesn't take on water when rolled significantly. On the other hand, a multihull vessel (i.e., a catamaran, 2 hulls; or a trimaran, 3 hulls), will eventually reach a roll angle where it will continue rolling to full horizontal (i.e., capsize), even without wind forces. The angle at which the multihull vessel will capsize may be referred to as a "capsize angle" and means that the vessel will not right itself after the capsize angle is exceeded—obviously a catastrophic situation for either a crewed or uncrewed vessel.

SubSeaSail has conceived a type of sailing vessel that reduces the heeling moment, especially for multihull vessels, so that sailing vessels may continue sailing in conditions that would normally roll a single hull vessel to extreme angles, or that would capsize a multihull vessel (Fig. 4).

The second patent pending relates to a *method, apparatus, and system for recovering a sailing vessel*. It describes a self-righting sailing vessel. The self-righting sailing vessel may determine the occurrence of several predetermined events. In combination with the submerging capability being designed into the vessel, the self-righting sailing vessel will be able to submerge when faced with a severe storm/typhoon, when in a collision

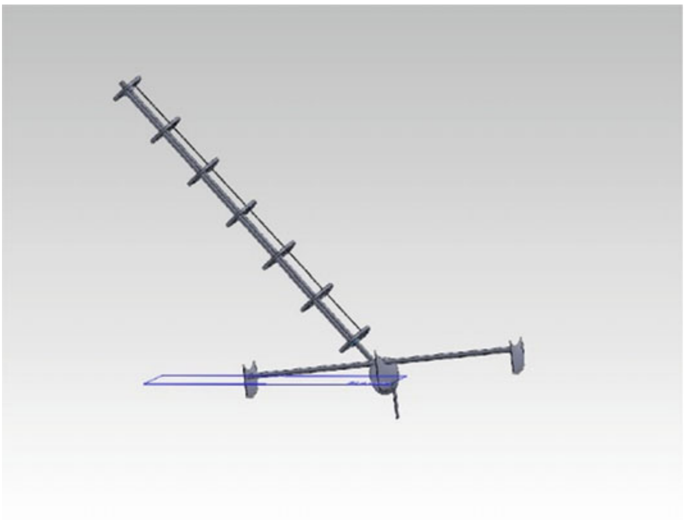

Fig. 4 Trimaran with rolled rig in response to heeling moment (*Source* SubSeaSail LLC)

course with another vessel or a large marine mammal, to hide from detection, etc. If for some reason the vessel is tipped to the point of capsizing, for example due to a rogue wave or high gusts that cannot be handled by the heeling wingsail, the self-righting sailing vessel will be able to right itself underwater. The self-righting sailing vessel will be configured such that its rig is more buoyant than the rest of the vessel when the vessel is completely submerged beneath the water, causing the vessel to move toward an upright position while underwater. When the vessel is pointing toward an upright position, the vessel may begin ascending until it surfaces and is ready to continue sailing on top of the water.

Autonomous marine vessels will become more ubiquitous, as they offer capabilities unmatched by crewed vessels, such as the ability to undertake long voyages without the need for on-board personnel, food or water. In some cases, even fuel is not required, as in the case of uncrewed sailing vessels. Autonomous sailing vessels may be particularly useful in both commercial and military applications, as they are quiet and can operate for long time periods without human intervention.

Some first use opportunities could include expeditionary force resupply, humanitarian aid delivery, inter-island and remote island delivery, and delivery of small loads of specialty liquids for research and industrial purposes. Autonomous, 100% energy harvesting, small load vessels will require minimal investment by ports to accommodate them and, in some cases, may help resuscitate small to medium-sized ports that have been suffering in the shadow of the big ports.

6 Conclusion

SubSeaSail represents a "Case Study" of how technology can be used to dramatically improve ocean observation (HORUS vessel) and complement highly efficient, large tankers with small, specialty multihull vessels (HERMES) for applications that are unserved or underserved today. It is a BlueTech company that is developing innovative, differentiated, autonomous sailing vessels augmented by solar power to be 100% energy independent. The vessels SubSeaSail is developing depart from traditional monohull vessels by being either a monohull semi-submersible observation vessel (HORUS) or multihull surface vessel (HERMES) focused on smaller loads.

The current HORUS vessel is light and easy to deploy, retrieve, and store. It will be able to "hear" via acoustic array and/or see via cameras if it is being approached to be able to submerge to avoid bad actors, or know via its weather station (or remote command) that it should submerge to avoid bad weather, or using AI or remote command, submerge to listen and monitor underwater.

HERMES will be bigger and need to deal with collision avoidance. However, the submerging capability will be very important to avoid bad actors/weather, avoid collisions, and to act as offshore, secure storage. HERMES could be used in smaller ports that have factories/refineries that could benefit from point-to-point deliveries thereby reducing reliance on a small number of hub ports, reducing port infrastructure and dredging needs, and reducing road traffic.

Important autonomy issues need to be addressed. Nevertheless, it is not "if" but "when" autonomous vessels will be accepted into the global ocean logistics enterprise. The convergence of autonomy, decarbonization, and sailing offer one route into the future. SubSeaSail looks forward to working with others to promote a successful integration as we move toward decarbonized shipping that can provide service even to remote islands.

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CHAPTER 5

Crowdsourced Bathymetry and Automation: An Evolutionary Process to Improve the Means of Navigation

Steven Geoffrey Keating

Billions of measurements for millions of square kilometres.
Quote from Dr. Mathias Jonas, Secretary General of the International Hydrographic Organization

1 Introduction and Scope of Chapter

This chapter investigates how an emerging concept called Crowdsourced Bathymetry (CSB) can leverage international cooperation and automation to improve the means of navigation in a manner fully consistent with the Law of the Sea (i.e., body of international law comprised of customary international law and treaties; Rothwell & Stevens, 2010,

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21), including the United Nations Convention on the Law of the Sea (UNCLOS, 1982). CSB is defined as "the collection and sharing of depth measurements from vessels, using standard navigation instruments, while engaged in routine maritime operations" (IHO, 2022a). Crowdsourcing is becoming a ubiquitous, well-recognized methodology for "recruiting or allowing tasks to be performed by voluntary groups of people or to the general public, often by asking for help on the internet" (Cambridge University Dictionary, 2022a).

This chapter also examines the *interest tensions* relating to CSB. These exist where a resource, technology, or discovery produces divergent interests among intersecting or competing agents. For example, there is an undeniable interest tension between the growing demand for marine protein by a burgeoning population and the realization that marine life is not inexhaustible and catch limits on marine species is necessary for resource conservation. "A number of issues have emerged as particular concerns at this stage in our attempts to manage river fish, fisheries and their environment. A tension continues to exist between use and conservation" (FAO, 2004).

Interest tensions relating to CSB are those associated with the objective to maximize public access to bathymetric data as opposed to those which seek to protect coastal State (CS) sovereignty in the Territorial Sea (TS) and sovereign rights to living and non-living resources in its Exclusive Economic Zone (EEZ).

UNCLOS defines the territorial sea as "that zone which extends from the baseline up to a limit not to exceed 12 nautical miles in which the sovereignty of a coastal State extends (subject to other provisions of UNCLOS and other rules of international law) beyond its land territory and internal waters" (UNCLOS, 1982, arts. 2, 3).

The EEZ is "an area beyond and adjacent to the territorial sea, subject to the specific legal regime established in this Part, under which the rights and jurisdiction of the coastal State and the rights and freedoms of other States are governed by the relevant provisions of this Convention" (UNCLOS, 1982, art. 55). "The exclusive economic zone shall not extend beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured" (UNCLOS, 1982, art. 57).

CSB, which offers a unique opportunity to leverage the collateral benefit of routine soundings consistent with existing maritime best practices, is separate and distinct from hydrographic surveying and Marine Scientific Research (MSR), and can be used without intruding upon the rights of CSs under the Law of the Sea. The chapter encourages CSs to support the broadest utilization of CSB that will enable States, international organizations (IGOs), and other Blue Economy stakeholders to have access to an increasing set of bathymetric data, even if such ultimate stakeholders later use the data to advance science in the maritime domain.

The Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) describes the Blue Economy as seeking "to promote economic growth, social inclusion, and the preservation or improvement of livelihoods while at the same time ensuring environmental sustainability of the oceans and coastal areas" (IOC, 2022).

The maritime domain is recognized as being "all areas and things of, on, under, relating to, adjacent to or bordering on a sea, ocean or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, vessels and other conveyances" (Keating, 2018; The White House, 2013).

This chapter is divided into the following sections: (1) Introduction, (2) Perspectives on Bathymetry, (3) Safety of Navigation (SoN) Information Evolves from a Unilateral to a Cooperative Multilateral Model, (4) Framing CSB within the Law of the Sea, (5) Discussion of Interest Tensions, and (6) Concluding Thoughts and Recommendations.

2 Perspectives on Bathymetry

For millennia, humans have gazed into the water to gage its depth. Ancient Egyptian carvings depict a man using a slender pole to "sound" the depth in waters off of present-day Somalia (Elhassan, 2015). Interestingly, other primates have demonstrated tool use to measure depth; researchers have observed gorillas using sticks to determine water depth (Breuer et al., 2005; Pickrell, 2005).

2.1 Questions on the Homo Sapiens' Evolutionary Processes

Knowledge of water depth was arguably essential to understanding two, fundamental questions advancing homo sapiens' evolutionary processes:

1. 'Is the water too deep to walk through?' This knowledge would be essential to the safe fording of streams and rivers upon which hominid migration depended. "It is generally believed that apes do

not swim and avoid entering water. Therefore, if our ape ancestors preferred to be on land then our earliest human ancestors would do the same" (Trethewey, 2018a, 2018b, 4). The primordial concern persists today in figures of speech such as "out of your depth" or "in over your head," meaning "in water that is so deep that it goes over your head when you are standing" (Cambridge University Dictionary, 2022b). Chimpanzees, the nearest genetic relative to humans, generally demonstrate fear of water ("chimps cannot swim and most chimps are terrified of immersion", Safina, 2020, 319);

2. As human ancestors developed watercraft, 'Is the water deep enough to safely float a vessel?' This understanding allowed for relatively safe exploration and transportation by water. Early voyages from the time of Queen Hapshetsut of the 18th Dynasty of Egyptian Royalty would have sailed in relatively shallow waters. "[T]he queen sent five ships, about 70 feet long with 18-foot beam. They had to be shallow-draft to sail the reef-choked inshore channels of the Red Sea, to beach and Handle cargoes" (Villiers et al., 1973, 23).

2.2 Bathymetry

Sometimes the water column is relatively transparent, enabling visual sensing to approximate depth. Other times, the water column is cloudy, turbid, preventing visual perception. Therefore, mankind has progressively developed tools to remotely sense depth, ranging from lead lines on natural fiber rope to electronic echo sounding (Grządziel & Wąż., 2018). As early at the Fifth Century B.C.E., the Greek historian Herodotus recorded that Greek seafarers were using leadlines (The Mariner's Museum, 2008).

"Bathymetry is the study of depths of water in oceans, lakes, and seas from the surface to the bottom" (Mayer, 2016). The International Hydrographic Organization (IHO), an international consultative and technical body, defines *bathymetry* as "[t]he determination of ocean depths. The general configuration of the SEA FLOOR as determined by profile analysis of depth data" (IHO Hydrographic Dictionary, 2021a). Bathymetry is a subset of *hydrography*, defined as:

> the branch of applied sciences which deals with the measurement and description of the physical features of oceans, seas, coastal areas, lakes and rivers, as well as with the prediction of their change over time, for the

primary purpose of safety of navigation and in support of all other marine activities, including economic development, security and defence, scientific research, and environmental protection. (IHO Hydrographic Dictionary, 2021b)

Hydrography includes not only bathymetry, but also the shape and features of the shoreline; the characteristics of tides, currents, and waves; and the physical and chemical properties of the water itself. (National Ocean Service, 2021)

2.3 Hydrographic Information

Bathymetric and hydrographic information are also recognized subsets of geospatial information, the latter which the United States defines as "information that identifies the geographic location and characteristics of natural or constructed features and boundaries on or about the earth and includes:

A. data and information derived from, among other things, remote sensing, mapping, and surveying technologies; and
B. mapping, charting, geomatics data, and related products and services (U.S. Code, 2021).

2.4 Recognition by the UN Committee of Experts on Global Geospatial Information Management (UN-GGIM)

The nesting of marine geospatial information concept is also recognized by the United Nations (UN) in its UN Committee of Experts on Global Geospatial Information Management (UN-GGIM) under which operates a dedicated UN-GGIM working group on marine geospatial information (UN-GGIM, 2022) (Fig. 1).

The next section examines the evolution of navigational information from closely held State interests to broadly shared data intended to reduce risks for mariners.

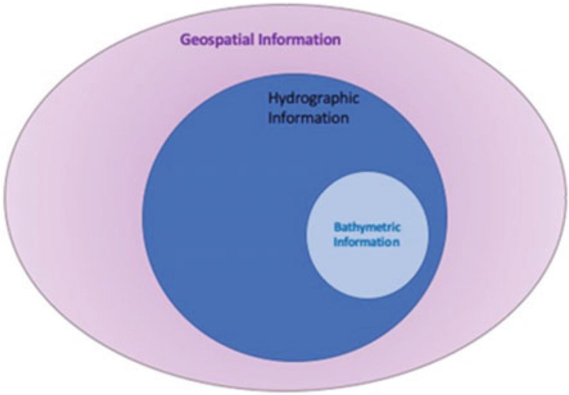

Fig. 1 Nested sets of geospatial information (*Source* Author)

3 SoN Information Evolves from a Unilateral to a Cooperative Multilateral Model

Prudent navigators use all available means for navigation and learn from those who have gone before them. "The art and skill of navigation was probably learned well before the days of writing, by word of mouth from master to pupil at first, and then by many years of experience. To be an experienced navigator involved feats of memory and was a great achievement indeed" (Trethewey, 2018a, 2018b, 14).

The first recorded sailing instructions are said to have originated in "ancient times," and the earliest preserved nautical charts, called *Portolan charts*, originated sometime in the thirteenth century (BSH, 2022; Nicolai, 2015). Because the creation of early charting was costly and time-consuming, mariners often protected their nautical charts as intelligence or State secrets. "[C]ompared with previous centuries of ocean navigation, in which nautical charts were carefully guarded as state and industry secrets" (Arctur, 2011). For example, an edict of a Portugese King, dated 13 November 1504, authorized execution for "anyone revealing discoveries or plans for missions of explorations." (Bergreen, 2003, 24–25).

Over time, the international community evolved toward a more cooperative model for improving the means for safer navigation (Arctur, 2011; Brown, 1983). Avoiding maritime disaster has long motivated cooperation between seafaring nations. For example, the International Convention for the Safety of Life at Sea (SOLAS) came into being as a direct response to the loss of the *Titanic*, which struck an iceberg on 15 April 1912 and sank with a loss of approximately 1,500 lives (NOAA, 2018; Safety4Sea, 2021). Ironically, the echo sounding device which revolutionized the science of bathymetry and navigation safety was invented by Alexander Behm, a German physicist who had been trying to use sound waves to detect icebergs in order to prevent the very kind of disaster which befell the Titanic. While Behm did not achieve his principle objective of detecting ice in the horizontal plane, he was able to reasonably determine depth of the water column in the vertical plane. Behm then patented this technology, which over the past century has been used on hundreds of thousands of vessels to reliably determine water depth (Wille, 2005, 14–19).

Throughout history, humans have developed technology to alert mariners of dangers through communication by signal or symbol. By receiving these warnings at a distance, either in time or position, mariners approaching a new location could avoid hazards which previously befell others. One magnificent example of such technology was the Great Light of Pharos, an ancient structure which is reported to have reached 133 meters in height and warned vessels of dangerous shoals in the Nile Delta near Alexandria, Egypt (Trethewey, 2018a, 2018b, 14). While early mariners may have had primal fears of sailing into the unknown waters beyond the horizon, the irony is that open sea voyages may have presented weather-related risk, but were "mostly free from the dangers of reefs and other underwater dangers" (Trethewey, 2018a, 2018b, 14). The construction of the Great Pharos of Alexandria demonstrated a policy trend to share information with outsiders in order to make voyages to Alexandria less risky. The construction of the Great Pharos would likely have improved commerce between Alexandria and foreign merchants. This technological advancement represented a cooperative approach to access navigational information.

The Twentieth century witnessed numerous, cooperative, multilateral efforts to establish institutional mechanisms to improve navigational safety: SOLAS in 1914, updated in 1929, 1948, 1960, and 1974 (IHO Hydrographic Dictionary, 2021b; SOLAS, 1974); 1972 Convention on the International Regulations for Preventing Collisions at Sea (COLREGs, 1972); and the 1978 International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW, 1978). These treaties demonstrate the efficacy of international standards, cooperation, and information sharing to reduce maritime risk while protecting the sovereign rights of individual States. Cooperative sharing of marine geospatial information, including the "the production of up-to-date charts has had a positive impact on economic development in coastal areas, stimulating trade and commerce and the construction or modernization of harbor and port facilities" (Roach, 2015, 291–292).

3.1 Precursors to Cooperative Bathymetry

Another Twentieth-century effort specifically focused on Bathymetry: the General Bathymetric Chart of the Oceans (GEBCO). While the genesis of GEBCO may be traced to activities involved with both oceanography (defined as "[t]he study of the sea, embracing and integrating all knowledge pertaining to the SEA's physical boundaries, the chemistry and physics of sea water, marine biology, and submarine geology. In strict usage oceanography is the description of the marine environment, whereas oceanology is the study of the oceans and related sciences", IHO Hydrographic Dictionary, 2022a), and physical geography (i.e., "the study of the natural features of the earth, such as mountains and rivers", Cambridge University Dictionary, 2022c).

GEBCO had its origins in the 7th International Geographic Congress held in Berlin in 1899 with the intent to "develop and international nomenclature and systematic terminology for sub-oceanic relief features" (GEBCO, 2003, 1). However, it was not until 1903 when His Serene Highness (HSH) Prince Albert I of Monaco provided the institutional vision and financial support to organize and fund what became known as GEBCO (GEBCO, 2003, 2, and Sound Images of the Ocean, 66).

Since 1903, GEBCO has dedicated efforts to expand knowledge of the seabed. Consistent with its founding purpose, GEBCO is intended to "provide the most authoritative publicly-available bathymetry of the world's oceans" (GEBCO, 2021). GEBCO operates under the joint authority of the International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) (GEBCO, 2021). Throughout its history, GEBCO has received sounding data from various nations and ships (GEBCO, 2003). "Due to his position and the relationships he maintained with other Sovereigns and Chiefs of State, the Prince [of Monaco] was able to obtain bathymetric information rather quickly from a variety of ships, namely military, scientific, commercial and cable-laying vessels" (GEBCO, 2003).

3.2 Cooperative Hydrography

The International Hydrographic Organization (IHO) is an exemplar of multilateral effort to improve the means of marine navigation. The IHO was originally conceived as the International Hydrographic Bureau (IHB) and formed by 18 States in 1921 to achieve the following objectives:

1. to establish a close association between Hydrographic Offices (HOs) [of Member States];
2. to encourage the adoption of the best methods for carrying out hydrographic surveys and coordinating hydrographic work, with a view to rendering navigation easier and safer throughout the world;
3. to obtain uniformity as far as possible in hydrographic documents, so that mariners may use publications issued by other countries (Bermejo Baró, 2019, 2).

The IHB's original 18 Member States represented a diversity of both industrialized nations and developing nations (Bermejo Baró, 2019). By 1922, Spain and Sweden, Italy, Egypt, and the United States of America (USA) joined the IHB (Bermejo Baró, 2019). The IHB changed its structure and its name to the IHO in 1967 (Convention on the IHO, 1967).

At present, the IHO has 98 Member States with the mission "to create a global environment in which States provide adequate and timely hydrographic data, products and services and ensure their widest possible use…" by applying the vision "to be the authoritative worldwide hydrographic body which actively engages all coastal and interested States to advance maritime safety and efficiency and which supports the protection and sustainable use of the marine environment" (Preamble of the Convention on the IHO, 1967).

3.3 Cooperative Multidisciplinary Efforts

Both GEBCO and the IHO came into existence through the visionary patronage of HSH Prince Albert I of Monaco. The Principality of Monaco continues to graciously support the progress of GEBCO and the IHO. Although GEBCO predates the IHO, the IHO became a sponsor of, and a direct contributor to, the GEBCO objectives. Following the publication of the 2nd Edition of GEBCO, the Principality of Monaco asked the IHB to take on the management of GEBCO. The International Hydrographic Conference of 1929 and 1932 considered the request and directed the IHB "to maintain the GEBCO up to date in accordance with the specifications established by the Prince of Monaco" (Bermejo Baró, 2019, 15; GEBCO, 2021).

This multidisciplinary cooperation is reflected in the partnership between the IHO and the IOC to oversee the work GEBCO, demonstrating the commitment to maximize our knowledge of the oceans through the democratization of bathymetric data. Two of the stated objectives of the IHO are: "(a) To promote the use of hydrography for the safety of navigation and all other marine purposes and to raise global awareness of the importance of hydrography; (b) To improve global coverage, *availability and quality of hydrographic data, information, products and services and to facilitate access to such data, information, products and services*" (italics added for emphasis, Convention on the IHO, 1967, Article II). This work also complements the objectives of the United Nations efforts regarding ocean science and the SEABED 2030 project discussed below.

The UN Decade of the Ocean evolved from a proposal made by the IOC to establish a ten-year period that would be dedicated to ocean science for sustainable development, resulting in the UN General Assembly proclaiming the *United Nations Decade of Ocean Science for Sustainable Development* beginning on 1 January 2021 (Ryabinin et al., 2019, 3). The vision statement of the UN Decade of the Ocean is "the science we need for the ocean we want" (The Ocean Decade, 2021).

Seabed 2030 is a collaborative project between GEBCO, the Nippon Foundation, and other entities to facilitate the complete mapping of the world's ocean by the year 2030, and to compile all bathymetric data into the GEBCO Ocean Map grid, made freely available online (MundoGEO, 2021). Launched in 2017 at the United Nations Ocean Conference, the Nippon Foundation-GEBCO Seabed 2030 Project is officially endorsed as a Decade Action of the UN Decade of Ocean Science for Sustainable Development (Seabed 2030, 2021a, 2021b). In order to divide the challenge of organizing efforts to map the sea floor, Seabed 2030 leverages the collaboration of one Global Center and four (4) regional Centers (Southern Ocean, Atlantic & Indian Oceans, the Arctic & North Pacific, and the South and West Pacific), in addition to the IHO's Data Centre for Digital Bathymetry (Seabed 2030, 2021c). Seabed 2030 is an ambitious initiative—achieving its goals will require a cooperative approach that leverages every platform that can collect bathymetric information in a manner consistent with the Law of the Sea and sound maritime practices. Some data will be collected by scheduled, purposeful hydrographic surveys; however, the small numbers of dedicated survey vessels necessitates the aggregation of data that may have been collected under other conditions such as contemplated by CSB.

The IHO Data Centre for Digital Bathymetry (DCDB) is an integral element in the system of international cooperation to maximize bathymetric knowledge, advancing the objectives of Seabed 2030 and GEBCO. Established by the IHO in 1990 and located at the National Oceanic and Atmospheric Administration's National Centers for Environmental Information in Boulder, Colorado, and currently led by Ms. Jennifer Jencks, the DCDB "archives and shares, freely and without restrictions, depth data acquired by hydrographic, oceanographic and other vessels during surveys or while on passage" (Seabed 2030, 2021d).

The DCDB is an official repository for the IHO, aiding the success of both the IHO Crowdsourced Bathymetry initiative and the Atlantic Ocean Research Alliance's (AORA's) Atlantic Seabed Mapping International Working Group initiatives (AORA-CSA, 2016). The IHO's Inter-Regional Coordination Committee oversees the work of the Crowdsourced Bathymetry Working Group (CSBWG), whose objectives include but are not limited to, "maintain the IHO publication B-12—*IHO Guidelines on Crowdsourced Bathymetry*… and… monitor Member State and Regional progress regarding development of best practices and CSB initiatives…" (IHO CSBWG Terms of Reference, 2021).

According to the DCDB website, the DCDB holds more than "30 terabytes of primarily unedited single and multibeam bathymetric data contributed by industry, government, academia, and crowdsourced efforts" (Seabed 2030, 2021d). The DCDB is also the main archive of bathymetric data aggregated in support of Seabed 2030 (Seabed 2030, 2021d). Thus, it is important for the DCDB to be able to differentiate CSB data from data that is the product of systematic survey efforts, especially where the geospatial location of the data falls within the TS of a CS. The legal implications of this will be discussed further below. The DCDB exemplifies the multilateral, democratization of knowledge, obtained through current technology.

4 Framing CSB Within the Law of the Sea

The following subsections provide a definition of key concepts, including CSB, a distinction between CSB and Hydrographic Surveying and Marine Scientific Research, as well as how the IHO Actively Supports CSB.

4.1 Defining Key Concept

CSB, as well as SNI, MBES, RMO, are defined and detailed in the following subsections.

4.1.1 Definition of CSB

CSB is defined as "the collection and sharing of depth measurements from vessels, using *standard navigation instruments (SNI)*, while *engaged in routine maritime operations (RMO)*" (IHO, 2022a). This definition appears straight-forward but has raised some debate for reasons explored below.

4.1.2 SNI Is Not Defined in UNCLOS, SOLAS, or IHO Documents

Some proponents of CSB suggest the term term SNI is synonymous with "shipborne navigational systems and equipment" as described in SOLAS Chapter V, Regulation 19 (SOLAS, 1974, Chapter V, Reg. 19.2). This means that the vessel is using navigational systems and equipment required by international convention and best maritime practices. One of the required navigational systems and equipment for vessels of 300 gross tons, or more is an "echo sounding device or other electronic means, to measure and display the available depth of water" (SOLAS, 1974, Chapter V, Regulation 19.2.2.3). Gross tonnage refers to the total measured cubic volume, i.e., 100 cubic feet per ton of 2240 lbs., based on varying formulas, as established by the International Convention on Tonnage Measurement of Ships, 1969). The term "echo sounding" may also appear as "echo sounding" or "echosounder" in this chapter, depending upon the sources cited.

For nearly a century, the Single Beam Echo sounding device (SBES) has been the standard navigational instrument for determining the depth of the water column ("the very first systematic survey of a world ocean with echo sounding bathymetry…took place from 1925–1927", Wille, 2005, 16–18). A single beam echo sounder (SBES) is defined as "an echo sounder that transmits and receives a sound pulse providing a single spot depth, as opposed to a Multi Beam Echo Sounder" (IHO Hydrographic Dictionary, 2022b). Some experts argue that Multi Beam Echo Sounders (MBES) should not associated with SNI, as these are specialized systems designed for hydrographic surveys and deep-water bathymetric data collection. However, this argument fixates on labels rather than capability, as more vessels employ MBES and SBES become more precise.

4.1.3 The IHO Defines an MBES As:

A type of Swath(e) Sounding System in which the equipment emits a timed Pulse of sound that is narrow in the fore-aft direction and wide in the across track direction. The reflected sound is received by several Receivers arranged as an Array. By use of Signal processing of the Signal received at combinations of the Receivers a much larger number, potentially many hundreds, of Acoustic receive Beam angles are formed. For each received Beam the time interval between the emission and reception of the reflected sound is converted into a Range. Geometry is then used to convert each Range and receive Beam angle to depths and also to position these depths within the Swath(e) on the Sea Floor. MBES systems may also be referred to as beam-formers (IHO Hydrographic Dictionary, 2022c). While MBES Systems may be the preferred methodology for doing deep ocean bathymetric surveys, providing the dense data sets per survey line, SBES are still used for hydrographic surveying to this day.

Some CS Hydrographic Offices (HOs) want to exclude MBES data from CSB unless the CS provides prior permission. This approach is problematic for the following reasons: (1) neither SOLAS nor UNCLOS address the type of echo sounding device that may or may not be used for RMO; (2) many hydrographic surveys are still conducted with SBES, and (3) MBES is becoming more prevalent among non-survey vessels. CSB should be sensor *agnostic* and made publicly available as long as the vessel is conducting RMO and not a prescribed survey.

4.1.4 RMO Is Likewise Not Defined in UNCLOS, SOLAS, or Other Conventions

Perhaps as challenging of a term of art to describe as SNI, for the purposes of CSB, RMO are those operations where the echo sounding device is not operated for the principal purpose of conducting a bathymetric or hydrographic survey but where it is incidental to the safe navigation of the vessel.

The echo sounding devices that SOLAS Chapter V compliant vessels operate automatically "ping" a signal downward toward the seabed and continually measure the time difference between signal output and return signal. Based upon the speed of sound in water, corrections for interference from external influences like salinity, temperature, ship noise, etc., the echo sounder calculates the depth of the water from the transducer. On many vessels, the depth of water is displayed at the bridge for navigation but not necessarily recorded. However, on vessels which are required by SOLAS to carry a Voyage Data Recorder (VDR) (SOLAS, 1974, Chapter V, Regulation 20), these VDRs retain up to 48 hours of sounding data on the designed free floating VDR device (IMO, 2012, section 5.4.3). While VDRs are not required on all vessels at sea, they are required on all passenger ships, roll-on roll-off ships, and ships, other than passenger ships, of 3,000 gross tonnages and upwards constructed on or after 1 July 2002 (SOLAS, 1974, Chapter V, Reg. 20.1). Based upon this requirement, VDRs may also be considered part of SNI. Nothing in SOLAS nor UNCLOS precludes a vessel from storing sounding data in digital form. In fact, new Voyage Data Services are arising to monitor vessel positional and performance data, so echo sounding data may also be captured by such services as well.

According to the IMO "[t]he purpose of a voyage data recorder (VDR) is to maintain a store, in a secure and retrievable form, of information concerning the position, movement, physical status, command and control of a ship over the period leading up to and following an incident having an impact thereon…This information is for use during any subsequent safety investigation to identify the cause(s) of the incident" (IMO, 2012, Annex 21, 2).

The VDR construct leverages data collected for SoN to inform boards of inquiry on causal chains for maritime incidents or disasters. The VDR construct also represents the principle that echo sounder data may be stored and retrieved for beneficial purposes, using previously collected data to improve understanding of the casualty and hopefully prevent similar events in the future. The rationale for CSB is analogous, to preserve and share sounding data, “bathymetric data in a format that is useful to the broadest possible audience” (IHO, 2022a, 7).

4.1.5 Automation Will Enable CSB

Echo sounders generally operate automatically to display immediate depth readings, but in most cases the presentation of the depth is momentary. Not all depth data is permanently stored to a VDR. As a result, proponents of CSB support the development and distribution of data loggers (DLs) which can actually store more data than a SOLAS-mandated VDR. Professor Brian Calder,Associate Director of the University of New Hampshire Center for Coastal & Ocean Mapping/Joint Hydrographic Center Jere A. Chase Ocean Engineering Lab has developed a prototype DL, called the Wireless Inexpensive Bathymetry Logger (WIBL). Below is a paraphrase of an online Q & A, in which Dr. Calder explained the WIBL as follows:

> The WIBL project (Calder, 2022) is an open-source (and open-hardware) attempt to provide a full-stack Volunteer Bathymetric Information (VBI) collection system. That is, it provides reference designs for the hardware data logger itself, the manufacturing files required to physically make them, and the software (firmware for the logger, data transfer mobile app, and cloud data processing and archive submission) to make the whole system run. The repository for the project is freely available online (WIBL project, 2022). The unit leverages standard marine electronics interfaces, and therefore can be used to log any data that appears on the two most common marine data network interface types. The WIBL system should store the data until a regular port call, at which time the data can be uploaded to the cloud for transfer to a Trusted Node (IHO, 2022a, 10) or directly to the DCDB.

The value of the WIBL Project and DLs in general is that they automatically, and independent of crew activity, transmit echo sounding output to an easily installed onboard storage system for retaining and disseminating bathymetric data. This is data that would otherwise be lost in the wake of the vessel’s track. When contemplating thousands of vessels making multiple voyages each year, these data points will prove valuable to a wide array of stakeholders in the years to come, especially as some of these vessels will operate in remote areas lacking baseline depth soundings.

4.1.6 *Opportunistic Platforms for CSB*

At any given moment, thousands of vessels collect sounding data as part of SOLAS-mandated or standard navigation practices. The incidental benefit of potentially billions of data points cannot be ignored, but CSB should be construed as the aggregation of bathymetric data, the collection of which is incidental to RMO and not the principal purpose for the intended course of the vessel. This caveat will be explored further when distinguishing CSB from hydrographic surveying or MSR. Broad categories of vessels are listed below as non-exclusive examples of opportunistic platforms:

Merchant vessels in transit. As of 2021 independent reports identify more than 5,400 container ships (Statista, 2021) and over 2,000 tankers (Statista, 2022) operating worldwide. Many such vessels follow standard routes, but even fixed shipping routes must alter to avoid weather events, environmental hazards, or limit harm to whales endangered by increased maritime traffic (NOAA, 2012; *The Guardian*, 2022). Modified routes may transit over unsurveyed waters, so the aggregation of bathymetric data from these passages would fill voids with a baseline of imperfect data. Nonetheless, even if a merchant vessel maintains a fixed route, CSB may assist change detection, especially if the vessel is transiting shallower waters in which a SBES may be precise. CSB-enabled change detection can advance the concept of smart ports.

A fleet of over 300 passenger vessels represents a growing area of activity for CSB (Cruise Mummy, 2022). Passenger ship routes may vary based upon market expectations, and a growing demand for expedition-type cruises will put cruise vessels in more remote areas. While there may be inherent risks of navigating passenger ships in unsurveyed waters, the ultimate aggregation and dissemination of such CSB will also advance collaborative hydrography.

Privately owned vessels and superyachts represent a relatively untapped fleet of coastal and ocean-capable watercraft to contribute data to CSB. While large, superyachts are generally smaller than most merchant ships. Having shallower drafts than most cargo ships, they may also travel to smaller ports, and remote, unsurveyed areas, providing valuable CSB to the *DCDB*.

Fishing industry vessels, which may be transiting further from home-ports due to fish stock migration will also present an opportunity for aggregation of CSB data to the DCDB. Some fishery vessels use MBES (Schneider von Deimling & Weinrebe, 2014, “Conclusions”), raising the question of whether the sounding data obtained by MBES on a fishing vessel during authorized fishing operations, a fisheries survey, or in transit from port to fishing ground should be recognized as CSB. Assuming the fishery vessel is conducting RMO consistent with its purpose, and the vessel is required by SOLAS or navigational best practices to be operating an echo sounding device, then it would be reasonable to treat such data as CSB.

Proponents of CSB also suggest the use of research vessels to acquire passage sounding (IHO, 2022a, 2, 3, 34) data while in transit to or from the survey or research locations. Contrary views exist as to these vessels because they may employ MBES and carry specially trained crews. These concerns are addressed in Sect. 5.

4.2 Distinguishing CSB from Hydrographic Surveying and Marine Scientific Research

Some notes on how CSB should not be conflated with hydrographic surveying and MSR, along with IHO's active support of CBS are provided below.

4.2.1 CSB Should Not Be Conflated with Hydrographic Surveying, Despite the Fact That Both Seek to Measure Water Depth

UNCLOS specifically references Hydrographic Surveying in Art. 21 (Innocent Passage) and Art. 40 (Transit Passage through International Straits) but UNCLOS does not define *hydrographic surveying* (Tanaka, 2015, 362) and this absence of clarity in the convention has led to years of scholarly debate. The UN recognizes the IHO as a competent international organization relating to UNCLOS and hydrography (UNCLOS, 1982, Annex II, Commission on the Limits of The Continental Shelf, Art. 3, para. 2), and the IHO does provide a workable definition for hydrographic survey as:

> A survey having for its principal purpose the determination of data relating to bodies of water. A hydrographic survey may consist of the determination of one or several of the following classes of data: depth of water; configuration and nature of the bottom; directions and force of currents; heights and times of tides and water stages; and location of topographic features and fixed objects for survey and navigation purposes. (IHO Hydrographic Dictionary, 2022d)

The critical difference between CSB and Hydrographic Surveying is that CSB is the result of data collection *incidental* to the safe navigation of a vessel doing RMO, *collection not being the principal purpose of the vessel's track*. The question of whether "the principal purpose" is a quantifiable concept that could be determined by percentage is worthwhile. For example, if a collateral benefit for taking a route would still enable the principal success of the purpose of the RMO (e.g., cargo delivery) but would also enable the collection of new lines of bathymetric data, one can argue that the added data is not the principal purpose of the voyage but an incidental benefit. A practicable example is that a cruise ship routinely goes to polar regions and targets the expedition cruise market, would the fact that the cruise ship made slight course adjustments in order transit unsurveyed waters now alter the characterization of the activity as a "hydrographic survey?" This chapter argues against such a conclusion because the principal purpose of the vessel's voyage is to take passengers to experience glaciers, icebergs, and arctic sea life. A minor course alteration to obtain additional soundings does not convert a passenger ship into a survey ship where the principal purpose of the passenger ship voyage is maintained. Also, hydrographic surveys are conducted by specially trained professionals who are normally certified in accordance with national HOs pursuant to IHO-recommended practices. "All survey work must be performed by qualified personnel. The personnel must be trained and capable. Formal qualifications, such as from CAT A and B accredited courses are preferred, but proven working experience may be sufficient. Personal professional accreditation schemes should also be considered" (IHO, 2020a, Annex B.4, 33). Generally, crews aboard vessels contributing to CSB are not trained hydrographers or bathymetrists.

4.2.2 CSB Should Not Be Conflated with MSR

While UNCLOS references MSR 85 times throughout its Articles and devotes all of Part XIII to MSR, the convention did not define the term because consensus did not exist as to limits on MSR. "During UNCLOS III various possible definitions of MSR were mooted, some of which sought to restrict the term only to pure research, and others which encompassed all scientific studies in the oceans, including research connected with exploitation of natural resources" (Rothwell & Stevens, 2010, 321). Some attempts by international bodies have been described as "too sweeping," which may be inferred as overly broad (Churchill et al., 2022, referring to the definition proposed by the Subsidiary Body on Scientific, Technical and Technological Advice of the Convention on Biological Diversity).

Much has been written on what MSR *is not*. Debate has ensued and persisted over the years as to whether MSR subsumes hydrographic and military surveying, operational oceanography, bioprospecting, and exploration for marine archeological/historical artifacts (Churchill et al., 2022). CSs like the United Kingdom and the United States distinguish data collection activities such as hydrographic surveying as distinct from MSR (Churchill et al., 2022, 784). As UNCLOS separately itemizes Hydrographic surveying from MSR in a series of its Articles, pre-eminent scholars posit that "good arguments exist" for distinguishing hydrographic surveying from MSR (Churchill et al., 2022, 785; Soons, 1982, 125). Another respected scholar noted "While Part XIII of the LOS Convention fully regulates MSR, it does not refer to survey activities at all" (Roach, 2015, 285–302).

MSR has traditionally been purposeful, planned, and in general, "was carried out by dedicated research vessels, within a limited time frame and at a relatively precise location" (Churchill et al., 2022, 796). It was not atypical for a vessel to conduct MSR in a geographical "box" in order to collect samples or to observe natural phenomena. Such intentional collection is part of the rationale why CS consent is required under UNCLOS for MSR in the TS (UNCLOS, 1982, art. 245) or the EEZ (UNCLOS, 1982, art. 246). CSB is different in that CSB seeks to use echo sounding data collected pursuant to SOLAS mandate or SoN best practices. CSB is data *collateral to freedom of navigation and RMO*. The object of CSB is to leverage data lawfully obtained pursuant to safe navigation practices. Some erroneously conflate CSB with MSR because the data *might be used* to advance general knowledge in support of SEABED 2030 or GEBCO objectives. How data might be used should not constrain data collection already required or authorized by another international convention. For example, scholars note that satellite remote sensing for MSR purposes does not implicate the MSR Regime of UNCLOS (Churchill et al., 2022, 797). Likewise, weather observations collected as part of safe navigation practice should not be characterized as MSR.

4.3 *The IHO Actively Supports CSB*

The IHO sponsors the CSB Working Group and encourages private entities contributing to the knowledge of the seabed by sharing data collected with SNI during RMO (Hydrographic Geoinformation Services, 2022). In 2017, noting that the depth of a significant percentage of the world's seas, oceans, and waterways has yet to be measured directly and that bathymetric knowledge underpins the safe, sustainable, cost-effective execution of almost every human activity in, on or under the sea, the IHO Members States resolved they should also consider implementing mechanisms that encourage the widest possible availability of all hydrographic and particularly bathymetric data…including but not limited to…crowd-sourced bathymetry and satellite-derived bathymetry (IHO, 2020b). The IHO also encourages the Regional Hydrographic Commissions (RHCs) to adopt a collaborative approach to freely share CSB data. While recognized by the IHO, RHCs are independent of the IHO and may include CSs who are not IHO MSs.

Consistent with IHO Resolution 1/2017, the IHO issued a series of Circular Letters (CLs) requesting Member States (MSs) to "Opt In" to a framework to maximize sharing of CSB data, collected by ships within waters subject to their national jurisdiction (WSNJ). In addition, for the purposes of CSB, WSNJ include internal waters, TS, and EEZ. MSs have the option to support or object to CSB data sharing for depth measurements from their internal waters, TS, and EEZ. The CLs also asked the MSs whether they wanted the right to review CSB data obtained from their WSNJ before being deposited into the DCDB and whether they wished caveats on further dissemination of CSB data (IHO, 2022b). At present, the United States and five other nations have opted to allow CSB of All WSNJ with no caveats. Canada, Denmark, and Norway have opted to allow CSB of All WSNJ with caveat that no MBES-derived data to be included without prior permission. Argentina, Brazil, South Africa, and Sweden have opted to allow CSB of their EEZs only.

While the IHO Secretary-General strongly believes in the necessity for CSB maximization, the IHO is demonstrating a deferential approach allowing MSs to determine the degree to which they will release CSB data aggregated in their WSNJ. The DCDB will store all data but honor the "options" expressed by the MSs. However, for Seabed 2030 to succeed, an increasing number of MSs must Opt to make CSB in all their WSNJ publicly available without caveat.

5 CSB Balances Interest Tensions

In systems of international governance, tensions often exist between competing values. International law, and the world politics that creates and sustains it, has increasingly manifested a tension between the primacy of state sovereignty and other values that would challenge that primacy" (Coplin, 1965, 629; Cronin, 2002; Pease & Forsythe, 1993). Regarding data in general at the macro-level, the question is what factual information should be made publicly available versus what information is proprietary to the property owner. "Copyright cannot exist over ideas or facts; therefore, no data ownership rights exist" (European Commission, 2022, 18). More specifically with CSB, there is a perceived interest tension between the collaborative sharing model that observed bathymetric data should be made publicly available versus the CS interest to minimize global access to observed bathymetric data inside its EEZ. This raises the fundamental question of whether the CS may exclusively possess the right to know the depth of water at any given location within WSNJ. Regarding bathymetry in areas where ships may have the need to navigate, the answer to the question should be no. Sounding information obtained through SOLAS mandate or best SoN practice should not be restricted.

UNCLOS rules regarding MSR and hydrographic surveys notwithstanding, ships entering and leaving other CS ports should not have to request permission of the CS to know the depth of water under keel in order to enter the port to load and unload cargoes. That permission is implied by the CS's willingness to conduct trade with other flag States. In addition, the CS is obligated under SOLAS Chapter V to "prepare and issue nautical charts…satisfying the needs of safe navigation" (SOLAS, 1974, Chapter V, Reg. 9 2,2). So in many cases, CSs *publish* surveyed depths of harbors that are within the internal waters of the CS. Some harbors may be surveyed intermittently, and some harbors may be subject to silting or bottom transposition, so the operation of vessel echo sounders is essential to not only the safety of the visiting ship but also to the interests of the CS. In the United States, a vessel that detects an anomaly in the charted depth of the harbor is encouraged to submit An Aid to Navigation Discrepancy Form to the U.S. Coast Guard so that the incident might be investigated and reported in Notices to Mariners (U.S. Coast Guard Navigation Center, 2022).

The UN Decade demonstrates an international commitment to the democratization of ocean science, and expansion of availability of data for a broad range of uses, including SoN. For example, an official from UNESCO's IOC stated "The idea of the Decade is to achieve a major change in the knowledge management of the ocean…whereby all nations, stakeholders and citizens have access to ocean data and information technologies and the capacities to inform their decisions" (Ryabinin et al., 2019, 4–5). The Interest Tension exists in the desire to publicly share bathymetric data for the benefit of the global community that tugs against the interests of the coastal State to exercise sovereignty over its TS and exercise sovereign rights to living and non-living resources in the EEZ. As one respected scholar argues, excessive coastal State control of factual data "would deprive the people of all nations of the benefits of free and open access to data that enhance safety and environmental protection" (Roach, 2015, 302) which would be contrary to the goals of the UN Decade and Seabed 2030.

UNCLOS establishes rules governing the conduct of MSR for the protection of coastal State sovereignty (UNCLOS, 1982, arts. 19, 245) and sovereign rights (UNCLOS, 1982, arts. 246, 248), but these rules govern the conduct of MSR *in TS, EEZ, and on the Continental Shelf* (UNCLOS, 1982, arts. 245, 246). This implies a contemporaneous presence of the vessel in the WSNJ collecting the data which constitutes MSR. However, CSB results from SoN soundings obtained by vessels doing activities other than Hydrographic surveying or MSR.

Representatives of some countries have expressed concern that certain non-coastal State actors (NCSA) would use the pretext of CSB and RMO to conduct surveys or MSR in violation of UNCLOS, arguing "In crowd-sourcing, anyone can survey and anyone is also allowed to view the data. In other words, bathymetric data will be free and available to anyone" (Luma-Ang, 2017). Again, these critics mistakenly conflate CSB with hydrographic surveys. Stated earlier, CSB data by definition is collected by vessels using SNI in RMO, as opposed to specialized vessels performing hydrographic surveys as their principal purpose. Even if a vessel using SNI conducting RMO is in the course of Innocent Passage, that activity is not a hydrographic survey, so it would not violate UNCLOS Art. 19(2)(j). Nothing in UNCLOS prohibits retention of passage soundings incident to freedom of navigation. CSB involves *aggregating* passage soundings to add to a global dataset of soundings that may fill the gaps in our understanding of the ocean bottom. CSB data may not be as precise as that produced by hydrographic surveys, but to paraphrase a bathymetric scholar, some knowledge is better than no knowledge, as long as that knowledge is caveated that it is the product of CSB (Rondeau, 2019). Also, some CSB may approach the quality of surveyed data. Artificial Intelligence could be employed to predict conditions under which CSB may be more dependable.

There is a risk, however, that some State or non-state actors might use the pretext of RMO to conduct surveys or MSR in violation of UNCLOS. To counter this possibility, Automatic Identification System (AIS) (IMO, 2022) tracks and remote sensing may detect vessels that appear to be loitering or performing grids in a manner inconsistent with stated RMOs, especially if within WSNJ. CSs may approach and demand the alleged violator to desist and issue diplomatic démarches. That being said, some CSs may overcorrect and interfere with not only RMO but actual surveys in the EEZ that are fully authorized by UNCLOS (Churchill et al., 2022, 784–785).

6 Concluding Thoughts and Recommendations

CSB is a logical, albeit opportunistic, extension of the evolution on collaborative efforts advancing SoN and Ocean Sciences. It complements and catalyzes the efforts to achieve goals established by the UN Decade of Ocean Science, GEBCO, and Seabed 2030.

CSB is *incidentally* acquired by vessels using SNI in RMO and is either mandated by SOLAS or best navigation practices. At the time the data is acquired during RMO, CSB is neither hydrographic surveying nor MSR, even if the data might be subsequently used for hydrography or to advance scientific research. Recognizing CSB as *sui generis* does not prevent the planning or conduct of actual hydrographic surveying or MSR activities that actually meet the conceptual norms of such activities. The DCDB can still archive survey or MSR data but metatag it in a way that differentiates it from CSB. Accordingly, CSB does not infringe CS interests protected by UNCLOS.

In conclusion, CSB is distinct from hydrographic surveying and MSR and not a replacement for them. Leveraging passage sounding data expands our knowledge of the seabed and can inform planning for strategic hydrographic surveys to be performed by autonomous or robotic platforms, thereby limiting CO_2 output. CSB aggregates pre-collected data that may be used to improve the means of navigation, supporting safe and sustainable use of the oceans fully consistent with the intent of the Law of the Sea.

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CHAPTER 6

The Use of Marine Autonomous Systems in Ocean Observation Under the LOSC: Maintaining Access to and Sharing Benefits for Coastal States

Luciana Fernandes Coelho and Roland Rogers

1 Introduction

Marine autonomous systems (MAS) have been used in ocean observation on the water surface, column and sea floor, providing purposeful

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data in expedited time (Moltmann et al., 2019). For instance, tsunami warnings following the eruption of the volcano *Hunga Tonga-Hunga Ha'apai* prevented deadly consequences (NOAA, 2022). However, one might question the need for dedicated legislation regulating the use of MAS (Bax et al., 2018).

This chapter responds to such an inquiry by analysing whether the framework governing marine scientific research (MSR) under the United Nations Convention on the Law of the Sea, 1982 (LOSC or Convention) could be a purposeful benchmark to regulate the use of MAS in ocean observation. It starts examining operational aspects of MAS deployed in ocean observation, then revises the framework governing MSR under LOSC, and ends analysing if and how to reconcile such framework and the use of MAS.

For the purposes of this chapter, ocean observation refers to activities examining elements of the physical environment in the ocean space. Sustained observations are measurements taken on an ongoing basis for seven years or more, primarily serving the public good services and supporting research in the public interest (Cravatte et al., 2016, 4). Experimental observations are measurements taken for less than seven years for research and development purposes, advancing knowledge on the physical environment and climate, exploring technical innovation and/or leading to improvements in the effectiveness and efficiency of observing system programmes (ibid.).

With the absent definition for MSR in the LOSC, States and scholars diverge on how to classify ocean observation (Huh & Nishimoto, 2017a; Mateos & Gorina-Ysern, 2010; Wegelein, 2005). De facto, the LOSC framework governing MSR does not conflict with ocean observation, the reason why the former could serve as a yardstick for the latter.

There is no legal definition for MAS. The term is used by the oceanographic community in relation to the six models of carriers of sensors discussed here. Scholars have examined the status of MAS (Bork et al., 2008; Hofmann & Proelss, 2015; Veal et al., 2019), with significance for military uses and ethical implications (Gorina-Ysern, 2003; Gorina-Ysern & Tsamenyi, 1997; Johansson, 2018). These have been followed

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by concerns over safety and risk to the marine environment (Klein et al., 2020). Less noticed, taking the MSR framework as a benchmark, the use of MAS might be detrimental to meeting the benefit-sharing obligations, which can justify coastal States' denial of permission for future research projects in their waters.

The chapter's findings are supported by documental analysis, perspectives substantiated by one of the author's experiences managing scientific programmes by the National Oceanographic Centre in the UK and views from researchers. The study focuses on MAS applied for scientific and peaceful purposes, excluding those with commercial, military or defence applications. It only considers research sponsored and promoted by States and competent IOs, excluding privately funded, philanthropic and citizen science MSR. Competent International organisations are the ones whose mandate include coordinating and promoting MSR, including those listed in LOSC' Annex VIII (OALOS, 1991, 1).

2 Operational Aspects of MAS Employed in Ocean Observation

We examine six types of MAS, determining in each case the measurements that can be made, potential sensors, capability of being launched, piloted and recovered independently of a mothership, traceability, range of modus operandi and autonomy (IMO, 2021). The MAS discussed are classified in the levels of autonomy D3 and D4 (Table 1).

Table 1 Degrees of autonomy proposed by the International Maritime Organization

Degree	*Description*
D1	Some operations may be automated and unsupervised, but with seafarers on board ready to operate and control shipboard systems and functions
D2	The ship is controlled and operated from another location, and seafarers are available onboard to take control and operate the shipboard systems and functions
D3	The ship is controlled and operated from another location. There are no seafarers on board
D4	The vessel's operating system can make decisions and determine actions by itself

Source Prepared by the authors

2.1 Marine Autonomous Surface Ship (MASS)

MASS (NOC, 2022a) have a length overall (LOA) ranging from 1 to 5 m; although some operated by commercial survey companies may have up to 70 m. They are a mix of in-house and commercially produced MASS which can be deployed for months. Their power sources include solar, wave, wind, hybrid fuel cells and traditional marine engines. They are fitted with passive and active sensors covering measurements of meteorological, oceanographic, biological, photographic and acoustic parameters. Some can deploy and recover other MAS, such as UUVs and ROVs (AutoNaut, 2020).

MASS have been launched and/or recovered from mother ships, researching States, coastal States, third-party States or combinations thereof. The piloting has taken place on mother vessels and/or remote piloting centres located in researching States, coastal States, third-party States or a combination. They are controlled using satellite communications with access to the data collected via the same capability and tracked using AIS. Measured data is saved onboard the MASS.

They can be operated at autonomy level D4 but are commonly controlled at D3 level.

2.2 Unmanned Underwater Vehicles (UUV)

UUVs are either electric-powered, classed as Autonomous Underwater Vehicle (AUV; for examples, see NOC, 2022b), or use buoyancy engines, classed as gliders (for examples, see NOC, 2022c).

UUVs are a mix of in-house and commercially produced capabilities with sizes varying between man-portable to 10 m. They are fitted with passive and active sensors covering measurements of oceanographic, biological, chemical, optical—including imagery—and acoustic parameters. UUVs have been deployed on experimental observations lasting from one day up to several months, from shallow waters >50 m down to full ocean depth.

UUVs have been launched and/or recovered from mother ships, researching States, coastal States, third-party States or a combination. The piloting has taken place on mother vessels and/or remote piloting centres located in researching States, coastal States and third-party States or a combination. On the surface, they are controlled using satellite communications with access to the data collected via the same capability and tracked by AIS. When submerged, they run on pre-programmed tracks and depths. Measured data is saved onboard.

UUVs are operated at autonomy level D4 when submerged and at level D3 when on the surface and when underwater acoustic telemetry is available.

2.3 Remotely Operated Vehicle (ROV)

ROVs (NOC, 2022d) are generally commercially purchased, but some marine research institutes build in-house vehicles. Their sizes vary from man-portable to those requiring specialised containers for transport and bespoke launch and recovery gantries. They are operated down to full ocean depth with an average of 6000 m and are fitted with passive and active sensors covering measurements of oceanographic, biological, chemical, optical—including imagery—and acoustic parameters.

ROVs have been launched, recovered and operated from mother ships, although they can be launched and recovered from MASS (Ocean Infinity, 2020). The piloting is undertaken from remote centres in researching States, coastal States and third-party States or a combination. There are now commercially available ROVs that can be detached from their umbilical and operate as full AUVs. It is this latter type of ROV is the main reason for their inclusion in this paper.

ROVs usually are operated at autonomy level D3.

2.4 Profiling Floats (PF)

Most PFs (Argo, 2022) are commercial products. They are fitted with sensors covering oceanographic, biological and chemical measurements. Recent developments have seen floats capable of being operated down to 4000 m. They are carried along by ocean currents and are not recovered.

PFs are launched from research vessels and ships of opportunity. There have been trials of both air-launched PF and from MASS. The piloting is remote and can be undertaken from centres in research, coastal and third-party States or a combination. On the surface, they are controlled using satellite communications with access to the data collected via the same capability and tracked using AIS. When submerged, they run at pre-programmed depths.

The level of autonomy for PF is D3.

2.5 Seabed Observatory (SO)

SOs (NOC, 2022e) come in many forms, from a buoyed system such as the Porcupine Abyssal Plain (PAP) to fixed submerged seabed structures. They are generally produced in-house by research institutes with bespoke capabilities. SOs can be found both in shallow water and deep ocean and are operated down to full ocean depth, running pre-programmed depths. They are fitted with passive and active sensors covering the measurement of oceanographic, biological, chemical, optical and acoustic parameters.

SOs can be long-term installations that are serviced by research vessels. Observatories on the seabed either store the data onboard, which is recovered when serviced, or give real-time access to it when cabled to a shore-based receiving station. SOs like the PAP are controlled using satellite communications with access to the data collected via the same capability from the surface part of the observatory.

They are primarily operated at autonomy level D4 but at times work the D3 level.

2.6 Remotely Piloted Aircraft (RPA)

RPA (the acronym is synonymous with Unmanned Air Vehicle)—or drone—can either be propeller powered fixed-wing or rotary-wing. Most RPAs are man-portable though large ones require special launch and recovery capabilities (Air-Sea Interaction Laboratory, n.d.). They are fitted with passive and active sensors covering the in-air measurement of optical in a broad-spectrum range, like temperature and meteorological parameters (Ridge & Johnson, 2020).

RPAs have been launched and/or recovered from mother ships, researching States, coastal States, third-party States or a combination. They use radio frequency communications for both piloting and data transfer. Backups of the data and operating parameters are stored onboard.

Shipborne and land-based RPAs are operated at autonomy level D3.

3 Legal Aspects of Using MAS in Ocean Observation

The LOSC provides a comprehensive framework governing MSR undertaken by States and/or competent IOs using vessels, installations and equipment (Papanicolopulu, 2017b, 1733). The Convention's MSR regulation is mainly located in Part XIII, which seeks to strike a balance between freedom to conduct MSR and the jurisdiction of States (Gorina-Ysern, 2003; Soons, 1982).

The framework applicable to areas under national jurisdiction (AUNJ) and international cooperation, also aims to strengthen developing States' marine sciences capacities (Coelho, 2022; Salpin, 2013; von Kries et al., 2015).

The non-monetary benefits target the capabilities explained in Table 2.

The rights and obligations related to such benefits differ in each maritime space and depending on the legal basis supporting them.

3.1 The Consent Regime

The consent regime is a degree of rights and obligations of coastal vis-à-vis researching States and competent IOs varying in each maritime AUNJ. Benefit-sharing obligations are tied to the coastal states' rights to withhold clearance for a project. In internal waters, territorial sea and archipelagic waters, coastal States have the discretion to deny consent and request any benefit, including monetary (Huh & Nishimoto, 2017b, 1648; Salpin, 2013).

In the EEZ and on the continental shelf, coastal States must grant clearance in normal circumstances, whereas researching States and IOs must comply with post-cruise obligations under article 249 (Huh & Nishimoto, 2017b, 1681). These obligations have the twofold purpose of confirming the MSR project's bona fides and sharing benefits (Coelho, 2022). Only in a limited number of circumstances Coastal States have a wider margin of discretion to withhold consent and impose additional compliance measures.

The first circumstance is when the MSR project involves the construction, operation or use of artificial islands and installations (article 246(5)(c)). The second one is when the project is of direct significance for the exploration and exploitation of marine resources. "Direct significance" refers to research findings expected to enable locating, assessing and monitoring the status and commercial availability of marine resources (DOALOS, 2010, 10). Third, consent may be denied when the project involves drilling into the continental shelf or introducing harmful substances into the marine environment (article 246(5)(b)). The final circumstance relates to previous research that failed to comply with the

Table 2 Modalities of benefits (considered for this study)

		Articles
Training and Capacity Building	**Consent regime**	
	Participate on board of vessels, craft, or installations	249(1)(a)
	Receive support to assess and interpret data, samples, and information	249(1)(d)
	International cooperation*	
	Promote training and capacity development	244(2)
	Create favourable conditions for MSR and integrate the efforts of scientists	243
	Strengthen MSR capabilities of developing States	244(2)
	Provide training and education for developing States	268(d)
	Promote the exchange of scientists and experts	269(c)
Access to Data, Samples, Information and Knowledge	**Consent regime**	
	Access data, samples, information, and knowledge	249(1)(b)(c)
	Prior agreement for releasing information with economic significance	249(2)
	International cooperation	
	Promote the flow of data and information, including about health, the safety of persons and the marine environment	242(2)
	Disseminate proposed significant programs and their objectives	244(1)
	Facilitate the acquisition, evaluation and dissemination of marine technological knowledge, information and data	268(a)
Enable Research Infrastructure	**International cooperation**	
	Develop marine technology and technological infrastructure	268(b)(c)

(continued)

Table 2 (continued)

		Articles
	Establish and strengthen national and regional marine scientific and technological research centres	275–276
Establish Legal and Policy Framework 	**Consent regime**	
	Establish guidelines to assist in ascertaining the nature and implications of MSR	251
	International cooperation	
	Create favourable conditions for MSR	243
	Conclude contracts and agreements for the acquisition of marine technology under equitable and reasonable conditions	269(b)
	Establish guidelines for the transfer of marine technology	271

Source Prepared by the authors, based on (Coelho, 2022)

duty to inform the nature and objectives of a given MSR project or the post-cruise obligations.

3.2 International Cooperation

The duty to cooperate with the objective of increasing knowledge of the marine environment is applicable in all maritime zones. States and competent IOs can freely negotiate how to facilitate the clearance process as far as the research project has peaceful aims, respects the sovereignty, sovereign rights and jurisdiction of States and mutually benefits all participants (article 242).

IOs have been vital in creating favourable conditions for MSR and enhancing capacities. However, developing countries' participation in international collaborations is still asymmetrical (IOC-UNESCO, 2020; Tolochko & Vadrot, 2021). The use of MAS could improve their participation, as such systems are usually cheaper to purchase and maintain. However, this is not without questioning the shortcomings of the LOSC in regulating the employment of MAS.

4 Using MAS and Maintaining the Balance Envisioned by the Framework on MSR

The LOSC is a product of its time (Buga, 2015). Nevertheless, it is considered a "living instrument" with the flexibility to accommodate changing circumstances either through interpretation (Heidar, 2020; McLaughlin, 2020) or subsequent practice (Buga, 2015). This section analyses if and how the MSR's framework might regulate the use of MAS preserving the balance between States and sharing benefits with coastal States. It examines potential incompatibilities between aspects of MAS and the legal framework proposing interpretative guidance. After, it assesses the informal contribution of non-binding instruments to advance interpretation and implementation. Lastly, it explores two cases in which MAS were employed in ocean observation and benefits were shared.

4.1 Evolutionary Interpretation of Part XIII

In AUNJ, using MAS in MSR and ocean observation potentially causes loopholes related to the three main aspects explored in the following.

4.1.1 When Coastal State Consent Is Needed

The status of a given MAS is relevant to determining the need for coastal States' consent. MAS are generally classified as a vessel, installation, structure, platform, device, equipment or craft, which are terms not defined in the LOSC (Veal et al., 2019). It behooves national laws to establish which MAS are considered vessels (Veal et al., 2019; Wegelein, 2005). Installations are larger devices, mobile or fixed, employed to stay in place for longer periods (Hofmann & Proelss, 2015; Wegelein, 2005, 138–235). They usually serve to carry equipment, and some have the capability of manning. This terminology includes structure and platforms (ibid.). Equipment, which includes crafts and devices, are smaller instruments employed for a specific purpose and a short period (Hofmann & Proelss, 2015; Veal et al., 2019; Wegelein, 2005, 137). "Device" is used generically or when no other classification is applicable (Veal et al., 2019).

when the MAS is not considered a vessel, if it is deployed from a mother vessel, the clearance process is connected to the latter (ibid., 32). Conversely, the device has an autonomous status when deployed from shore or a platform without the status of a vessel, like a "ship in its own right" (ibid., 32), which could trigger the need for consent to each MAS. Communication through official channels or between scientists from the States concerned could help clarify the procedure to obtain consent and expedite it (article 250). Article 247 also provides a viable solution, facilitating authorisation when the MSR project is under the auspices of competent IOs in the EEZ or on the continental shelf of a State member.

The project's geographical location and the MAS expected date of first appearance and departure, i.e., launch and recovery, play a role in assessing when consent must be requested and has consequential effects on the allocation of liability. It is indisputable that consent is needed when the State in which the device transits coincide with that overseeing the location of data gathering. A diverse situation takes place when they are different.

In the territorial sea, archipelagic waters or straits used for navigation of a third State, if considered vessels by national laws, a MAS would be entitled to the right of innocent or transit passage (articles 17, 52, and 38). In this case, the MAS would have to comply with national laws and regulations (article 21), refrain from carrying out research during the passage (articles 19(j), 40 and 54), navigate on the surface and show the identification of the State of registry when it is an underwater vehicle (article 20). If not qualifying as a vessel, the MAS unlikely is entitled to innocent passage, potentially necessitating permission from third States when transiting (Veal et al., 2019, 33; Wegelein, 2005, 135).

In the EEZ and on the continental shelf, the principle of freedom of navigation prevails. However, it is uncertain whether the project's geographical location and the date of first appearance and departure, which must be informed in the pre-cruise phase, include just the site of data collection or also areas of transiting (article 248(c)(d)). Again, national laws must clarify this issue (article 246(1)), which can create a troublesome situation in projects involving multiple States or when the MAS collects data when transiting with no capability of determining when and where the collection will start. As a default, researching States should notify third States of MAS passaging through their EEZs and continental shelves or potentially drifting in AUNJ.

4.1.2 When the Consent Can Be Withhold

The status of MAS and the types of measurements supported by each technology are significant to recognise the likely circumstances under which coastal States have the discretion to withhold consent and request compliance with obligations other than those prescribed by article 249.

In the territorial sea, coastal States have the exclusive right to grant consent for MSR and the discretion to impose requirements, including monetary benefits (Huh & Nishimoto, 2017b, 1648; Salpin, 2013). Conversely, in the EEZ and on the continental shelf, coastal States have limited discretion to deny clearance to MSR projects. One example is when the activity involves the deployment of installations and structures. Interestingly, such discretion is not extensive to projects using equipment (Papanicolopulu, 2017b, 1735).

Notwithstanding the guidance provided in the previous subsection, the assessment criteria to identify a system as installation or equipment are insufficient because there is no threshold on the system's size and time of employment for each classification. For instance, the extended range of time in which MASS and UUV can stay at sea could cast doubts on their classification as equipment. More clarity on the legal criteria to determine the status of each MAS would be helpful. In the meantime, communication between official channels or scientists would be valuable to fill this gap.

Coastal States' discretion to withhold consent is also applicable if the MSR has economic significance. At first glance, this would not be the case for ocean observation; however, many parameters measured by the systems discussed can have commercial applications. Therefore, pre-cruise information should certify, beyond doubt, the nature of the research.

4.1.3 How to Comply with the Benefit Sharing Obligations

Obligations from whichever source of international law usually require an action or omission, and sometimes the achievement of a result (ILC, 2001, 55, para. 3). Since the distinction between obligations of conduct and result is not exclusive (ibid., 56, para. 11), an assessment of articles 242–244 and 249 in light of the Vienna Convention on the Law of Treaties and the doctrine of obligations provides a nuanced perspective.

Articles 242–244 establish goal-oriented obligations, which necessitate a permanent evolution leading to a particular 'defined or definable' outcome, even if no specific deadline exists (Wolfrum, 2011, 376). Consequently, cooperation concerning MSR should be continued, addressing shared challenges and unequal capacities to conduct MSR and utilise scientific knowledge. Furthermore, the format to accomplish such obligations' goals is less relevant, allowing to accommodate MAS features.

In article 249, researching States and/or IOs sponsoring research bear responsibility for pre-cruise information and complying with post-cruise obligations, even if the activity is actually undertaken by a research institute. When such an institute is not a governmental entity, one could refer to parallel responsibilities for States and private persons (Wolfrum, 2011). In this case, while the formers must ensure that the latter behave in a certain way (ibid., 379), research centres are responsible through State Parties for adopting specific actions (DOALOS, 2010), some of which constitute benefits.

To meet their duties, researching States and IOs should adopt the necessary steps, like enacting internal laws and procedures compelling compliance with post-cruise obligations and monitoring enforcement. But, they are not legally required to ensure the obtainment of a result (Wolfrum, 2011). This conclusion is confirmed by the language used in article 249, which limits compliance to 'when practicable,' 'as soon as practicable,' and when requested by coastal States; or uses the vague obligation of 'undertake to provide' (article 249(1)(c)). However, since consent can be withheld due to outstanding obligations from a previous project, it is on researching States' interests to compel research institutes to fulfil their obligations.

Valuable training and capacity-building opportunities come from the right to participate in the MSR project onboard research vessels, installations or equipment, mainly because not all States have access to research vessels and state-of-the-art technology (IOC-UNESCO, 2020). In the absence of capacity to carry crew in many MAS, participation can occur in piloting centres, developing human capabilities to build in-house systems or training in assessing and analysing data.

The use of MAS might not affect the duty to provide access to data, samples, information and knowledge because data collected from MAS is usually stored onboard and can be processed and shared soon after its collection. In the case of SO, data can be accessed in real-time. When article 249(2) applies, researching States should be prompt to filter any data bearing economic significance for coastal States.

4.2 Informal Law-Making Instruments

This subsection explores soft-law and self-regulatory instruments alike adopted by IOs and private entities, which, despite lacking binding force, generally "announce and reflect eras of change and are often harbingers of legal progression" (Friedrich, 2010).

4.2.1 International Organisations

Seeking to induce the implementation of Part XIII, the United Nations Division for Ocean Affairs & Law of the Sea (DOALOS) published a guide in 1991, revised in 2010. Both editions draw attention to the clearance procedure and consultation between scientists from involved States as appropriate steps to build trust, expedite consent and share benefits (DOALOS, 2010, p. 28).

The guide emphasises that researching States must demonstrate the peaceful purpose of the project and its contribution to a body of knowledge in the consent form, thus, differentiating it from prospection, exploration and exploitation and attesting to its harmlessness to national security. Also, the adoption of measures to minimise impacts on the marine environment like risk assessment should be informed (ibid., 40). Of relevance, the form template includes space to describe the MAS used (ibid., 33). Conversely, Coastal States must inform the expected level of participation, the format in which the data should be provided, and the existence of ecological or culturally sensitive areas and areas-based management tools (ABMT) (ibid., 31, 42 and 45).

Local scientists' involvement in the project's early stages can promote meaningful participation for developing States and garner consensus on how to align the technicalities of MAS with Part XIII's obligations (ibid., 29–32). It may also open opportunities for adding local and regional areas of interest to the project proposal, incorporating traditional and local knowledge, promoting the optimal utilisation of the information provided, and realising the transfer of technology (Bax et al., 2018). A similar approach has been adopted to discuss aspects of intellectual property rights (DOALOS, 2010, 32; Gorina-Ysern, 2003).

The Intergovernmental Oceanographic Commission of UNESCO is pivotal in triggering cooperation and accommodating the MSR's framework to changing circumstances. It had an active role in drafting the DOALOS guide and, in 2007, published a guideline on the procedure for MSR carried out by itself, acting as a competent IO, according to article 247. Although never used, such an instrument sets a precedent for other IOs (GOOS246, 2021, 23).

4.2.2 Private Sector

In compliance with the parallel obligations upon States and private entities, the scientific community adopted self-regulatory instruments seeking to minimise the environmental impact of MSR and assure safety standards (InterRidge, 2009; ISOM, 2007). The industry established codes of conduct reporting best practices for deploying MAS (UK, 2018). States published guidelines informing scientific institutions on how to conform to the LOSC requirements (NOC, 2019; SUT, 2007; UNLOS, 2021). The latter exemplifies how States can improve the implementation of Part XIII by what McLaughlin (2020) calls conduciveness. However, the instruments consulted only superficially discuss the post-cruise obligations. The private sector should be more active in filling this gap.

4.3 Case Studies

The following cases exemplify MSR and ocean observation projects promoted by IO and States using MAS in which LOSC provisions on MSR were applied, and benefits were shared.

4.3.1 Argo OceanOPS and ARGO Floats

The outputs of the ARGO array inform our long-term understanding of climate change and provide critical inputs into ocean–atmosphere forecast models used for weather forecasting. Furthermore, access to the observations in near real-time is open to all States, even if they are not net providers of ARGO floats to the array.

The floats launched on the high seas are free to drift into coastal States' waters eventually. Coastal States have seen these unscheduled excursions into States' EEZs as unpermitted MSR. IOC addressed such anomaly in 2008 via the adoption of a Guideline regulating the deployment of profiling floats in the High Seas within the framework of the Argo Programme (IOC Executive Council, 2008).

Member States of IOC agreed that coastal States concerned should be notified in advance of the deployment of floats with the potential entrance into their waters (Mateos & Gorina-Ysern, 2010). Besides, IOC and the World Meteorological Organisation act as clearing house mechanisms, receiving and releasing data collected in the public domain. IOC compromised to verify ways to maximise the number of States participating in the project and benefiting from it (IOC Assembly, n.d.). Coastal States have the right to retain the publication of data collected in their EEZs with economic significance (IOC Executive Council, 2008, Annex).

The data generated by the Argo Float Programme has been applied to education and capacity development by the Pacific Islands Applied Geoscience Commission (SOPAC) and by a partnership with the US in South America and Africa (Roemmich et al., 2009). Hence, through a soft-law instrument that resembles Part XIII's provisions, IOC member States adapted the rights and obligations to the respective features of floats, sharing benefits.

4.3.2 Commonwealth Marine Economies Programme (CMEP) Containerised Autonomous Marine Environmental Laboratory (CAMEL)

The CMEP was launched in 2015 to support Commonwealth SIDS' sustainable growth by strengthening scientific and technological capacities, developing plans for environmental protection and designating ABMTs (UK, 2016; Ziegwied, 2018). CAMEL was designed as a project of CMEP aiming to expand the use of state-of-the-art technology, which is cheaper and easier to maintain than a traditional research vessel (Ziegwied, 2018). The facilities generally involve an operations container, a workshop, a C-Worker-4 Unmanned Surface Vehicle, an UUV ecoSUB and three exchangeable sensors (ibid.). The capability covers oceanography, hydrography, marine meteorology and marine environmental security measurements (ibid.). It also involves capacity development since representatives of SIDS receive training on using the CAMEL system.

Between 2018 and 2019, CAMEL has already been successfully deployed for scientific data collection in Belize, contributing to investigating ocean acidification in shallow waters, including the Belizean Barrier Reef, with reduced costs compared with traditional methods of in situ investigation (Cryer et al., 2020). In 2019, it was used in Dominica, where CAMEL enabled producing marine habitat maps in support of two marine protected areas (NOC, n.d.).

In this case, bilateral agreements were capable of implementing the obligations of conduct concerning international cooperation achieving the required access to and benefits from MSR using MAS as laid out in Part XIII, as well as transferring marine technology.

5 Conclusion

By the time we celebrate the LOSC's 40th anniversary, this study evidenced the Convention's fitness for purpose by demonstrating the framework's governing MSR suitability to serve as a benchmark regulating the use of MAS in ocean observation. The chapter examined situations in which the use of MAS challenges identifying when coastal States' consent is needed, when it can be withheld, and how to comply with benefit-sharing obligations, suggesting States and competent international organisations pathways. Furthermore, it assessed informal law-making processes advancing the Convention's flexibility to changing circumstances, with particular emphasis on the DOALO's guide and work of IOC-UNESCO. The latter was a protagonist in establishing a regulatory instrument concerning the use of profiling floats based on Part XIII, garnering consensus between divergent positions. A second case evidenced how Part XIII can trigger collaborations advancing the use of MAS in ocean observation and sharing benefits.

Thinking about the LOSC at 50 and aligned with the Decade of Ocean Science for Sustainable Development objectives, an updated DOALOS Guide and a platform assembling IOC's best practices have been proposed (GOOS246, 2021, 39). These exercises could advance the implementation of Part XIII, in light of new technologies and improve developing countries' participation in marine sciences. The Argo Guidelines could inform discussions, particularly its notification system and the use of IOs as clearing house mechanisms. The guide's new edition should emphasise the relevance of the consent form and official/direct communications between States involved to build trust and to identify: when consent is needed, how to avoid withholding it and ways of complying with the benefit-sharing obligations in light of new technologies. An expanded discussion on data sharing and property rights would also be beneficial. Besides, DOALOS and IOC could increase dialogue with sub-regional and regional organisations. The latter would be more equipped to assist States in adjusting legal, policy and administrative procedures to process the consent request within the permitted time frame and enjoy the benefits accrued from MSR.

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PART III

Smart Ports

CHAPTER 7

Implications of Technological Innovation and Respective Regulations to Strengthen Port and Maritime Security: An International Agenda to Reduce Illegal Drug Traffic and Countering Terrorism at Sea

Adriana Ávila-Zúñiga-Nordfjeld, Hans Liwång, and Dimitrios Dalaklis

1 Introduction

The International Ship and Port Facility Security Code (ISPS Code) is one of the most important instruments of international law regarding port and maritime security. This regulatory framework was adopted under

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the auspices of the International Maritime Organization (IMO) after the tragic events of September 11, 2001, and it entered into force, in 2004, under Chapter XI-2 of the Safety of Life at Sea Convention 1974 (SOLAS Convention). However, there is still room for improvement and the ISPS Code as it stands now is not the final solution (Mitropoulos, 2004).

The SOLAS Convention, as adopted under the auspices of IMO, deals with a diversity of areas related to maritime safety, including, for example, specifications of minimum standards for the construction, equipment and operation of ships. It also addresses port and maritime security through the ISPS Code, which provides "the comprehensive set of measures to enhance the security of ships and port facilities, developed in response to the perceived threats to ships and port facilities in the wake of the 9/11 attacks in the United States" (International Maritime Organization, 2012). Whereas part A establishes the mandatory provisions, the not mandatory ("recommended") part B comprises guidelines explaining how to comply with the mandatory requirements established in part A. One of the core instruments of the ISPS Code is the Ship Security Assessment (SSA), which requires specific equipment and security systems to protect the ship, its crew, cargo and the marine environment from several security threats such as terrorism at sea, piracy, illegal traffic of drugs, weapons and currency and stowaways among others (International Maritime Organization, 2012).

One of these mandatory tools is the Automatic Identification System (AIS). Nevertheless, Regulation 19 of SOLAS chapter V requires the AIS "to be fitted aboard all ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size. The requirement became effective for all ships by 31 December 2004. Ships fitted with AIS are expected to maintain the AIS in operation at all times except where international agreements, rules or

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standards provide for the protection of navigational information" (International Maritime Organization, 2012). According to the mentioned regulation, the AIS shall provide information including the ship's identity, type, position, course, speed, navigational status and other information related to safety to other ships fitted with the AIS, aircraft and shore stations.

In a similar approach, Long-Range Identification and Tracking (LRIT) is an electronic system developed by the IMO to enhance maritime security. It is a satellite-based tracking system that utilizes shipboard equipment already installed under the Global Maritime Distress and Safety System (GMDSS) to track SOLAS-classed vessels over 300 gross tonnage engaged on international voyages. Under this requirement, vessels must transmit LRTI information encompassing the ship´s identity, its location (latitude and longitude) and the date and time of the position four times daily and within six-hour intervals. Yet, even if the routine tracking is officially every six hours, the regulation establishes that on board terminals must be able to be remotely reprogrammed to transfer LRIT information every 15 minutes, if necessary. Its primary function is to provide information about the identity of ships and their actual location with enough time for a Contracting Government to evaluate security risks posed by such ships to its coast and territorial waters and implement deterrence measures to respond to security threats. Contracting governments to the SOLAS Convention can request information from foreign-flag ships sailing within 1,000 nautical miles of their coasts or intending to enter their ports. Under the LRIT regulation of the SOLAS Convention as established in Chapter V (Regulation 19-1) entered into force on January 1, 2008, all ships are required to comply with the exclusive exception to ships whose operation is limited to coastal areas defined by its flag Administration and which are equipped with an AIS (International Maritime Organization, 2012).

These mandatory equipment are essential for the security of ports, vessels and oceans. However, new novel technology has been developed that should be assessed to be incorporated as part of the compulsory tools on board vessels to improve the security of vessels and ports and the reduction of illegal drug trafficking by sea, such as Automated or Autonomous Underwater Vehicle (AUV) systems.

2 Port and Maritime Security and Illegal Drug Traffic by Sea

In port and maritime security, risks can change dramatically, although there are no changes in ship operations. Changes result from interdependencies between the situation on board and the political, economic and social situations in the areas transited and visited (Liwång et al., 2015). Maritime security includes a range of threats ranging from terrorism at sea to trafficking of drugs, weapons and currency and stowaways. Drug trafficking is an illicit global trade-industry that involves the cultivation, production and manufacture of diverse substances, including synthetic drugs. Law prohibits the trade of such substances, including money laundering. The latter seeks to disguise the illegal origin of drug traffic revenues. Regrettably, an increase of 11% of drug users worldwide is expected by the UNODC by 2030 (United Nations Office on Drugs and Crime, 2021).

The United Nations Office on Drugs and Crime (UNODC) informed that in 2019, the global quantity of cocaine seized increased by 9.6% in relation to the previous year to reach 1,436 tons (of varying purities), establishing a new record. The same agency also pointed out that the 90% increase in the amounts of cocaine seized during the period 2009–2019 might reflect a combination of factors, including a rise in cocaine manufacture (50% between 2009 and 2019) with the consequent increase in cocaine trafficking, as well as an intensification in the efficiency of law enforcement, which may have contributed to an increase in the confiscation rate (United Nations Office on Drugs and Crime, 2021).

The cited report says that from the 15 countries reporting the most significant quantities of cocaine seized in 2019, 10 were from the American continent, 4 from Western and Central Europe and 1 from Asia. The bulk of the cocaine seized worldwide continues to be confiscated in the Americas, which accounted for 83% of the global quantity intercepted in 2019. In fact, the majority has been seized in South America. In this region, the total quantity of cocaine seized augmented by 5% between 2018 and 2019, which in absolute numbers is 755 tons, a record high, with most countries in the sub-region, including Bolivia, Brazil, Colombia and Peru, reporting significant increases (United Nations Office on Drugs and Crime, 2021) (Fig. 1).

The UNODC informed in a previous report from 2008 that most heroin and morphine are produced exclusively from Afghan opium and

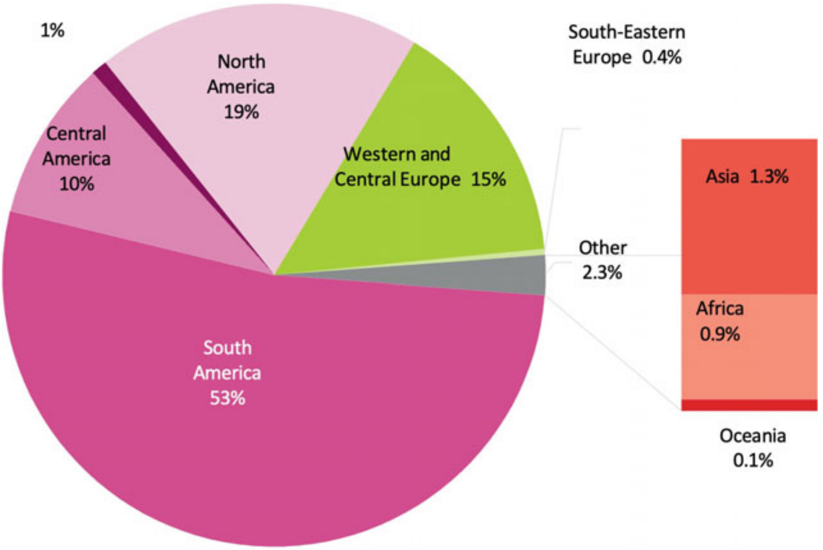

Fig. 1 Global quantity of cocaine seized, 2019 [*Source* World Drug Report 2021 (United Nations publication, Sales No. E.21.XI.8])

trafficked worldwide via routes flowing into and through the countries neighboring Afghanistan, while "the Balkan and northern routes are the main heroin trafficking corridors linking Afghanistan to the huge markets of the Russian Federation and Western Europe. The Balkan route traverses the Islamic Republic of Iran (often via Pakistan), Turkey, Greece and Bulgaria across South-East Europe to the Western European market (…) and the northern route runs mainly through Tajikistan and Kyrgyzstan (or Uzbekistan or Turkmenistan) to Kazakhstan and the Russian Federation" (Figs. 2 and 3).

Illegal drug trafficking and chemical precursors worldwide are carried out primarily by sea, in container vessels or packages affixed to the bulbous bow of vessels (Avila-Zuniga-Nordfjeld & Dalaklis, 2020). These authors highlight in their research results (concerning ports of Mexico) the following:

a. "an increased trend toward illegally transporting narcotics drugs in packages affixed to the bulbous bow of vessels;

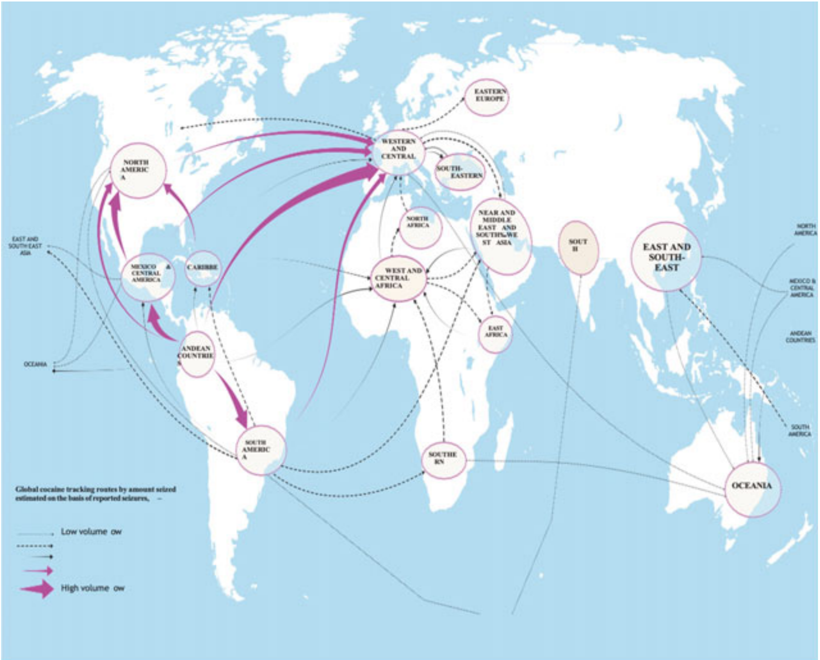

Fig. 2 Main cocaine trafficking flows (*Source* World Drug Report 2021 [United Nations publication, Sales No. E.21.XI.8])

b. unauthorized access of small boats and fishing boats in the navigation channels or at the waiting berth area to recover illegal carriages of narcotic drugs;
c. use of divers from organized criminal organizations to recuperate narcotic drugs packages affixed to the buboes bow of vessels;
d. limited human resources, and specifically lack of professional divers, for hull inspections at most ports.
e. Lack of underwater drones for hull-vessel inspection at all maritime ports."

Harney (2017), in his study about the ranking of drug traffic and smuggling methods, also emphasized the use of container vessels for the transport of drugs across the continents. As criminal groups in Latin

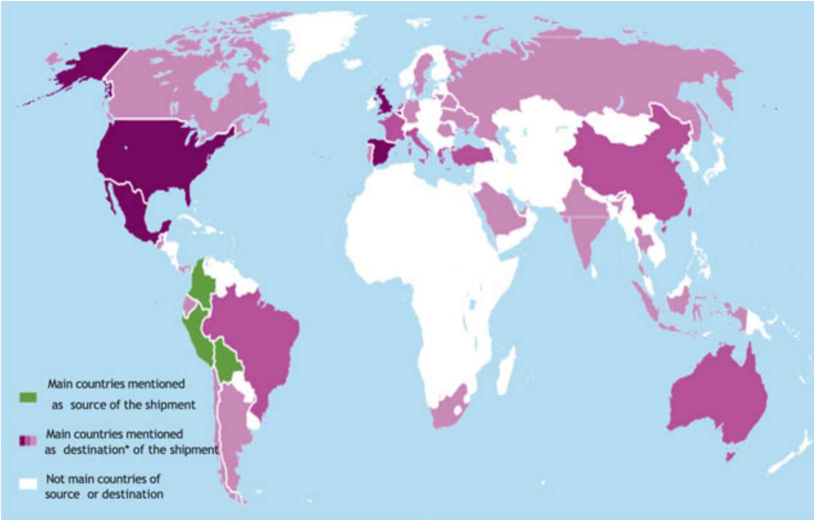

Fig. 3 Main countries identified as source and destination of cocaine shipments (As stronger the color, mayor number of cocaine shipments) (*Source* World Drug Report 2021 [United Nations publication, Sales No. E.21.XI.8])

America increasingly shift their focus to the profitable European cocaine market, more and more advanced ways are being developed to smuggle colossal quantities of drugs across the Atlantic; while controlled by an operator, an underwater drone would use magnets to attach itself to the hull of unsuspecting cargo ships crossing the Atlantic. Once within easy reach (i.e., 20–30 miles of the European coast), the operator could detach the drone, which would then broadcast its location via GPS to be collected by traffickers. In March 2021, the first such submarine built by a criminal organization in Europe was captured by Spanish police in Malaga (Bleszynska, 2021).

On the other hand, the Convention against Illicit Traffic in Narcotic Drugs and Psychotropic Substances (1998), establishes several obligations that the Contracting governments must undertake to combat and punish this type of criminal activity. The treaty includes a list of actions that parties must undertake, e.g., fighting its illicit cultivation, production, transport, sale and distribution, as well as money laundering, through drug seizure, law enforcement and international cooperation for its combat and investigation.

3 AUV Systems

The use of AUV systems in the maritime sector has increased steadily during the last couple of years, playing various roles not only related to hull inspection for maintenance purposes but also for security reasons to counter maritime security threats and drug traffic by sea. Therefore, AUVs systems can be an efficient solution offering new possibilities in "ocean production, environmental sensing and security" (Bhat et al., 2020).

Currently, AUVs are utilized in a number of maritime operations, including search and rescue, where "multi-robot systems have the potential to significantly improve the efficiency of SAR personnel with faster search of victims, initial assessment and mapping of the environment, real-time monitoring and surveillance of SAR operations, or establishing emergency communication networks, among other possibilities. SAR operations encompass a wide variety of environments and situations, and therefore heterogeneous and collaborative multi-robot systems can provide the most advantages" (Peña Queralta et al., 2020). AUVs are also used to handle oil spills, where they "can navigate autonomously and track oil spill on the sea surfaces. This system can self-adapt and path plan amidst environmental changes, including the temporospatial variation of the oil concentration" (Pashna et al., 2020).

Different countries, such as Australia, the United Kingdom, the United States, Canada and the Netherlands, as well as certain others, mainly in Europe, have already implemented the use of AUVs for maritime surveillance and law enforcement in the broader effort against drugs and transnational organized crime. With their intelligent and advanced capabilities, AUVs make inspections and surveys easier, even in the harshest operating environments. With the increase of their use in maritime operations around the world, their overall cost has also been reduced significantly, yet the technology is improved to expand its utilization to areas that were not envisaged originally. There is a variety of AUVs for different depths with a full HD low-light camera and additional auxiliary lighting. Additionally, these systems may be equipped with positioning sensors to track and log data, which combined with sensors along the hull on the external part, improves position accuracy and the security of the vessel in the moment that sensors send signals of working movements around the hull to the underwater robot, it autonomously leaves its area. AUVs may start inspecting the vessel and record any irregular movement, allowing the ship master to detect incidents where drug packages are affixed to the bulbous bow or other parts of the hull and call the authorities to start its confiscation and consequent law enforcement procedures.

Now compact underwater drones can be handled by one person yet provide live video and navigational capability in strong current (Chambers, 2017). This provides shipping companies and port authorities with easy and cost-efficient access to inspect what is below the waterline and get the opportunity to address potential criminal issues.

In the implementation of innovative technology, such as AUV systems, there is a need for organizational and structural changes to provide for the effective use of innovative technology and avoid only replacing old technology with new ones. Additionally, the organization needs to see the system as a capability enforcer. This could, for AUV systems, provide extra challenges since the implementation involve letting go of control and leaving certain decisions to the technology itself (Tärnholm & Liwång, 2022). Therefore, there is a need for also legislative support.

4 General Discussion

The implementation of AUV systems for inspections in the shipping industry has become essential as the maritime community realizes its potential to eliminate safety hazards and maritime security threats related to unlawful drug traffic by sea. AUVs allow performing inspections without delay at much lower costs, which also impact the health of human resources as divers, AUVs can remain in water depths for long periods before they have to be recharged, inspecting the concerned vessel thoroughly.

However, these novel technological developments need to be assessed regarding international legal principles, such as the right of visit and inspection as provided for in the United Nations Convention on the Law of the Sea (UNCLOS), to evaluate its inclusion in the current international legal framework for maritime security and particularly, the SOLAS Convention to make them mandatory on board vessels sailing international routes to contribute in the war against drugs and respective law enforcement. Natalie (2019), argues that the legal regime relevant to

MAVs is the regime used by navies for peacetime operations, which application has already led to discussions about the status of MAVs as warships and their possible immunities and highlights questions about the rights of navigation that might apply in relation to MAVs, including whether they enjoy the right of innocent passage and what might constitute "normal mode" in the context of transit passage. The author emphasizes that maritime security encompasses more than the peacetime operation of navies and extends to diverse law enforcement activities in response to crimes at sea.

Thus, this paper contains a call to the international maritime community to analyze the use of AUV systems for maritime security inspections, including drug trafficking and terrorism, as part of the required security equipment to be established in the ISPS Code, enacted in the SOLAS Convention to enhance counter-smuggling operations at sea. Implemented measures, such as UAV systems, need to be effective and low risk. The IMO Formal Safety Assessment (FSA) approach is a structured and systematic methodology to help evaluate new regulations to balance the various technical and operational issues (International Maritime Organization, 2018). However, the complex interdependency between ship operations and the wider society and the significant third-party risks related to drug trafficking imply that there needs to be extra care taken when applying the FSA to a security context. On the other hand, even if the main focus of the ISPS Code is on terrorism and the IMO has left Contracting Governments to determine the extent to which the ISPS Code, the Ship Security Assessment (SSA) and respective Ship Security Plan (SSP) and corresponding Port Facility Security Assessment (PFSA) and Port Facility Security Plan (PFSP) shall integrate measures for countering armed robbery, drug smuggling, stowaways, illegal migration and the security of dangerous goods (Avila-Zuniga-Nordfjeld, 2018), the trend from drug cartels toward illegally transporting narcotics drugs in packages affixed to the bulbous bow of vessels, could also be used by terrorist groups to affix explosives and bombs at the hull of vessels to attack targeted ports.

To effectively deal with the steady increment in the use of drugs worldwide and all the social problems that it brings consequently, the international institutions involved in the fight against transnational organized crime, including drug trafficking, such as the IMO, should start the evaluation of the international legal framework and its shortcomings about the war against illicit traffic of drugs. It is also fundamental to identify potential areas for contribution and improvement to ensure that innovative technologies, such as AUVs, comply with international law, which might also include the assessment of the legal uncertainty concerning unmanned ships and vessels. As national maritime authorities are the first line of defence against new security threats by detecting and establishing deterrence measures for newly identified security risks, it cannot be denied that shipping companies and vessel owners also have a responsibility to contribute to the combat against this type of international crime and exploit the benefits offered by maritime automatic vehicles to address those security threats.

5 Conclusions

The evolution of maritime security and intelligence cooperation worldwide has forced drug cartels to innovate and incorporate novel technology into their drug-smuggling methods. Besides, terrorist organizations and drug cartels often cooperate in their criminal operations. It should not be surprising that terrorist groups learn and implement successful drug-smuggling strategies and affix bombs to the external part of hull of vessels to be detonated at a targeted port. Thus, the international community, including the IMO and UNODC must start the analysis to make suitable reforms to the international legal framework, incorporating such novel technology as maritime automatic vehicles for ship inspection as part of the counter-measures and techniques to secure ports and oceans.

Certain innovative stakeholders are already experimenting with the idea. Recently (2021), an underwater drone used to foil drug smugglers attempting to bring contraband into the UAE has gone on show at the Gulf Information Technology Exhibition (Gitex) in Dubai. This remote-controlled drone for underwater surveillance has been used by Dubai Customs since August 2020. It is fitted with a 4 K high-definition camera, it can record live video and take clear photographs to enable investigators to complete a more thorough inspection of vessels arriving at the dock. These images are relayed to the designated operations office and when the concerned officers evaluate the received images, they can easily decide if there is a need to investigate further (Webster, 2021).

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CHAPTER 8

Automated Port Operations: The Future of Port Governance

Andrew Baskin and Mona Swoboda

1 Introduction

Automation in the port sector is the full or partial substitution of analog or manual operations through the use of equipment and processes that do not involve human intervention (Notteboom et al., 2022). Automation requires a systematic and repeatable process. In ports, automation involves three main dimensions (in order of most automated to least): within the yard, various interfaces, and the foreland and hinterland (Notteboom et al., 2022). Container yards are frequently automated, with terminals using information systems to manage the flow and stacking of

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containers. This enables optimized positioning of containers and equipment to improve overall throughput within given spatial constraints (Abdul Rahman et al., 2016). One of the most common examples is the use of automated guided vehicles to move containers from one location in a terminal to another. Further, various interfaces can be automated, such as automated mooring systems that quickly dock and undock vessels and automated gate systems that can accurately and quickly identify a driver's identity, a license plate number, and a container number. These interfaces can improve cargo processing times and reduce errors. Finally, foreland and hinterland automation involve processes that are not directly tied to terminal operation but can benefit terminal operations, such as automated aspects of ship, truck, and rail operations.

Most terminals that are fully or partially automated were developed as greenfield rather than brownfield, as it is simpler to automate a new terminal than to retrofit (and disrupt) existing operations. As of late 2021, there are more than 50 at least partially automated terminals across the world, primarily but not exclusively in Europe and Asia (ITF, 2021). Automation is increasing at a global level, with partially automated terminals implemented in countries as wide-ranging as Australia, Mexico, Morocco, Panama, the United Arab Emirates, and the United States.

The growth of automation is changing the port sector in a variety of ways, affecting its finances, human capital, and operational cadence, among others. These changes necessitate the development of modern port governance priorities for which innovative ways of collaboration among relevant decision-makers and stakeholders will be essential.

2 Why Automate?

A primary reason why ports consider automation technologies is to attempt to increase port productivity (McKinsey, 2017), where port productivity is defined as total traffic handled (Karnoji & Dwarakish, 2018), and port efficiency, which is defined as the maximum output obtainable in the use of a given level of resources (Talley, 2009). Port users are demanding increasing levels of productivity and efficiency: shipping companies want containers to be loaded and unloaded as quickly as possible from ever-larger vessels to minimize the time those vessels spend in port and deliver cargo to shippers who want their cargo so they can meet just-in-time inventory management strategies. Automated operations, which eliminate production reductions during shift changes and theoretically maintain constant levels of performance, are assumed to increase such productivity as well as overall reliability by providing increased insight into the data that helps measure performance. Research on this topic has produced ambiguous results, with some studies showing that automated terminals are less productive (Chu et al., 2018), others concluding that automation provides lower productivity on a per hour basis but higher overall productivity due to more consistent performance and longer operations (Moody's, 2019), yet others showing that automation of terminals improves efficiency in some aspects of terminal operations but not others (*Journal of Commerce*, 2013), and other yet again that efficiency depends more on port size, specialization, and location than on levels of automation (Ghiara & Tei, 2021).

In addition to productivity, efficiency, and reliability, reduced costs are another reason some ports choose to automate operations. In general, automated operations reduce labor costs and increase capital costs, which is particularly attractive to ports in high-wage countries (ITF, 2021). One study has estimated labor-cost savings at 33% (Oliveira & Varela, 2017); another noted that a conventional container terminal in Canada had nearly 3.5 times the number of workers as an automated container terminal in Australia with roughly the same throughput (Prism Economics & Analysis, 2019); and, at a port automation project at Pier 400 at the Port of Los Angeles, a terminal operator has acknowledged that, for instance, driverless straddle carriers will replace existing cranes and trucks operated by 500 workers (Roosevelt, 2019). While these and other findings suggest that automation will significantly reduce the number of dockworkers, it can also increase the number of staff that can be employed elsewhere within the port (ITF, 2021). In ports where labor is short, the reallocation of workers may provide opportunities to better position and align the port's workforce with modernization efforts.

Two additional reasons for port automation projects are at times raised: worker safety and environmental sustainability. In regard to worker safety, the automation of certain tasks within the terminal and condition monitoring of important pieces of terminal equipment, are supposed to decrease the number of worker injuries. However, there are currently low levels of automation of certain tasks with known safety risks, such as twist-lock handling (Kugler et al., 2021). Further, although analysis from the Port of Oakland (Sisson, 2019) was promising, empirical research on this topic remains sparse. Concerning environmental sustainability, analyses have focused on how automating operational processes can reduce environmental pollution (Shi et al., 2019) and how optimizing automated container terminal layout can reduce emissions (Wang et al., 2019), among others. Yet results remain inconclusive.

3 Human Factors

Nonetheless, the port automation trend is developing rapidly and is leading to a paradigm shift in the industry. Along with the projected operational benefits, the adoption of automated processes is also expected to have a significant impact on the human factor and must be addressed through integrated port governance (Kim et al., 2019).

While gender imbalance in the port sector remains a (governance) challenge, automation can present an opportunity to eliminate real and/or perceived physical barriers that may prevent women from performing certain tasks in the port. In 2020, the International Maritime Organization (IMO) urged its Member States to remove any social, psychological, and physical obstacles for women and increase their participation in the historically male-dominated sector (IMO, 2020). In addition, the United Nations Conference on Trade and Development (UNCTAD) together with the United Nations Entity for Gender Equality and the Empowerment of Women (UN Women) developed several policy briefs highlighting that continued gender inequalities will negatively affect trade (UNCTAD, 2020). Consequently, it is in a port's best economic interest to create equal opportunities for all genders in all fields of port operations as this will result in a greater pool of human capital that can positively contribute to its performance. Here, automated, and in some cases manual yet remote, operations have the potential to create new and more inclusive employment opportunities for women, even though further studies and data will be needed to make conclusive assumptions (Kim et al., 2019). In addition, automated operations can enable increased accessibility to port-related roles that, without automation, might be limited to only able-bodied workers.

4 Port Governance and Automation Changes

Port governance is the framework governing conduct, authority, and institutional resources employed to facilitate port development and oversee port activities (Notteboom et al., 2022). Despite the initial inconclusive results on the benefits of automated port operations thus far, automation is a clear trend among many of the largest ports and is a topic of increasing priority for ports of other sizes. This trend brings with it corresponding governance challenges that, when considered, can help facilitate stakeholder decision-making as it relates to the implementation of automated operations. These challenges include investment decisions, adapting to evolving government policy, managing labor relations, and tackling growing cyber risk.

4.1 Investment Costs

First, the cost–benefit calculus of implementing port terminal automation is different than that for conventional terminals. Port terminal automation requires significant upfront capital investments in new technologies and a concomitant commitment to fixed terminal capacities lacking in flexibility. These investments typically are for longer time periods before the realization of a return on the investment (Notteboom et al., 2022). This obligation can be a challenge for ports lacking the access to capital necessary for such investments, or for ports that can access such capital, but only under conditions different than those from previous investments.

This type of significant financial obligation and expanded investment horizon requires consideration of new business models and, perhaps, a different approach to collaboration. For instance, the need to conduct a cost-benefit analysis with the aforementioned atypical factors can require buy-in, or at least the tacit approval of, an array of interested stakeholders. These stakeholders can include government officials, labor interests, and, in some cases, corporate overseers in distant headquarter offices. The need for such wide-ranging consultation necessitates consideration to broader stakeholder coordination than might have been required for previous investments.

4.2 Government Policy

Second, government policy regarding port terminal automation varies widely. Although there is a broad range of levels of government involvement in port management, administration, operations, and investment (see earlier discussion of automation), few ports are fully privatized, and therefore subject at some level to government policy. As described in the previous section, the changes to business models and collaboration frameworks that investments in, and the social effects of, automated operations present will require government input, even if only tacit. And governments have taken a wide array of positions on port automation.

The government of South Korea (Government of the Republic of Korea, 2020), for example, has released strategies and plans that take a favorable position on smart ports, which includes port automation. The European Union has also taken a broadly positive approach to port terminal automation. For instance, in 2020 the European Union funded the Advanced, Efficient and Green Intermodal Systems project, which seeks to connect autonomous ships with autonomous ports (European Commission, 2020).

In the United States, on other hand, the federal government has taken legislative action to limit port automation. Federal legislation in the United States that provided funding for port infrastructure development forbade the use of funds to purchase fully automated cargo handling equipment if it was determined that the purchase of such equipment would result in a net loss of jobs within a port or port terminal (National Defense Authorization Act, 2022). Further, state legislatures have taken action restricting port automation. The Senate of the State of Washington adopted a bill to ensure that federal and state funds are not used for the purchase of port automation equipment (Senate of State of Washington, 2021), and the State of California established a task force to evaluate the impact of port terminal automation on employment (California Assembly Bill, 2019).

This range of government positions, and that a specific government's position might evolve over time owing to changed political circumstances or simply additional information regarding port terminal automation outcomes in other jurisdictions, dictates that ports considering automation projects should continue to engage with governments in a collaborative fashion on this topic.

4.3 Labor Relations

Third, the trajectory of the port automation trend has caused, and is continuing to cause, concern among unions and other labor groups. Unions expect that, while the effect of automation on total employment is unclear, the effect on lower-skilled workers will be high (Esser et al., 2019). The trend toward automation is expected to focus port jobs on high-skilled personnel. While this shift might not affect overall port-labor numbers, it will present significant challenges for existing port personnel, and particularly lower-skilled personnel.

This in turn introduces governance challenges. Relations between ports and unions can be contentious. Trade unions and other entities that represent port workers have expressed hesitancy regarding, or outright opposition to, automated operations. Many unions view automation projects as existential threats, as the technology can eliminate existing dockworker jobs. For instance, the expected effects on labor of automation have already caused conflicts between unions and terminal operators, such as in 2019 in both the Port of Los Angles and the Port of Vancouver. Other unions have taken a more constructive approach, focusing on negotiating labor deals favorable to dockworkers, such as in the Ports of Antwerp and Hamburg (Barnard, 2016). Regardless, the labor composition changes that will result from automation will require cooperation and collaboration among ports and unions. This should include consideration to formal training and re-skilling programs, the reallocation of workers rather than the total elimination of jobs, the creation of more accessible roles that require new skills, and buyouts for current workers who choose not to participate in the evolution toward automated operations.

4.4 Cybersecurity

Finally, in an increasingly digital world, all organizations are vulnerable to cyber risks. Even traditional port terminals, with a mix of information technology (IT) and operational technology (OT) connectivity but with human intervention in most processes, have such vulnerability. Such vulnerability, even in the absence of automated operations, can lead to existential crises for ports. A notable example is the NotPetya malware that affected A.P. Moller-Maersk in 2017. The malware spread through Maersk's systems, disrupted operations globally, and forced facilities and offices in many countries to revert to manual, handwritten records to manage and track shipments. This caused a significant backlog and stalled logistics and resulted in estimated losses of USD 300 million (Milne, 2017).

Automation of port terminal operations, and the increased interconnectivity it requires, adds a layer of potential vulnerability beyond that of non-automated port terminals. This is because automation requires the convergence of and connectivity between IT-based systems and OT-based systems. This connectivity can create new vulnerabilities, particularly for

IT networks that connect to complex systems involved in automated cargo handling. For instance, cyber threat actors could use digital controls to manipulate automated systems, such as damaging an automated crane's operating system, rendering it inoperable. In automated terminals that sacrificed flexibility for increased productivity and/or reliability, this can create significant operational delays and economic losses.

Thus, how port stakeholders decide to invest in managing cyber risk and developing cybersecurity capacity is a crucial aspect to automation. Cybersecurity is broader than simply being an IT issue and instead requires a whole-of-organization approach. This approach needs to encompass a wide variety of internal and external stakeholders, including those with an interest in IT, finance, human resources, and physical and operational security, among others. Accordingly, the cybersecurity investment decisions that automation entails require improved collaboration among port stakeholders to ensure that investments in cybersecurity-related human capacity, organizational processes, and technical tools are appropriate.

5 The Way Ahead

Regardless of the current perception of benefits, government perspectives, labor pressures, or cybersecurity risks, automated operations are becoming increasingly widespread across the globe. More than 50 container terminals around the world have automated operations to some extent, mostly as new terminals (greenfield) as opposed to the transformation of manual terminals into automated terminals (brownfield). Terminals in Europe and Asia were among the first to automate operations and continue to jointly form a majority of automated terminals. Terminals in other parts of the world, notably North America and Oceania, are also beginning to automate operations. Although automated terminals account for less than five percent of global container terminal capacity, their growth is expected to continue (ITF, 2021). In this sense, constructive approaches to collaboration among a variety of port stakeholders, including operators, authorities, labor, and users, will be critical to the effective implementation of automated operations.

5.1 Investment Decisions

As of 2022, various analyses of port terminal automation have questioned whether it brings the promised gains in productivity and efficiency. Yet, McKinsey notes that successful port terminal automation could result in productivity rises of nearly 35%; incremental improvements in port terminal automation equipment, processes, and management could yet lead to such gains. Certainly, in light of the trend toward automation in many of the world's largest terminals, investors and operators are optimistic about this outcome.

Nonetheless, the significant upfront and fixed investment costs, reduced operational flexibility, and longer timeframe for returns on terminal automation investment necessitate more in-depth analyses of the costs and benefits of this relatively new approach. Questions have been raised about the secrecy of existing analyses and whether the costs and benefits are fully divulged before investment decisions are made (ITF, 2021). Terminals considering automation investments should clearly and, when appropriate, publicly detail such analyses, thereby enabling investors and others with an interest in the terminal, such as governments and labor interests, to understand the risks, patience, and flexibilities such investments require. This collaborative approach should contribute to improved opportunities for buy-in of relevant stakeholders and, therefore, increase the likelihood of successful automation project implementation.

5.2 Government Role

Government policy continues to be a mixed bag. Governments that have expressed concern, or at times even taken legislative or regulatory action, about automated terminals have mostly done so in the context of concern about job losses. However, government action is not likely to last long as a bulwark against technological progress. Government action on the side of benefits that are concentrated (the relatively few jobs in ports) rather than diffuse (more productive and efficient port terminals better serving local, national, or regional economies) is short-sighted. The spate of port congestion in ports around the world, but in particularly largely unautomated ports in the United States, in late 2021 and continuing into 2022 further reinforces the need to enable port terminals to make investments that they believe will improve their productivity and efficiency.

Rather than act to impede, or at worst prevent, private terminal operators from making what they believe to be prudent investment decisions in the belief that doing so will protect jobs, governments should focus on their role as intermediary between port management and labor interests. Terminal automation decisions are at the heart of many port-labor disputes, such as those in the Ports of Los Angeles and Long Beach in the United States (Tirschwell, 2020) and the Victoria International Container Terminal in Australia (Wallis, 2021). Port work stoppages can and do have enormous implications for entire economies, and port-labor disagreements about automation are likely to continue. Governments have a key role to play in facilitating agreements on sensitive matters such as terminal automation and ensuring the continued operation of ports, which are critical cogs in most economies.

5.3 Port Labor Governance

In acknowledging that adoption of automation technologies is likely to also continue to require new skillsets within the workforce, ports and unions should take this opportunity to focus their attention on two aspects:

1. Increased training and re-skilling opportunities for existing port personnel; and
2. Reasonable buyouts for existing port personnel who are unable or unwilling to participate in the necessary skills evolution.

The topic of training and re-training is critical. Vaggelas presented a conceptual framework for this need, noting that training should focus on the changing nature of port jobs; the changing skills required of port jobs; the various types of technologies used in a port; and ensuring that workers are multi-skilled and capable of a variety of port-related tasks (Vaggelas, 2019).

This training aligns with the general evolution from "strength to skill" of port work, valuing technical skills, such as technological aptitude, more than the brute strength necessary for, for example, stevedoring work in decades past. Formulating and providing equal opportunities for the development of these new and more sophisticated skills can greatly benefit from a gender perspective or so-called gender mainstreaming. As per UN

Women, "gender mainstreaming is a set of specific, strategic approaches as well as technical and institutional processes adopted to achieve [gender equality]," including equal labor opportunities (UN Women, 2022). In this context, automation can in fact bolster gender equality efforts when women receive the proper training to compete for the new multi-task positions (Kim et al., 2019). These changes can benefit port terminals with automated operations, as they will have a deeper pool of human capital that can contribute to productive and efficient operations. Further, workers with improved training will have increased skills and qualifications that can provide port terminals with the ability to re-allocate workers and skillsets as necessary.

Change, no matter how potentially beneficial in the long run, can be wrenching. Accordingly, a framework for dialogue about these issues is critical. An example of the necessary platform for such dialogue is the European Social Dialogue for Ports, which the European Union launched in 2013. This Dialogue concentrates on health and safety matters as well as training and qualifications schemes for port-labor. Although it has yet to address in earnest the effects on port-labor related to automation, such discussions would be a natural fit for its already-existing framework.

Further, this type of negotiation and compromise is possible at the port level. The Port of Hamburg, for instance, has a collective agreement with a formal social dialogue framework that ensures the early involvement of worker representation, called a works council, when new technological projects are proposed. This includes automation projects, in which the port and works council seeks to mitigate the effects of new technologies on workers while maintaining an organizational culture of innovation (Hamburg Hafen Logistics, 2020). In addition, in the Port of Antwerp, at the MSC PSA Europe Terminal labor unions and terminal ownership engaged in negotiations that resulted in the decision to only semi-automate the terminal but with labor unions agreeing to increased greater operational flexibility (Bottalico, 2022). The frameworks, which formalize collaboration and consultation between port management and labor, created by the Ports of Hamburg and Antwerp are examples that other ports can follow as they seek to gain worker buy-in for potential automation projects.

5.4 *Cybersecurity*

Ports and terminals that are seeking to automate operations should ensure that they simultaneously consider investments to manage the resulting increased cyber risk. The governance challenges are numerous and include ensuring that security is considered and built into automation investments; ensuring compliance with relevant legal requirements, such as the European Union's Network and Information Directive or the cybersecurity aspects of the United States' Maritime Transportation Security Act; and seeking cyber insurance to manage balance sheet risk in the event of a cyber-attack.

Port stakeholders are not starting from scratch in managing the increased cyber risk that automation creates. Entities such as the European Union (European Union Agency for Cybersecurity, 2020), International Association of Ports and Harbours (International Association of Ports & Harbours, 2021), and Organization of American States (Organization of American States, 2021) have issued guidelines to guide port stakeholders in their management of cyber risk. The frameworks, which suggest collaboration and information-sharing between public and private entities with an interest in port productivity, efficiency, and reliability, should be useful to port stakeholders seeking to automate operations while managing the concomitant increase in cyber risk.

6 Conclusions

Port terminals across the globe are continuing to automate. Despite mixed early assessments of automated operations' overall benefits, the push toward automation, in particular in large container terminals in regions with high labor costs, appears to be on an inexorable climb. The port terminal automation trend is motivated by the desire to reduce costs, increase productivity and reliability, and bring improvements in inclusion, accessibility, safety, and environmental performance. Estimates of financial benefits vary, and some research points to a potential reduction in operating expenses, including labor, of up to 33%. Environmental and safety benefits are also expected, although still evolving. In addition, automation in ports has the potential to increase gender equality and inclusion as it dismantles existing physical barriers that, prior to automation, only certain (able-bodied) workers could perform.

Nonetheless, this trend carries corresponding governance challenges, including ones related to investment decisions, government policy, cybersecurity, and labor relations. The significant upfront capital expenditures and longer time periods before realizing a return on investment are a change from the calculus involved in previous financial decision-making. Government policy regarding port terminal automation varies across jurisdictions, and, because government involvement in port operations also varies widely, terminal operators wishing to make automation investments are required to tailor such investments in accordance with a range of different legislative, regulatory, and policy approaches. Cybersecurity risks, which are present in non-automated port terminals, become heightened in automated terminals with a greater reliance on interconnected systems, and require a comparable increase in attention. Finally, and often most prominently, union and other labor groups are often, but not always, opposed to port terminal automation projects owing from fear of job losses.

Amid this evolving governance landscape, the various stakeholders involved in port terminal automation decisions should aim to develop and institutionalize formal cooperative port governance models to the extent possible. Terminal operators should be transparent about the costs and potential benefits of automation. Labor unions should work toward training and re-skilling opportunities for port personnel, tying personnel pay to the increases in efficiency that automation could bring, and reasonable buyouts for personnel who prefer to not participate in this next phase of port terminal operation. Finally, governments should try to facilitate formal agreements on port-labor and related social matters and play an active role in the continued evolution of port operations.

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CHAPTER 9

Canada's Rapidly Evolving Smart Ports

Yoss Leclerc and Michael Ircha

1 Introduction

Canadian Port Authorities (CPA) have demonstrated resiliency as multimodal nodes in global supply chains (Leclerc et al., 2021). Canada's ports operate in a complex, multi-jurisdictional and ever-changing environment that requires operational nimbleness and adaptability. The global economy, growing international trade, and emerging markets continue to pressure ports to enhance their efficiency, performance, and productivity. Canadian ports are responding to these pressures by embracing

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leading-edge technologies reflective of the Fourth Industrial Revolution (4IR).

The World Economic Forum defines the Fourth Industrial Revolution as "a fundamental change in the way we live, work and relate to one another.... characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres" (Schwab, 2016). In order to remain competitive while ensuring sustainability, Canadian ports are adopting leading-edge 4IR technologies to streamline and optimize their operations. In other words, Canadian ports are embracing the new concept of Smart Ports.

Smart Ports can be defined by the use of "automation and innovative technologies including Artificial Intelligence (AI), Big Data, Internet of Things (IoT) and Blockchain to improve performance" (PTI, 2021a). The emergence of Smart Ports reflects the fourth generation of port evolution. As shown by Berns et al. (2017), until the 1960s, first-generation ports focused on loading and unloading commodities. In following decades, second-generation ports, seeking to broaden their scope expanded into industrial ports. By the late 1980s, third-generation ports became "intelligent", using the Internet to share information and data as trade facilitators within their logistics and supply chains. In the twenty-first century, fourth-generation Smart Ports use sophisticated digital integration to become data service providers with the full potential of IoT networks and smart data solutions.

Achieving holistic port digital integration requires the active participation of transportation and logistics partners including terminal operators, logistics firms, commodity suppliers and distributors, marine and inland transport providers. Smart Ports are key nodes in logistics and supply chains; the place where supply and demand meet, essentially "a physical manifestation of a platform business model" (Berns et al., 2017). Canadian ports, as federal agents, are particularly suited to serve as "honest brokers" in aggregating and sharing relevant real-time data within their logistics and supply chain network.

Advanced Smart Port technologies allow ports to rationalize, reorganize and streamline their operations to enhance economic efficiency, productivity, and environmental performance. This specifically relates to safety (vessel traffic, port congestion), operations (delays, operating errors, data, and information), security (illegal activities, cyber security) and environmental protection (pollution, emissions, development, green energy, and resource use). The COVID-19 pandemic accelerated the transformation of ports and other organizations into the 4IR through the emphasis on "touchless" interactions, automation and using digital technology to limit person-to-person contact.

This chapter examines the evolution to Smart Ports from the Canadian perspective. A review of Canada's three major container ports demonstrates the steps they have, and are taking as they evolve into Smart Ports. The chapter concludes with a discussion on what lies ahead for Canadian ports.

2 Regulatory Framework

2.1 United Nations Sustainable Development Goals (SDG)

In 2015, the United Nations (UN) adopted 17 integrated Sustainable Development Goals (SDG) with countries committing to achieving them by 2030. The SDGs range from ending extreme poverty and fighting inequality to addressing climate change and nature loss to ensuring the world's economic growth and development occurs in a sustainable manner (Herweijer et al., 2020). Along with 191 countries, Canada has committed to implement the UN's SDGs. In the 2018 federal budget, the government allocated funds to create an SDG unit. All federal departments and agencies reviewed existing policies and programs to realign them in support of the UN's vision and SDGs.

In a comprehensive World Economic Forum study of the applicability of 4IR technologies for implementing SDGs, Gawel and Herweijer (2020) found they "could have a high impact in particular across 10 of the goals, and that 70% of the 169 targets underpinning the goals could be enabled by existing Fourth Industrial Revolution technology applications".

Ports around the world have a significant role in achieving applicable SDGs using appropriate 4IR technologies as they shift into being Smart Ports.

2.2 IMO Single Window (SW)

The International Maritime Organization (IMO) is a specialized UN agency responsible for regulating shipping. To ensure the effective and efficient clearance of ships through ports, the IMO introduced regulations in the Convention on Facilitation of International Maritime Traffic

(FAL), requiring electronic data exchange and recommending using a "single window" approach to avoid data duplication and ensuring accuracy (IMO, 2016). The single window's goal is to ensure that information and data is only submitted once, electronically. This single point of entry enables reliable real-time dissemination to relevant stakeholders and others in the supply chain. The COVID-19 pandemic stressed the need for ports to establish integrated automated electronic data exchange platforms to reduce or eliminate physical interactions.

2.3 Canada in Context

Canada has been an early adopter of maritime innovation to support its ports. In 2016, the federal government unveiled a Transportation 2030 vision to ensure a sustainable future for the transportation system that is "safe, secure, green, innovative, and integrated" (Transport Canada, 2016). Transport Canada's Canadian Transportation Act Review Report outlined the need for climate change action in the maritime transportation sector, including the requirement for ports to focus and invest in innovation and climate change adaptation (Emerson, 2016).

The federal government established funding programs to support marine sector initiatives that are green and innovative. In 2018, the government established the National Trade Corridor Fund (NTCF) to support strategic investments to improve transportation system fluidity and performance including adding capacity and alleviating bottlenecks. Further, the NTCF seeks to increase the transportation system's resilience in response to a changing climate and ensuring adaptation to new technologies and innovation (NTCF, 2018).

By November 2021, Canada Port Authorities had received federal NTCF support of more than C$843million. Federal financial support was matched or exceeded with provincial funding, as well as contributions from CPAs and private sector partners. The CPAs' NTCF projects were generally for infrastructure upgrading, expansion and system improvements aimed at enhancing efficiencies and reducing the ports' environmental footprints (Infrastructure Canada, 2021).

In 2020, Sustainable Development Technology Canada announced a commitment for funding of C$750 million over 5 years to support cleantech innovation as part of its C$15 billion plan, A Healthy Environment and a Healthy Economy (SDTC, 2020). Also in 2020, the government published its Hydrogen Strategy for Canada laying out Canada's approach to generating green hydrogen as the means of achieving net-zero-carbon emissions by 2050. Ports will have a major role as hydrogen hubs supplying fuel for ships, port operations and land-based transportation equipment (NRCAN, 2020).

3 Canadian Regulatory Framework

In Canada's federal system, ports and navigable waters are part of the federal government's jurisdiction. Canada Port Authorities (CPA) were established by the Canada Marine Act comprising the government's National Ports System operating under a more commercialized business and governance model. The Act specifies the purpose of Canada Port Authorities is it to contribute to national economic competitiveness, growth, and prosperity; satisfy user needs at a reasonable cost; provide a high level of safety and environmental protection; and manage port lands, infrastructure, and services in a commercial manner (CMA, 1998a).

Canada Port Authorities are federally incorporated, autonomous, non-share corporations that operate at an arm's length from the federal government. Although the federal government is the sole shareholder, the legislation does not allow the government to direct or influence CPA actions. Canadian Port Authority actions are circumscribed in the Letters Patent issued by the federal government on incorporation. The Letters Patent allows CPAs to engage in activities related to shipping, navigation, passenger and goods transportation, cargo handling and storage, and other related activities. Canada Port Authorities are also limited to a set ceiling in their commercial borrowing capacities as defined in their Letters Patent (CMA, 1998b).

Canada Port Authorities are governed by a board of directors nominated by port user groups and various levels of government to implement "user pay-user say" principles. Although appointed by the Minister of Transport, the directors operate according to business principles with the authority to determine CPAs' strategic directions and make commercial decisions (Transport Canada, 2021).

While operating at arm's length from government, CPAs are federal agents, and as such, come within the scope of other federal legislation, including the Federal Administration Act, Official Languages Act, Access to Information Act, Environmental Protection Act, Impact Assessment Act, Fisheries Act, Maritime Transportation Security Act and Regulations, and so forth.

To a degree, these federal statutes constrain some of the CPAs' commercial abilities. For example, under the Financial Administration Act, CPAs are required to submit a five-year business plan and an annual, audited financial report. As federal agents, CPAs must maintain full bilingual capability in Canada's two official languages, French and English. Like all government departments and agencies, port authorities must be open and transparent in providing public access to information (respecting commercial confidentialities). From an environmental and sustainability perspective, the Canada Marine Act and Environmental Protection Act mandate CPAs to protect the land, air, and water within their jurisdiction. Under the Impact Assessment Act, CPAs are responsible for reviewing the potential effects of proposed port development projects on federal lands and waters as well as neighbouring communities. Port safety and security is governed by Transport Canada's Maritime Transportation Security Act and Regulations.

Canadian Port Authorities set their own fees (e.g., berthage and wharfage), but such fees must be fair and reasonable. They are responsible for the maintenance of commercial shipping channels and financing their own dredging requirements. Canadian Port Authorities are landlord ports, leasing out port lands and operations to private terminal operators.

By law, CPAs must be financially self-sufficient, financing operations from revenues and borrowing from commercial banks for capital projects. They do not receive appropriations or funding from the government to meet operating costs or deficits, nor any federal loans or government guarantees of commercial loans. Canadian Port Authorities cannot pledge federal real property as security for any borrowing, and, unlike their American counterparts, they do not benefit from any interest-free loan or bond issue status, nor have taxing powers. Further, CPAs provide an annual gross revenue charge to the federal government along with annual Payments in Lieu of Taxes (PILT) payments to their respective local municipalities (Transport Canada, 2021).

In a subsequent Canada Marine Act amendment, CPAs may receive federal program payments under limited circumstances, specifically for emergencies and as capital cost contributions for infrastructure, environmental sustainability, and security. Thus, CPAs finance capital projects from their own revenues, private sector partners, commercial loans, and support from specific federal programs related to infrastructure, environment, or security.

Canada has been involved in a leapfrog evolution of technologies and systems and has developed a regulatory framework to address challenges and issues related to digitalization, automation, and remote operations. Under its Transportation 2030 strategy, the government has worked diligently on providing clear rules and guidance for innovation and new technologies and continuing its efforts to digitize services for the marine sector (Transport Canada, 2016). One example of Canada's strong involvement in these matters is the strong support given to the Canadian network for innovative shipbuilding, marine research and training (CISMaRT) and the National Research Council (NRC), which is chairing the Canadian Forum for Maritime Autonomous Surface Ships (CFMASS) Testing/Research and Development Subcommittee.

Canada's maritime domain is governed by several acts and regulations with the most important being the Canada Marine Act and Canada Shipping Act. Transport Canada is responsible for the implementation and enforcement of these acts.

The Canada Shipping Act (CSA) seeks to address ongoing challenges with disruptive technology in the marine transportation sector such as the Maritime Autonomous Surface Ships (MASS) concept. Transport Canada has been involved since the beginning of this emerging era of digital navigation and has been developing appropriate regulatory and legislative frameworks. It has taken into consideration the needs of private and government stakeholders while monitoring international developments by foreign governments and international regulatory bodies. For instance, multi-disciplinary groups are currently focusing on legal and ethical questions concerning MASS and the International Regulations for Preventing Collisions at Sea (COLREGs) under Canadian law. The legal issue relates to COLREGs' definition of a vessel and whether an autonomous vessel would qualify under these regulations (Katsivela, 2021).

As far as Canada Marine Act (CMA) is concerned, the regulatory framework was developed for Canadian Ports Authorities to be competitive, efficient, and commercially oriented. Hence, the CMA provided CPAs with the power and the financial leverage to develop and implement strategies and initiatives to ensure their attractiveness and relevance as international gateways. Under the CMA, CPAs have been investing considerable effort and resources to transition from "Intelligent" to "Smart Ports" with the introduction of automation and digitalization into their operations and activities. Further, CPAs have established long-term relationships and /or partnerships with universities and the research and development sector to ensure ports cope effectively with the evolution of technology and leverage emerging tools to remain relevant and competitive.

4 Smart Port Drivers

Over several decades, the maritime sector has responded to continuous growth despite occasional slowdowns. Commodity throughput in CPAs has increased at a relatively steady pace as they served growing trades and new markets. For example, CPAs grew 2.1% per year compounded from 2011 to 2020 (Binkley, 2021).

Canadian ports serve as "landlords" leasing federal port lands and facilities to private terminal operators. As a result, ports are complex and diverse as they deal with multiple stakeholders including a range of companies, operating different equipment, and requiring varied products and services. In addition to this complex cluster of often competing firms, the fear of transparency is a major concern. As a result, companies interacting with the port are often hesitant to share information with a central agency that can aggregate and share information amongst relevant stakeholders (Berns et al., 2017). Such hesitancy is a barrier to Smart Port development. On the other hand, digitalization helped to mitigate the challenges of uncertainty by ensuring more reliable, timely and accurate exchange of data and information amongst port stakeholders.

The need for touchless and remote technologies driven by the COVID-19 pandemic accelerated the transition to digitalization, automation, and the aggregation, analysis and dissemination of big data. This transition to Smart Ports will ensure resilient and efficient operations, profitability improvement (e.g., digital monitoring can increase reliability and lifespan of assets) and support a sustainable and agile organization. In the mature ports sector, size and throughput are no longer the only measures of success, efficiency and smarter operations have become key. "It is no longer the largest port that will survive but the smartest" (Berns et al., 2017).

5 Intelligent Versus Smart Ports

The twentieth century witnessed the evolution of ports through several generations leading to the third where ports became "intelligent". Advancing information and communication technologies (ICT) enabled ports to develop situational awareness of people, processes, procedures, and the flow of information/data via the Internet. Indeed, the Internet was the catalyst for the transformation of ports to expand their corporate social and environmental responsibilities (CSR). The Internet also led to mass dissemination of information and data relating to CSRs, health, and environmental protection. Sustainability became the battle cry and ports responded by becoming efficient and effective as "Intelligent Ports". This third port generation witnessed a myriad of operating improvements including developing performance metrics for their supply chains, operations, health and safety, and environmental protection.

Today's emerging fourth generation "Smart Port" involves sophisticated digital technologies linked through the Internet of Things (IoT) to enhance the port and its stakeholders' overall performance. Smart Ports are becoming true supply chain facilitators in their role as neutral "honest brokers".

Despite Smart Ports being technologically innovative and competitive, there are many definitions of the concept, encompassing terms such as digital, connected, automated, leading-edge systems, AI, blockchain, data analytics, remote operating (robots, drones), green technologies, big data, and machine learning.

However, to be "Smart" a port needs first to be "Intelligent". Indeed, to fully benefit from today's technology, ports need to have a clear and comprehensive understanding of their mandate, purpose, and emerging challenges along with organizational agility, adaptability, and versatility to thrive in a continuously changing and unpredictable business environment.

An "Intelligent Port" operates efficiently in a dynamic environment, able to react and proact effectively to minimize external and internal impacts. "Smartness" is achieved with the introduction of correct technologies that increase connectivity, achieving horizontal and vertical integration of the entire port's ecosystem. The following table summarizes the many attributes of evolving "Smart Port" technologies and their potential port applications (Table 1).

6 Technological Evolution of Canadian Port Authorities

Canadian Port Authorities have been early adopters of new technologies to proactively build and use digital systems as Intelligent Ports. Over the past several years, they have been shifting to Smart Ports as

Table 1 Smart port technologies

Technology	*Characteristics*	*Use in smart ports*
Artificial Intelligence (AI)	Human-like logical thinking, learning, and judging on a computer Deep- and machine-learning based on accumulated experience Predictive decision-making support	Decision-making support Port facility management Supply chain monitoring and scheduling
Internet of Things (IoT)	Intelligent infrastructure and service technology for exchanging information between people and equipment, and between equipment Information collection in real time by attaching IoT sensors to containers, cargo, equipment, ships, berths, trucks, roads, rail	Real-time cargo tracking Monitoring ships, cargo, port operations, inland transport
Big Data	Extracting and analyzing data using complex data processing logic and distributed processing technology Predicting behavior and patterns based on data analysis	Disaster prevention and operational safety connected with external information such as weather
Blockchain	Preventing data fabrication and modification by sharing transaction details with all relevant users Distributed system to verify each transaction Supports record immutability, transparency, encryption verification and privacy protection	Maritime trade platform with multi-stakeholders Shipment tracking Berth and supply chain monitoring
Autonomous	Automating port facilities and transportation systems including equipment operations, cargo handling, and movement	Automated guided vehicles (AGV), automated stacking cranes (ASC), automated ship-to-shore cranes (STS)

(continued)

Table 1 (continued)

Technology	*Characteristics*	*Use in smart ports*
Digital Twin	Digital simulation of port layout and operations Pre-verification prior to operation to minimize trial error, increase operational efficiency, minimize accident potentials, and reduce design cost and time	Facility management Smart Port operations and management Safety training
Drones	Cost-effective, aerial, real-time visualization of port activities	Detecting oil and debris spills Incident management Infrastructure inspection (cranes)
Robotics	Machines replacing or augmenting human work Exoskeletons supporting workers to reduce heavy lifts and enhance safety Facility maintenance, defect checks, underwater and in-hold inspections, maintenance	Industrial robots for repetitive activities Drones Remotely operated vehicles (ROV)
Virtual Reality (VR) Augmented Reality (AR)	VR: interact with virtual objects in a virtual situation AR: virtual images overlapping in a real environment	3D virtual modeling Safety training Remote medical service onboard ships Emergency measures and incident management
Cloud	Internet resources supporting interconnectivity and scalability Provide common resources management, cost reduction and operational efficiencies	Data-sharing hub platforms Smart Port sharing and collaboration platforms
5G	Ultra-high speed, ultra-low latency communications improving data transfer and accuracy	Remote control and monitoring

Source ESCAP 2021, Park 2021, Saboonchi 2021, and Spanoghe 2021 they rapidly develop enhanced connectivity and ecosystem integration. The journey to Smart Ports is a long path strewn with challenges, failures, and successes. Many CPAs worked diligently to ensure a measured and controlled transition through organic processes focused on critical existing and emerging issues that need to be addressed. These issues included challenges such as operations (congestion, supply chain coordination), environment (emissions, noise, dust) and social (city-port relations, port expansion).

Amongst their other attributes, Smart Port technologies will lead to the reduction of CPAs' environmental footprint. Automation and digitalization enable operational optimization and reductions in energy/resources use (Baumgrass et al., 2015).

Canada has four major container ports: Vancouver, Prince Rupert, Montreal, and Halifax. Although Smart Port technologies are being applied in other ports (domestic containers, bulk commodities), container ports are the primary users of new technologies. This study considers the ports of Vancouver, Montreal, and Halifax. Prince Rupert is unique, serving as a full transshipment port with containers being transferred from ship directly to on-dock rail for shipment to Western Canada and the U.S. Mid-West. Thus, although Prince Rupert is Canada's third largest container port, it does not have the container handling complexities faced by other ports.

6.1 Port of Vancouver

The Vancouver Fraser Port Authority (VFPA) is Canada's largest port, handling 146 million tonnes of cargo in 2020. Located on Canada's West Coast, VFPA is a major component of the Pacific Gateway for trans-Pacific trades with a container throughput of 3.47 million TEU (twenty-foot equivalent containers). As a major North American gateway, VFPA has always been an early technology adopter in using digital technologies enabling connectivity, communication, and integration to enhance efficiency, effectiveness, and reduce environmental impacts.

In 2013, VFPA introduced the Smart Fleet trucking strategy to monitor and manage drayage activities within the port's jurisdiction. The Smart Fleet project installed global positioning systems (GPS) on port-licenced trucks to allow tracking and reporting on turn around and wait-times within the port. The project included a licencing system to ensure drayage firms could meet financial and operational obligations as well as monitoring vehicle age restrictions to lower air emissions and improve safety. Also, in 2015, VFPA introduced Climate Smart to assist port tenants conserve energy and reduce greenhouse gas (GHG) emissions. This project undertook GHG inventories of participating port tenants and identified ways to reduce them.

Along with the Canadian Coast Guard and the Pacific Pilotage Authority, VFPA is developing a new active vessel traffic management program (AVTM). The program prioritizes, sequences, and optimizes ship flows in the port to improve transparency, efficiency, reliability, vessel safety and environmental protection. The AVTM's advanced planning and scheduling addresses potential conflicts amongst vessel types serving different commodity sectors, and other marine transportation, including accounting for increasing demand, larger vessels, tidal windows, and transit times to and from terminals within the port.

The West Coast Supply Chain Visibility Program involves the VFPA, Transport Canada, Prince Rupert Port Authority, and other Pacific Gateway partners. Using smart technologies, this endeavour will enhance supply chain performance and reliability through a series of operational and planning tools increasing supply chain capacity to unlock the Gateway's full potential.

6.2 Port of Montreal

The Montreal Port Authority (MPA) is in a unique position as a deep-sea, all-season port located close to Central Canada and the U.S. Mid-west. The port's location enables maritime cargoes to be shipped up the St. Lawrence River deep into the industrial heart of North America. As a terminal port, vessels normally offload and reload all their cargo. In 2020, MPA handled 35.1 million tonnes, including 1.6 million TEU. Montreal is limited in the size of vessels it can serve due to ship draft restrictions in the St. Lawrence River. The largest container ship arriving at the port was the 6,730 TEU MSC Melissa (PTI, 2021b).

The MPA prides itself on being forward-looking. In 2019, MPA partnered with the Centre for Technological Entrepreneurship (Centech) and École de technologie supérieure (ÉTS) to establish North America's first port innovation accelerator (MPA, 2020A). The port innovation accelerator provides a meeting space for port experts, technology start-ups and PhD students from several universities advancing technological solutions to port logistics challenges including supply chain visibility and freight mobility, cybersecurity, process improvement and agility, and supply chain decarbonization.

An early innovative accelerator project was an augmented reality program through a partnership with the firm PreVu3D and ARA Robotics. Using advanced drone technology, the project developed a three-dimensional model of port locations and facilities. The derived digital twin improves port infrastructure and traffic planning, optimizes space use, and provides a virtual reality platform for security and fire prevention staff, infrastructure planning and development, and augmented port tours (Olivier & Saboonchi, 2020).

Early in the COVID pandemic, the port mobilized its partners to develop and implement an AI-driven solution to fast-track the delivery of critical COVID-related cargo. The natural language processing algorithm used in CARGO2AI identifies containers containing critical medical cargo onboard arriving vessels prior to berthing. Once offloaded, a real-time dashboard tracked the containers to expedite throughput, reducing container yard dwell time to less than 12 hours (Olivier & Morency, 2020).

In 2019, MPA launched its Trucking PORTal application (web and mobile) aimed at informing truckers and dispatchers of processing times at the various port terminals. The PORTal's algorithms include weather forecasts, number of vessels expected, and average number of registered terminal visits. The application provides a predictive model to improve operational efficiency, enhance environmental performance, and generate time savings for truck drivers.

In 2018, MPA joined with A.P. Moeller-Maersk and IBM in their TradeLens solution as part of a global blockchain-enabled shipping system. TradeLens enables the port to enhance business intelligence for better resource planning based on expected vessel arrival by integrating ship and cargo data into the platform to increase cargo movement visibility and cargo movement in the supply chain (MPA, 2018). The port has continued to develop its AI-driven platform generating predictive traffic flow models with 16-day planning horizon in support of resource allocation decisions by shipping lines, terminal operators as well as rail and trucking firms (Saboonchi & Olivier, 2021).

The MPA has partnered with the Port of Antwerp's epicentre project as part of an international consortium to design and launch projects to improve the global supply chain's efficiency, fluidity, and performance. The two ports are creating a cyber-secured trade corridor (MPA, 2020b).

Another intelligent corridor along the St. Lawrence River to Montreal is being developed by the Laurentian Pilotage Authority (LPA). Its "Optimized Pilotage Services" program is aimed at ships having uninterrupted passages to reduce travel times and generate accurate ETAs. The LPA platform integrates real-time data including pilot access, seasonal navigation rules, speed limits, currents, water levels, tides, ship water and air height, and water level clearance under bridges (Baumelle, 2021). The MPA's involvement with intelligent trade corridors, such as LPA's complements the Green Corridors initiative in the Clydebank Agreement undertaken at COP26. Green Corridors will connect two or more major port hubs supplying zero-emission fuels for visiting ships (Webb, 2021).

The many innovative smart port initiatives being undertaken by the Montreal Port Authority and its entrepreneurial partners reinforces its role as one of Canada's major Smart Ports.

6.3 Port of Halifax

The Port of Halifax is located on Canada's East Coast, close to the main Europe-North America shipping route. As Canada's nineth largest port, Halifax handled 8.2 million tonnes in 2020, including 0.6 million TEU.

The Halifax Port Authority (HPA) initiated its technological shift in the early 2000s with several initiatives focusing on supply chain performance through real-time information sharing and collaboration. As larger Ultra Class Container Vessels carrying over 10,000 TEUs have been using the port, in 2020, HPA acquired a new Saab Port Management Information System (PMIS) to streamline operations by allowing the port, its service providers and community to share information and collaborate. PMIS automates and executes a range of port operations in a transparent manner to all port stakeholders (MLP, 2020).

Like Montreal's port innovation accelerator, in 2021 HPA launched The PIER (Port, Innovation, Engagement and Research) as a living laboratory for transportation, supply chain and logistics. The PIER is designed to serve as a collaborative environment with partners sharing governance, investment, assets, problems, and projects. Essentially the lab will allow partners, entrepreneurs, researchers, and stakeholders to solve "wicked" industry problems and uncover new commercial opportunities. Besides the HPA, The PIER's major partners include CN Rail, PSA (global container operator), Bell Canada, Australia's OMC International, Accenture, Saab Technologies, and Halifax International Airport Authority (Trevor, 2021).

In 2018, HPA joined the blockchain-focused digital global shipping platform TradeLens developed by Maersk and IBM. TradeLens promotes information sharing across the shipping industry to reduce costs, improve productivity, increase the speed of goods delivery, and provide transparency. The collaboration integrates global shipping and trade partners including terminals, shippers, freight forwarders and ports in a single shared and trusted view of supply chain transactions (Peters, 2019).

Most CPAs have installed digital systems to improve operation efficiencies, such as mounting dashboards to provide stakeholders with information to support their decision-making processes. For example, the Port of Vancouver's dashboard provides stakeholders real-time supply chain status, truck terminal wait-times, rail, truck and vessel metrics, along with live webcam video feeds from many locations around the port. Ports have installed sensors at terminal entry gates to automate processing times, web cameras provide security and information to the port's community along with smart lights monitor and control traffic and alert users when a rail-crossing is closed.

Canada Port Authorities continue to adopt Smart Port technologies in their quest to enhance the efficiency and effectiveness of their cargo handling systems.

7 Conclusions: What Lies Ahead for Smart Ports?

Digital technology lies at the heart of Smart Ports, and it will continue to evolve as new innovative systems and applications are developed. For example, maritime service robotics is an emerging field which involves drones to identify vessel pollution, ship hull inspections, checking container stacks, delivering packages to ships at anchor and Remotely Controlled Vehicles (ROV) to inspect ship holds and hulls underwater (Johansson et al., 2021).

An emerging technology that will impact ports are Maritime Autonomous Surface Ships (MASS). Recently, as a demonstration of the technology, a remotely operated tugboat successfully circumnavigated Denmark. The "Nelly Bly" was operated remotely on her 1,000 nautical mile voyage from a control room in Boston (Kingson, 2021). These robotic vessels will need to interact with Smart Port technology to safely enter a port and berth.

In the longer term, innovative cargo handling solutions are being developed, such as the port of Hamburg's "HyperPort" concept. This approach uses the hyperloop technology to rapidly move containers inland to major hub destinations. Preliminary passenger tests have been conducted, now the technology is being considered for other applications including ports (Busse et al., 2021). In the Canadian context, hyperport technology could be used to rapidly ship containers between Montreal and Toronto, reducing truck traffic on the main connecting highway between these two large urban hubs. Similarly, a hyperport link could be developed between Vancouver and the inland port at Ashcroft BC.

Many Canada Port Authorities are partnering with universities and colleges to undertake applied research to address the challenging problems facing ports and their supply chain partners, including developing innovation centres to attract the best talent to tackle these challenges. Most CPAs support maritime-related education through scholarships and bursaries to encourage students to consider working in the ports and maritime sector. In some cases, CPAs sponsor Smart Port challenges seeking innovative solutions from students as part of their educational programs.

As the shipping industry shifts to low- and zero-carbon emissions using alternative fuels, ports will have to develop appropriate infrastructure and systems to support future zero-emissions bunkering operations. Major ports will become energy hubs, particularly as Canada and many other nations adopt green hydrogen as their zero-carbon emission fuel choice (NRCAN, 2020). Vancouver is looking to become an energy hub that uses artificial intelligence to predict patterns of consumption, production, and operations.

Relying on digital platforms to manage business intelligence, CPAs are investing time and resources to become Smart Ports rather than simply serving as cargo handling nodes in the logistics supply chain.

The strong resiliency of CPAs has allowed them to undertake the challenging and resource intensive transformation from a landlord port involved in land development to a fully integrated smart port operating as a network developer. Ports have been benefitted in partnering with universities in cutting-edge research projects in transportation, logistics, big data, artificial intelligence, and digitalization. Canada Port Authorities have learnt to leverage multi-disciplinary expertise in maritime law, urban planning, computer science and engineering to help them develop sustainable operational frameworks for their smart activities. Resiliency coupled with targeted government support has enabled CPAs adapt to the emerging 4th Technological Revolution.

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CHAPTER 10

Concession-Based Project Finance for Smart Ports with a Special Focus on Emerging Economies

Jason Chuah

1 Introduction

There is no denying that smart or automated ports are seen not only as an important solution to the problem of congestions or bottle-necks at ports and blockages in the logistics trail but also as a key plank in many a state's commitment to sustainable shipping (Chen et. al., 2019; Misra, 2017). This chapter turns to the matter of leveling up—the technology divide debate has not dissipated. Despite the febrile enthusiasm for smart or automated ports in the west, it must not be ignored that better connectivity and enhanced sustainability achievements could only be secured

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where the developing and emerging economies are also factored into the agenda of action.

As far as the emerging economies are concerned, certainly there are various reasons or issues limiting progress—one key limitation is the lack of access to financing. This chapter thus takes up the role of project financing in the development of smart ports in the developing economies. In particular, the question of concession financing. A traditional concession-based project finance endeavor is based on the state "giving" a concession or property right to the investors. In the matter of smart ports, property rights might pose a difficulty for the concessionaire. A smart port, by definition, is a hybrid of physical and cyber assets. Emerging economies, especially, need to develop a legal framework or infrastructure to respond to the brave new hybrid world of the virtual and physical. This work evaluates how that response might look like. It should be stated at the outset that not all states may adopt a legislative framework, preferring to leave project financing or private financing for infrastructure projects to private law regulation (notably contracts) (Pédamon, 2000).

Another important caveat is that not all public–private partnerships (PPP) for the provision of project financing are concession based. This chapter is content to focus on those which are, principally because in the context of developing economies a concession-based structure is more commonplace in the development of ports. This chapter is also not concerned with the issues of risk allocation and distribution, and bankability in relation to smart port investment by private investors.

2 Forms of Private Financing in Infrastructure

The World Bank generally recognizes three forms of private financing in infrastructure (IBRD, 1996):

(a) Purchase of public utility enterprises;
(b) Provision of public services without development of infrastructure;
(c) Construction and operation of public infrastructure.

2.1 Purchase of Public Utility Enterprises

Here, private investors, foreign or domestic, are given the right to acquire physical assets or the shares of a public utility undertaking. In the case of a port, the investors would thus be entitled to acquire a parcel of land on terms similar to other immovable property transactions permitted by the law of the country in question. The latter is slightly more sophisticated and allows the private investor to take control of all assets, including physical, ethereal, receivables or chose in action rights, of the public utility undertaking. Therein perhaps lies the difficulty for emerging economies where the public utility undertaking might not have been set up as a corporation with controlling shares which could be transacted on.

Although in a good number of jurisdictions there are national laws on the disposal of state property, many of these laws are based on colonial, pre-Independence notions of property—the context in the main being that of physical assets and chose in actions. A port may have a range of cyber-rights—including intellectual property, data, user licenses, and permissions. Whilst some of these are capable of being transferred to a "successor in title" by contract (for example in English law), these may not be properly classified as transactable under the state's private finance initiative or public–private partnerships laws. Hence, a drive to attract project financing for smart ports should start with a review of existing project finance legislation. Legislative enactment may be needed too to facilitate such concessions.

2.2 Provision of Public Services Without Development of Infrastructure

It is also entirely conceivable that the state might not wish to relinquish control over its physical asset, such as a port. In this type of infrastructure financing, the state may legislate for a private entity or investor to supply "public services" by means of licenses. In the context of a smart port, these could include establishing optimized operations, grid compliance and flexibility, enhanced communications using 5G, the electrification of shipping and logistics, and the development of new digital skills for port workers and users. From a sustainability perspective, the service provider might also be invited to provide on a license basis digitized know-how and AI led systems on power-use efficiency in port operations.

It is for the law of the host state to specify the kind of qualifications and criteria the service provider is expected to satisfy before being given the license to supply such services. Indeed, it is also envisaged that in the interest of transparency and open competition for the licensing procedures to require interested parties to make tenders through a public tendering system.

2.3 Construction and Operation of Public Infrastructure

Naturally a simplistic though not risk-free type of infrastructure investment is where the state gives the investor a concession to construct and operate the public infrastructure. In this scenario, the private entity is engaged to provide both works and services to the public. National laws will normally ensure that appropriate systems are put in place for the public procurement exercise. Some of the risks or challenges with this form of financing in the smart port context include the risk of control and accountability in the infrastructure being dissipated or reduced. In the smart port context where AI systems could have an expansive impact on data rights, security and safety interests, control and accountability are especially important considerations.

3 The Smart Port Template

It is perhaps apposite now to turn our attention to the notion of smart ports, especially in the context of emerging economies. It is not the intention here to retrace the historical evolution of the term "smart," whether in the context of ports or elsewhere. It suffices to state whilst smart might largely be taken to connote technology, some have pointed out too that it is about a state of mind (Martin, 2020). For our purposes, a reasonable working concept is needful for several reasons. First, where legislation is needed to facilitate the financing of smart port projects, a working definition or concept is useful for legal clarity. Secondly, clarity of concept is needful where recipient states or investors seek out funding opportunities established by various benevolent or aid organizations. Those organizations would ordinarily have established the parameters for their funding commitments to "smart" projects. Hence, some clarity of concept would help investors or host states find the right fit for their intended infrastructure project. Thirdly, increasingly more countries are developing laws and regulations on the control of use of certain technologies, such as AI systems. Ensuring compliance in the provision or facilitation of smart port services is better served by understanding "smart."

Smart ports might be said to be essential infrastructure which uses technologies such as AI, the Internet of Things, Big Data, Blockchain technology, augmented reality, and other smart and data-science-based interfaces (such as data-based marine Automatic Identification Systems) in the provision of traditional services (Oztemel, 2020). Crucially these technologies serve to cyber-connect the port and its operations to other users and providers in the wider networked maritime trade. From a non-technical perspective, the smart port is different to the traditional port in several respects. In the pre-container era, ports were largely a defined locality for the loading and discharge of goods intended for trade. They were largely owned and controlled by the state and whilst trade might be important, the port was also intended to serve as a point for border controls. In subsequent years, with containerization and multimodalism, ports became more closely linked to industrialization and the factories and production units. Now commonly called the third-generation era, ports are no longer merely the points of connection between land and sea but can serve through virtual networks as connection nodes, beyond the physical, between various stakeholders. Those stakeholders may be cargo receivers, shippers, government, industrial and mining hubs, and other places in the supply chain. The connected port is also increasingly perceived not merely as a trade-supportive measure, but as an effective national security contraption (Min, 2019). These stakeholders may even be based in other countries.

An important aspect of a smart port might be that the "port" need not be constrained geographically. That means the traditional view that a port is defined geographically or by location must yield to cyber-connectivity. Legislation defining ports for the purposes of investment and financing will also need revisiting. Taking the Port of London, UK as an example we see the Port of London Act 1968 providing in s. 5(1A) the power to the Port Authority to "provide, maintain, operate and improve such port and harbor services and facilities in, or in the vicinity of, the Thames as they consider necessary or desirable and to take such action as they consider incidental to the provision of such services and facilities." Moreover, s. 5(2) states that the Port Authority shall have power either themselves or by arrangement between themselves and another person to take such action as the Port Authority consider necessary or desirable whether or not in, or in the vicinity of, the Thames—(a) for the purpose of discharging or facilitating the discharge of any of their duties, including the proper development or operation of the undertaking; (b) for the provision, maintenance, and operation of—(i) warehousing services and facilities; (ii) services and facilities for the consignment of goods on routes which include the port premises; (c) for the purpose of turning their resources to account so far as not required for the purposes of the undertaking. Both provisions, one in relation to the general duty of maintenance, operation (s.5(2)), and improvements and the other in relation to ancillary powers (s.5(1A)), refer specifically to the vicinity of the river Thames.

However, in the context of a smart port, it is fairly obvious that connectivity could well mean that there is a cross-over of the virtual/cyber and physical and the traditional port area where ships call could well be linked to the hinterland or other regions (Molavi, 2020). This cyber-physical system (CPS) seeks to integrate sensor technology, data computation, and information networking into physical objects and infrastructure by connecting them to the Internet of Things (IoT) (NSF, 2018; Min, 2022). Sensor technology has made the demarcation between the human and machine must less stark; sensor technology predominantly aims to transform a physical "phenomenon" into an "electronic signal" which copies or mirrors human sensing capabilities (such as visual-spatial, musical-rhythmic, verbal-linguistic, logical-mathematical and bodily-kinaesthetic sensing) (Wilson, 2005). One commentator went on to comment, "since the improved connectivity among multiple ports, carriers, and shippers enables them to communicate and interact with each other more frequently, the CPS can be a catalyst for establishing collaborative commerce that creates synergistic effects via electronically linked port activities and related business transactions. Considering the aforementioned benefit potentials, it is worth assessing the true value of CPS and exploring the possibility of CPS applications to port environments." (Min, 2022).

CPS applications to ports are envisaged to play an important role in continuing the growth of smart port development. Indeed, it has been reported that the global smart port market would reach USD13.9 billion by 2027 at a cumulated average growth rate (CAGR) of 32.4% (Grandview Research, 2020). That pie is largely to remain untapped in emerging economies, without significant private or international financing. Compounding that is the fact that challenges associated with the maritime logistics interoperability, scalability, and security do render

CPS applications to ports more difficult than say, in education, security, health care, and other transportation sectors (Chen, 2017).

It follows thus from a policy perspective that it would be self-defeating to exclude cyber and cyber-physical infrastructure financing from the notion of port investment and financing.

4 Awarding the Concession for Smart Port Development

The UNCITRAL Model Legislative Provisions and the Legislative Guide 2019 are especially relevant in our evaluation as those provisions are distinctly recommended by the UN for national states to incorporate and embed in their legal systems for the facilitation of privately financed infrastructure projects. The 2019 Model Legislative Provisions and the accompanying Legislative Guide had sought to update, expand, and replace two earlier texts prepared by UNCITRAL, namely the Legislative Guide on Privately Financed Infrastructure Projects, which was adopted by UNCITRAL at its thirty-third session (New York, 12 June to 7 July 2000), along with the Model Legislative Provisions on Privately Financed Infrastructure Projects. These are generalized instruments and do not expressly make mention of port infrastructure projects. However, it would be helpful to examine the implications those provisions have for smart port investments, especially for emerging economies. The recommended legislative rules and the guide are highly relevant to emerging economies. These countries, unlike developed economies, are more likely to use and adopt the model laws from the UN as their own legislation to govern and manage public–private partnerships (see Wallace Jr, 2000b referring to the Legislative Guide on Privately Financed Infrastructure Projects).

The awarding of a concessionaire carries with it risks for both the awarding state and the investors. For the investor, the concession awarding exercise must command confidence and trust. For the state in question, there are critical pressure points where the risk of corruption to the risk of loss of public assets without proper accountability are real. Hence, the UNCITRAL Model Legislative Provisions attempt to delineate certain good practice guidelines for states. As regards the concessionaire, the Model Law makes it clear that concessions should be awarded on the basis of competition, transparency, efficiency, and fairness (Nicholas, 2012). An important corollary of the objectives of economy, efficiency, integrity, and transparency is the availability of administrative and judicial procedures for the review of decisions made by the authorities involved in the selection proceedings.

On competition, it is often suggested that an open competitive bidding process would secure the most competitive and fair tender for the concessionaire (UNCITRAL, 2019) at paras 5–16). The risk of abuse and corruption is obviously a concern with any other form of selection process. However, in the case of smart ports, it should not be assumed necessarily the open competitive tender selection process has to be optimal. The UNCITRAL Legislative Guide on Public–Private Partnerships does provide for a few limited exceptions to bypassing the open the tender system in preference for direct negotiations as a form of selection (see too Nyagormey et al., 2020, for a review of the criteria for evaluating unsolicited PPP proposals in the construction sector). These are:

(a) When there is an urgent need for ensuring the immediate provision of the service and engaging in a competitive award procedure would therefore be impractical, provided that the circumstances giving rise to the urgency were neither foreseeable by the contracting authority nor the result of dilatory conduct on its part. Such a special authorization may be needed, for instance, in cases of interruption in the provision of a given service or where an incumbent private partner fails to provide the service at acceptable standards or if the PPP contract is rescinded by the contracting authority, when engaging in a competitive award procedure would be impractical in view of the urgent need to ensure the continuity of the service;
(b) In the case of projects of short duration and with an anticipated initial investment value not exceeding a specified low amount;
(c) Reasons for national defense or security;
(d) Cases where there is only one private operator capable of providing the required service (for example, because it can be provided only by using patented technology or unique know-how).

Smart ports investment thus sits in a difficult position. At one level, smart ports might well fit within the technology and unique know-how exception in para (d) but para (d) is framed very narrowly. That may well make it difficult for smart ports even to qualify for an exception from the open tender process. However, given the importance of intellectual property rights in any national policy to encourage smart technologies, such as Big Data, Internet of Things, Blockchain, and AI, closing off the direct negotiations option might not be productive. Emerging economies stand at even a greater risk of failing to attract tech investors because intellectual property rights protection and enforcement might not be ideal. These countries will thus need to legislate or lay down very carefully the selection process for smart technology investment, including as regards smart ports. Procedural integrity, efficiency, and fairness might be protected to an appreciable extent if the following steps are integrated into the direct negotiations system.

(a) The state could require that the awarding agency must seek the approval of a higher authority prior to engaging in contract award through direct negotiations where certain threshold criteria are met. For example, the value of the project, the duration of the project, and the scale of the project could well be articulated at the outset;
(b) Ensuring that the approval process is formal—for example, the approval must be in writing and cannot be given by proxy, etc.;
(c) Placing a legal requirement for at least a minimum number of providers with whom the awarding authority or agency must seek out before concluding the final award;
(d) Where certain threshold criteria are met, the awarding authority is required to publish the invitation to tender or bid in specific media outlets to ensure that the field of interested bidders might be as wide as possible. The invitation however will need to be explicit about the technical requirements or specifications of the project; and
(e) As regards the negotiation exercise itself, it might be useful for the law or administrative guidance to require the deployment of similar questions and criteria for the negotiations. That ensures some degree of fairness between bidders. It is also advisable for the awarding authority to rely on independent third-party experts to participate in the negotiations. It is further submitted that as emerging economies are unlikely to have deep pockets to pay for experts and consultants, an international agency with a brief for smart ports might be prevailed upon to assist. The IMO for

example as part of its Blue Economy agenda of action could be a useful pillar.

Competition has also been previously seen through the lenses of how ports are controlled or managed by the state. The UNCITRAL pointed out in its Legislative Guide on Privately Financed Infrastructure Projects 2001 (now superseded by the 2020 Public Private Partnerships Guide) that as far as ports are concerned:

> In many countries, ports were until recently managed as public sector monopolies. When opening the sector to private participation, legislators have considered different models. Under the landlord-port system, the port authority is responsible for the infrastructure as well as overall coordination of port activities; it does not, however, provide services to ships or merchandise. In service ports, the same entity is responsible for infrastructure and services. Competition between service providers (e.g., tugboats, stevedoring and warehousing) may be easier to establish and maintain under the landlord system. (Legislative Guide on Privately Financed Infrastructure Projects 200, at para 42)

It is patently clear that this landlord system is unlikely to remain the dominant form as regards smart ports. The separation of responsibilities is based largely on the discreteness of the supply or logistics chain as presently understood and structured. With the interconnectivity envisaged by smart ports, where the "port" is likely to be a node at which different operations and services intersect, that separateness or discreteness is a fiction.

5 Subject Matter of the Concession

In the matter of smart ports, a specific challenge is defining in the national domestic legislation what it is that the state is giving the concession in respect of. In the conventional port infrastructure financing, the key subject matter is often the physical infrastructure—be it the land or a pre-existing facility in question coupled with the relevant services in question. In the case of a smart port, let's assume it is a license over a cyber provision which is being conceded by the state to the investor. For example, the state is seeking investment for the design, building, operation, and transfer (DBOT) of a closed or open blockchain. Such an "asset" to be licensed will need to be properly described in the concession agreement and/or the enabling legislation (Wallace Jr, 2000a). In the context of an emerging economy, it becomes thus crucial that the appropriate form and substance in the enabling legislation should be in place prior to the solicitation of such type of financing. The enabling legislation is important given that the UNCITRAL recommendation is that the project agreement and notably the concessionaire should be governed by the law of the host country (UNCITRAL Legislative Guide on Privately Financed Infrastructure Projects 2001, Recommendation 41).

It is apposite that the 2001 Legislative Guide provides in Recommendation 44:

> The project agreement should specify, as appropriate, which assets will be public property and which assets will be the private property of the concessionaire. The project agreement should identify which assets the concessionaire is required to transfer to the contracting authority or to a new concessionaire upon expiry or termination of the project agreement; which assets the contracting authority, at its option, may purchase from the concessionaire; and which assets the concessionaire may freely remove or dispose of upon expiry or termination of the project agreement". (2001 Legislative Guide, Recommendation 44)

That recommendation which would have found its way into many national legislations on privately financed infrastructure projects or public–private partnerships clearly envisaged property rights in a traditional sense. Such definitions should therefore be reviewed and clarified in the case of smart port investments.

Similarly, the Legislative Guide 2001 also recommends that the concession should not be assigned to third parties without the host state's consent (recommendation 50). The rationale is to prevent the loss of control of the asset to a third party who might not have been vetted as rigorously as the original concessionaire or ensure that the original concessionaire remains legal accountable. However, it is also pellucid that in certain cases assignment of the asset in question is not only important for financing reasons but also, for technological improvements and enhancements to be introduced by the third party. Other than following the recommendation of the Legislative Guide in delineating the parameters and conditions governing when consent by the host state should be given, there should be proper regard to the legal framework too. One of the more fundamental aspects of the host state's civil law therefore, should be to enable, inter alia,

(a) the recognition of smart or cyber-rights and assets;
(b) the transfer or assignment to take place legally; and,
(c) the collateralization and/or sub-division of the cyber-rights or assets.

It is useful to mention that in the UK for example, much work had been undertaken to create certainty around smart contracts and cyber-rights. The UK Jurisdiction Taskforce (UKJT), a taskforce of the Law Society's LawTech Delivery Panel, published in 2019 a statement on the legal status of cryptoassets (such as Bitcoin) and smart contracts. The so-called Legal Statement had been described by Sir Geoffrey Vos, Chair of the UKJT, to be "a watershed for English law and the UK's jurisdiction" and was "genuinely ground-breaking" as no other jurisdiction, at the time, had attempted to define the legal status of cryptoassets and smart contracts. The Legal Statement is certainly not law but the Law Commission had not disagreed with its findings in the latter's work on smart contracts (UK Law Commission, 2021).

English law is notorious in its reluctance to define "property." However, an important and authoritative description of the necessary characteristics of property can be found in *National Provincial Bank v Ainsworth* [1965] AC 1175 where Lord Wilberforce said that, before a right or an interest could be admitted into the category of property, it must be definable, identifiable by third parties, capable in its nature of assumption by third parties, and have some degree of permanence or stability. Certainty, exclusivity, control, and assignability have also been identified in the case law as characteristics of property rights.

The Legal Statement affirms that in general terms cryptoassets have all the legal features of property and should be treated as property, as a matter of legal principle. Whilst it finds that a virtual cryptoasset could not be physically possessed and are not chosen in actions, it concedes that some types of security could be granted over cryptoassets. It is submitted that although the Legal Statement was not directly concerned with cyber or data rights or assets (which could be distinguished from cryptoassets), the legal analysis applied would be useful in characterizing the proprietary nature of cyber or data rights. It is not intended to develop this plank of the argument any further other than stressing that these proprietary aspects of cyber or data rights are important when defining the subject matter for the concession.

A related question on characterization or definition is whether the "asset" to be made the subject matter of the license or concession is simply a "service." Naturally, if it were a plain and simple a public service which has been licensed to a private entity, that is well within most project finance legislation (see for example Recommendation 53, Legislative Guide 2001). However, in the case of smart ports, it is not always a discrete service which is being "privatized." It is a collection of physical systems, networks—open and closed sources, artificial intelligence decisions (existing or not yet in existence), data, etc. Defining thus the subject matter of the concession poses considerable challenges for the host state, especially a developing country.

6 Building the Smart Port Implementation Objectives into the Concession

The enabling legislation for the smart port concession would also need to be explicit about the policy objectives. The main challenge for host states in this respect is the lack of clarity as to what is being sought—it is of course one thing seeking private financing for the entirety of the smart port (noting that the smart port is necessarily more than the locality of the port) and quite another seeking financing for certain more narrowly defined technologies or technical services or equipment to be used in the smart port.

A host state needs to recognize or indeed establish the implementation plan for smart ports, defining the key performance indicators. Taking the introduction of the Internet of Things to a smart port project as an example, the host state might structure the plan into three phases:

(a) smart port infrastructure;
(b) smart port transportation; and
(c) smart port logistics.

This is of course a more simplistic model compared to the broad template discussed earlier. However, for the purposes of setting a narrowly defined smart port project these three phases should prove helpful.

Using IoT technology to upgrade from a traditional port supply chain to Smart Port clearly requires significant investment but the host state needs to set out what the investment should be directed at. In the context of IoT, the financing might focus on creating more efficient technologies (sensors, smart devices, cloud computing, etc.) and overcoming problems and impediments. It is vital to see financing simply as a means to create technologies but also a means to remove or reduce obstacles and risks. In the IoT and smart port context for example, research has shown that there are three obstacles or challenges investment can play an important part at addressing (Belfkih et al., 2017, at 1–2; Wiegmans, 2008):

(a) Heterogeneous technologies: the large equipment list and standards used in the port produce and exchange a large amount of data. Smart coordinators (middlewares) between the different actors and processes (terminal operator, logistical chain, vessel arrivals, departures information, etc.) are needed therefore to analyze and extract relevant data. It might also be possible to use SQL-like language with the IoT technology, to query and test sensor devices based on a sensor database approach;
(b) Large variety of data types: a large amount of data (AIS data, traffic data, logistic data, etc.) is used in the port. Investment should therefore aim at devising an efficient method to process and analyze them. Using the Big Data and data mining technologies to analyze and extract the pertinent data can provide the necessary tools for the IoT to accommodate the large variety of data in the port (Boullauazan et.al., 2022). Thus, investment in this defined activity would go some distance at supporting the transition to a smart port;
(c) Data transparency and security: logistic companies sought easily accessible information and a great deal of data transparency from the port. The IoT technology provides a data free flow and sharing concept between the different smart devices. Data is aggregated and analyzed to facilitate the interchange of information. Financing is required to provide for this level of interchange whilst at the same contractual and administrative controls should be in place to control how competing companies might be allowed to access shared data (Belfkih et.al., 2017, at 1–2; Wiegmans, 2008).

It is also to be advocated that there should also be an overarching objective to ensure that the smart port implementation activities and milestones are reflective of the state's commitments to sustainability (Ozturk, 2018) and its national security interests (Heilig, 2016; Weber, 2010).

7 Conclusions

It is not the intention of this chapter to address every aspect of smart port investment from a project finance perspective. The key findings in this research are that although many of the challenges to framing an appropriate legislative response to encouraging private investment in smart port projects are common to all states, some of the problems enabling the transition are more acute for emerging economies. This work also looks at how the amorphous concept of smart port has led to a lack of clarity in the legislative framework for supporting private financing in smart ports, especially in developing economies. It then makes some modest suggestions on how the legislative response might change better to accommodate the successful and needful transition from the classical port model to the smart port.

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CHAPTER 11

Smart Port State Enforcement Through UAVs: New Horizons for the Prevention of Ship Source Marine Pollution

Gabriela Argüello

Takeaways

1. Port State jurisdiction for the prevention of ship source pollution will continue to grow in relevance because UAVs assist in practices related to the territorialization of extraterritorial offenses.
2. UAVs and other surveillance technology allow States to influence ship's behavior en route to port.

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3. UAVs' deployment is a fundamental piece in emerging ubiquitous surveillance practices and their use must consider privacy and human rights issues.
4. UAVs are assimilated as aircraft to ensure their smooth incorporation into the legal system.
5. UAVs' assimilation as aircraft does not consider that the primary purpose of UAV is not aerial navigation between points A to B. Instead, UAVs are mainly data collection devices.

1 Introduction

The adoption of the UN General Assembly Resolution 'Transforming our World: 2030 Agenda for Sustainable Development' and its related Goal 14, 'Life Under Water,' recognized the fundamental importance of conserving healthy marine ecosystems and finding pathways for sustainable use of its resources (United Nations General Assembly, 2015). Such recognition was followed by the UN declaration of a Decade of Ocean Science for Sustainable Development from 2021 to 2030 to support the achievement of Sustainable Development Goal 14. Identifying and reducing marine pollution sources is fundamental to achieve marine environmental protection targets. Despite prolific regulatory and policy efforts, monitoring and enforcement gaps are still pervasive in the environmental law realm (Abbot, 2009; Tan, 2006). Technological development is perceived as a fundamental tool in closing such gaps.

Unmanned aerial vehicles (UAVs) are deployed to increase Maritime Domain Awareness and to enhance regional information systems. These vehicles with different levels of automation are becoming popular monitoring and enforcement tools for protecting the environment (Dooly et al., 2016; Klemas, 2015; Krystosik-Gromadzińska, 2021; Telesetsky, 2017; Wich & Koh, 2018). However, monitoring and environmental enforcement is only one example of possible UAVs' application. UAVs will increase surveillance activities in a wide range of areas including the detection and enforcement of illicit acts committed at sea (e.g., drug trafficking, maritime terrorism, piracy, human trafficking) and maritime safety, including search and rescue operations at sea (e.g., Klein, N., 2019).

It is important to notice that terminology and acronyms concerning UAVs vary significantly in the literature. Much of this terminology relates to the vehicle's level of automation, ranging from those that require human assistance to those that are fully autonomous and have decision-making capacities. In this paper, UAVs refer to aerial vehicles which do not have a pilot on board, and it encompasses several degrees of automation described in Table 1. If necessary, the text will distinguish between remote-controlled vehicles or autonomous vehicles (Table 1).

UAVs are also gaining popularity in the field of ship source pollution monitoring and enforcement. Their deployment could strengthen Port States remarkably since enforcement jurisdiction "depends upon knowing who is doing what where." (Guilfoyle, 2021) Scholars and policymakers highlight the benefits of using UAVs, such as drones, as cost-effective devices that can manage substantial data volumes while reducing human labor requirements and, foremost, eliminating human error (Paddock & Crowell, 2021; van Hooydonk, 2019). In the case of ship source pollution, UAVs could access sea areas that are either

Table 1 Levels of UAVs autonomy

Level of automation	*0*	*1*	*2*	*3*	*4*	*5*
Description	No Autonomy	Low Autonomy	Partial Autonomy	Conditional Autonomy	High Autonomy	Full Autonomy
Remote Pilot role	Experimented and trained pilot in charge	Pilot is still in control	Pilot is still in control	Pilot is there only in cases of emergency Artificial Intelligence (AI) decision-making	Pilot is not needed to control the flight. Pilot monitors the flight AI decision-making	No pilot. The UAV does not allow intervention in the flight management. AI decision making
Obstacle avoidance capacities	**None**	**Sense and alert:** equipped with sensors to identify obstacles such as walls. Level 2 UAVs can warn about these obstacles		**Sense and avoid:** sensors can detect obstacles and other hazards. Interact and make decisions with the traffic signals	**Detect and navigate:** UAVs can fly without a pilot in complex environments	

Source CloudFactory, 2021; Pohudina et al., 2022; Protti & Barzan, 2007 remote or cost prohibitive, monitor illegal and accidental discharges and assist in measuring water quality parameters (Paddock & Crowell, 2021). They can also deter illicit discharges and improve the accuracy of tracing the ship responsible for illegal discharges (Smith-Godfrey, 2021; Thompson & Davies, 2021). Despite the promises offered by the development of this technology, its governance is yet to be comprehensively addressed. Mainly, UAVs' deployment to prevent marine pollution is intrinsically linked with maritime surveillance practices.

This chapter will not discuss in depth the rationale of environmental regulation or the particular compliance and enforcement challenges that have already been extensively addressed (Abbot, 2009; Hedemann-Robinson, 2019). Based on this literature, I focus instead on the possibilities and limits of UAV technology to assist enforcement activities and the implications within the realm of maritime surveillance, data collection and aviation. Following these introductory remarks, the rest of the paper is structured as follows. Section 2 discusses the public perception of ship source pollution and how UAVs could make more visible small and recurrent pollution events that have cumulative impacts on the marine environment. Section 3 introduces Port State jurisdiction and its increasing relevance in ship source pollution prevention. Section 4 analyzes UAVs' legal status, the legal basis for data collection and emerging surveillance concerns. Section 5 presents the conclusions.

2 Public Perception of Ship Source Pollution

According to the United Nations Conference on Trade and Development (UNCTAD) (2021), over eighty percent of the volume of goods is carried by sea. From 2020 until mid-2021 international seaborne trade reached a total volume of 10,7 billion tons. Since shipping is vital to seaborne trade, such quantities are expected to grow, especially after the shipping industry recovers from the devastating effect of the COVID pandemic that disrupted supply chains and logistics worldwide. Additionally, the merchant fleet is also on the rise. In 2021, the commercial fleet reached over 2.1 billion deadweight tons (dwt), with an increase of three percent over the last year (UNCTAD, 2021). Considering the fundamental role of shipping in international trade and the related obligations to protect the marine environment from ship source pollution sources, it is not surprising that shipping is strictly regulated. To mention a few, regulatory standards for the prevention and mitigation of ship pollution are established in the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL), the International Convention for the Control and Management of Ships' Ballast Water and Sediments 2004 (BWM), the International Convention on Oil Pollution Preparedness, Response and Co-operation 1990 (OPRC) and the International Convention on the Control of Harmful Substances Anti-fouling Systems of Ships, 2001.

Despite the wide regulatory attention to prevent marine pollution, public perception usually links ship source pollution with significant oil spills. One may imagine a wrecked tanker spilling thousands of tons of heavy oil. The oil is then washed ashore, affecting the coastal environment and causing severe socio-economic impacts on activities such as tourism and fisheries. To name a few of these incidents, the *Torrey Canyon* (1967) was wrecked on the western coast of England; the Exxon Valdez (1989) caused a significant oil spill in the west of Tatitlek, Alaska; the *MV Erika* (1999) sank in the Bay of Biscay in France and leaked almost 20 000 tons of heavy fuel oil; the *MV Prestige* (2002) caused a major leakage on the Atlantic coast of Spain (Coelho, 2018; Marten, 2014; Rue & Anderson, 2009; Tan, 2006) and the *MV Wakashio* (2020) caused an oil spill off the coastline of Mauritius (Upadhyaya, 2021). These events caused international outcries and prompted immediate mitigation, remedy and enforcement actions. However, the comprehensive regulatory framework dealing with the prevention of ship source pollution has had positive effects in reducing major accidental oil spills. According to recent statistics from ITOPF Limited, oil spills have reduced considerably over the years, both in quantity and frequency (ITOPF, 2022).

Although accidental oil pollution from ships attracts social attention as no other harmful substance, ship source pollution is not confined to accidental oil spills, nor is it the most significant source of marine pollution. Most marine ship source pollution incidents are diffuse and have cumulative impacts on the marine environment. UAVs are particularly important to deter, identify and eventually enforce these small accidental and illegal discharges. The data collected could also raise social awareness about the pervasive nature of ship source pollution. Such awareness is fundamental to gaining support for actions directed to prevent, mitigate and remedy marine pollution (Lotze et al., 2018). It is essential to consider that ships may discharge many harmful substances into the marine environment, including oil, hazardous chemicals, sewage, garbage, alien species transported in ballast water and air pollutants. The latter enter the ocean through the atmosphere. Discharges can be operational and accidental (Argüello, 2019; Boyle & Redgwell, 2021; Tanaka, 2018). Small accidental and illegal discharges may cause significant environmental damage. Still, those are certainly more difficult to identify and even if discharges are noticed, the identity of the infringing vessel may still be unknown. Without such essential information, the possibilities of enforcement are bleak. This may change with the advent of UAVs. These small and cost-efficient aerial vehicles could monitor extensive maritime areas to collect a vast amount of data that could be used to enforce ship source pollution violations and possibly act as a deterrent mechanism against illegal discharges.

3 Port State Enforcement of Ship Source Pollution Standards

Port State enforcement jurisdiction intends to counteract the perceived deficiencies of Flag State jurisdiction (Marten, 2014; Molenaar, 2021; Rayfuse, 2016). In the realm of marine environmental protection, Port State enforcement grew considerably in scope and relevance after the adoption of the UN Nations Convention on the Law of the Sea (UNCLOS); the inclusion of Port State inspections in most of the treaties adopted under the auspices of the International Maritime Organization (IMO), and the development of nine regional Memoranda of Understanding (MoUs) concerning Port State Control. Article 218 of UNCLOS put the Port States into a privileged position to exercise extraterritorial jurisdiction to enforce international discharge standards when vessels lay voluntarily in the port. Such measures are established, for example, under the MARPOL or the BWM Convention. Arguably, self-regulatory efforts also contribute to the prevention of ship source pollution. A notable example is the Ship Inspection Report Programme (SIRE) that the Oil Companies International Marine Forum (OCIMF) established in the early 1990s to counteract substandard tankers. SIRE uses a uniform inspection protocol and the collected information is recorded on a database accessible to OCIMF members (Theotokas, 2018).

In this chapter, I discuss whether UAVs can enhance the enforcement powers of States as prescribed in article 218 of UNCLOS. This article deals with extraterritorial offenses, which should be understood as discharges occurring in areas beyond national jurisdiction. Port States may even enforce international standards when discharges occur in areas subject to the jurisdiction of another State if that coastal State requests the Port State to take enforcement actions. Having shared information systems may facilitate this cooperative enforcement approach. Arguably extraterritorial enforcement jurisdiction can only be exercised based on treaty norms (*M/V Norstar (Panama v. Italy) (Merits)*) and it is subject to the safeguards prescribed in UNCLOS' Part XII, Sect. 7 and the prompt release procedure prescribed in article 292. Of course, Port State jurisdiction could also be territorial (i.e., when the alleged illegal discharge occurs in internal, territorial sea and archipelagic waters) and quasi-territorial (i.e., discharges in the Exclusive Economic Zone) (Coelho, 2018; Molenaar, 2021; Ryngaert & Ringbom, 2016).

Port States enjoy an advantaged position to verify and enforce ship source pollution standards of foreign vessels while physically located at the port. However, the exercise of this jurisdiction is dependent on Maritime Domain Awareness (MDA). Not much can be done without information concerning potential illegal discharges and the identity of delinquent vessels. UAVs may support Port States in accessing and sharing the required information. The current trend is to frame the deployment of UAVs as an innocuous technological alternative to implementing existing regulatory frameworks and enhancing monitoring capacities. Guilfoyle (2021) calls this a turn to informality in maritime security, i.e., where several stakeholders, including governmental, non-governmental institutions, civil society and industry, engage in cooperative mechanisms without recurring to formal law-making process, e.g., treaty-based obligations. A case in point is the Common Information Sharing Environment (CISE) for the Maritime Domain. This is a European Union (EU) voluntary initiative to develop swift shared information systems between actors involved in maritime surveillance across several sectors, including ship source pollution (European Commission, 2019a). Since 2019 the European Maritime Safety Agency (EMSA) has been in charge of CISES's operationalization which requires the combination of several surveillance systems, including UAVs (European Commission, 2019b; Tikanmäki et al., 2021). The following section discusses the potential and limitations of using UAVs in monitoring and enforcement activities.

4 New Technological Horizons for Port State Enforcement

Although their governance is still unresolved, UAVs are already being used and tested in the transition to smart ports. The Port of Antwerp is becoming a leader in the possible uses of this technology. In 2021, it began testing autonomous drones as safety, security and monitoring tools. Their testing covers various activities, including "infrastructure inspection, surveillance and monitoring, incident management, berth management, and oil spill or drift detection." (The Maritime Executive 2021) The Port of Rotterdam and several Northern European Ports are also testing this technology (Turner, 2021). EMSA has several projects to surveil and monitor ship emissions in the Baltic Sea with remotely piloted aerial vehicles (RPAV). These RPAVs carry sensors that can measure, for example, sulfur oxides and CO2 emissions in a ship's plume and sensors that facilitate the identification of delinquent vessels (European Maritime Safety Agency (EMSA), 2020).

Arguably non-military uses of UAVs are multiplying, but we need to consider if this technological development can be accommodated within existing legal structures and what disruptions can be anticipated. Most importantly, potential abuses remain to be addressed.

4.1 Legal Status of UAVs and Marine Data Collection

UAVs include a variety of vehicles such as drones, balloons, remoted unmanned systems, gliders, airplanes and rotorcraft (Fiallos Pazmiño, 2020; International Civil Aviation Organization (ICAO), 2011). At the international level, ICAO's non-binding Circular No. 328 (2011) assimilated the legal status of UAVs to 'aircraft,' a term that is not defined under the 1944 Convention on International Civil Aviation (Chicago Convention) (Mendes de Leon & Scott, 2016). ICAO (2011) does define aircraft as "any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface." This means that vehicles such as floating sea gliders are excluded from this definition (Bork et al., 2008). According to ICAO's Circular 328 (2011) the status of aircraft is not affected in cases where pilots are remotely located or in cases of fully autonomous vehicles where pilots are no longer required. Undoubtedly, this assimilation is an alternative to avoid significant legal disruptions caused by technological developments and to fit UAVs with international and regional aviation frameworks.

At the EU level, article 3 (1) of the Commission Delegated Regulation EU 2019/945 also defines UAVs as aircraft that are either piloted remotely or are fully autonomous. National law is also relevant when considering the legal status of UAVs and their applicable legal framework. In accordance with article 96(b) of the Chicago Convention, this treaty regulates international aviation, i.e., transit through the air space over the territory of more than one State. UAVs operating exclusively on a State territory (including internal waters and the territorial sea) are subject to national legislation. On the high seas, UAVs, like any other aircraft are subject to the Chicago Convention (article 12). ICAO's rules also apply to UAVs exercising transit passage and archipelagic sea lanes passage rights in accordance with articles 39(3)(a) and 54 of UNCLOS. There is a disagreement, however, about aircraft operating in the air space above the EEZ. UNCLOS is silent on whether aircraft should follow ICAO's rules or national legislation (Churchill et al., 2022; Matthew & Camilleri, 2018; Molenaar, 1999). It appears that ICAO rules are applicable in air space above the EEZ. Such interpretation follows from the legal status of the EEZ. In this *sui generis* maritime zone, Coastal States have sovereign rights to conserve, explore and exploit natural resources. In principle, such rights do not radically change the jurisdiction concerning overflight in the airspace above the EEZ. This interpretation is in line with article 58(1) of UNCLOS, which refers to the right of overflight in relation to article 87, which refers to the freedoms on the high seas. According to the Virginia Commentaries, the reference to article 87 "made it clear that freedoms to be enjoyed in the exclusive economic zone were, for the most part, the same as those enjoyed on the high seas" (Nandan et al., 1993, 563).

From a law of the sea perspective, the assimilation of UAVs as aircraft is relevant to scrutinizing the eventual rights of overflight of UAVs over the air space above zones within and outside the jurisdiction of States. The spatial boundaries of vertical sovereignty over the air space remain, however, controversial (Oduntan, 2012; Reinhardt, 2007; Sgobba & Gupta, 2022). While most UAVs operate in the troposphere, i.e., the closest layer to land, some UAVs have been reportedly sent to operate in the stratosphere to collect data concerning the climate (Kemsley, 2013) and research is ongoing to develop high-altitude UAVs (Guérard et al., 2016). These may bring to the fore further legal developments concerning the limits between air space and outer space (Liu & Tronchetti, 2019). Nonetheless, we can safely assume that UAVs used for monitoring and collecting ship source pollution data will fly in the lowest atmosphere layer (troposphere), where vertical sovereignty is applicable. In the air space above internal and territorial seas, States have full sovereignty over their airspace and aircraft do not enjoy any right of the passage under international law. The right of innocent passage through the territorial sea is given to ships and no similar right has been recognized for aircraft (UNCLOS, article 17) (Rothwell & Stephens, 2016; Tanaka, 2018). In accordance with UNCLOS, articles 58 (1) and 87 (1)(b), in the Exclusive Economic Zone (EEZ) and the high seas, aircraft have a right to overflight over these maritime zones. It is relevant to note that the right of transit passage in straits used for international navigation and the right of archipelagic sea lanes passage in archipelagic waters also includes a right of overflight in accordance with UNCLOS articles 38 (2) and 53 (1), respectively.

States using UAVs to monitor and eventually enforce ship source pollution want to increase their maritime domain awareness. Their deployment rationale relates mainly to marine data collection rather than aerial navigation from point A to B. UAVs, such as those EMSA is currently using, may be equipped with a variety of sensors ranging from those that collect high-resolution images that can be georeferenced to other thermal sensors used to detect animals and fire (Wich & Koh, 2018). Other sensors may also be used for water sampling or to measure distances to an object, while 'gas sensors' are particularly useful to monitor specific emissions (European Maritime Safety Agency (EMSA), 2020; Wich & Koh, 2018). UAVs can arguably access remote sea areas and sonar sensors allow data transmission even in those remote areas (Pajares, 2015; Wich & Koh, 2018). Current research also includes the deployment of swarm drones (i.e., multiple UAVs having several degrees of coordination to solve a task collectively) to model oil spill detection. (Aznar et al., 2014). It is important to notice that marine data collection may be subject to specific legal regulations, such as scientific research.

Nevertheless, there is other data collection, i.e., hydrographic and military surveys, operational oceanography, resource exploration and development and environmental monitoring and enforcement (Roach, 2019). This paper is concerned with data collection for monitoring and enforcement purposes and this *intended* use distinguishes it from marine scientific research regulated under UNCLOS, Part XIII. Considering this intended use, and based on their enforcement powers, States could legally deploy UAVs in maritime zones within their national jurisdiction and on the high seas. However, UAVs' deployment in maritime zones of third States requires special analysis. Of course, in internal waters and territorial seas, express authorization is needed. Article 8 of the Chicago Convention prescribes:

> No aircraft capable of being flown without a pilot shall be flown without a pilot over the territory of a contracting State without special authorization by that State and in accordance with the terms of such authorization. Each contracting State undertakes to insure that the flight of such aircraft without a pilot in regions open to civil aircraft shall be so controlled as to obviate danger to civil aircraft.

It is interesting to note that article 8 refers exclusively to vehicles *without a pilot* and the provision does not refer to those aircraft that are remotely piloted. An interpretation of this article in accordance with its ordinary meaning may lead to the conclusion that this provision is exclusively concerned with fully autonomous vehicles where a pilot is no longer required and cannot intervene in the flight. (Mendes de Leon & Scott, 2016). However, ICAO clarified that the scope extends to "all unmanned aircraft, whether remotely piloted, fully autonomous or combinations thereof" (International Civil Aviation Organization (ICAO), 2015).

States can nevertheless enter into cooperation agreements to jointly deploy UAVs in areas within their territorial sovereignty to enhance their monitoring and enforcement capacities and establish shared data systems. The same arrangements are needed where transit passage and sea lanes passage apply because a constituent element of these overflight rights is the continuous and expeditious transit over straits used for international navigation or archipelagic waters and such a transit should proceed without delay (UNCLOS, articles 38 (2), 39 (1) and 53 (3) (Nandan et al., 1993)). However, transit does not include monitor and data collection from ships. Additionally, UAVs may be deployed to surveil selected ocean areas permanently. So, States cannot rely on their transit passage and sea lanes passage rights to deploy UAVs. According to article 58(1) of UNCLOS, in the EEZ, aircraft enjoy the freedom of overflight, which includes not only transit but also other 'lawful uses of the sea related to this freedom.' Traditionally, such lawful activities linked to the freedom of overflight include, for example, "mid-air refueling… and the winching of persons off a ship by a helicopter." (Churchill et al., 2022, 283) Whether monitoring shipping and potentially measuring emissions fall into the category of ‘lawful activities’ as prescribed in article 58 (3) of UNCLOS is controversial. This is because aircraft have a further obligation to exercise their freedom taking due regard for the rights and duties of the Coastal State (UNCLOS, article 58 (3)). One may argue, for instance, that Coastal States may, under certain circumstances, exclude aircraft from collecting data for marine scientific purposes (UNCLOS article 245, Hailbronner, 1983; Oduntan, 2012)). However, as previously stated, UAVs that collect marine data for monitoring ship discharges and eventually enforce them are not involved in marine scientific research. For example, one may claim that collecting aerial photography and sensor data, which is not related to the exploration and exploitation rights of coastal States is a lawful activity.

In accordance with relevant provisions of UNCLOS, Coastal States have jurisdiction to protect and preserve the marine environment (UNCLOS, article 56(1)(b)(III)). It appears that in accordance with article 218 (3) of UNCLOS, Port States have the discretion to assist Coastal States in gathering evidence of illegal ship discharges (through UAVs, for example) *if there is a request from a particular Coastal State*. From this article, it is doubtful that Port States may use UAVs or other aircraft to collect ship pollution data *ex officio* or claim such data collection to be within the right of overflight. It is, however, possible for States to enter into cooperation arrangements to monitor selected ocean areas jointly. As Churchill et al. (2022, 653) point out, the enforcement powers provided in article 218 of UNCLOS have not been widely used “because there is little incentive to devote the effort and expense necessary to take proceedings in respect of a discharge that may have occurred in a distant part of the world.” The incentives may increase, however, with the advent of UAVs, a cost-efficient technology that can reach remote and distant sea areas. The increased use of UAVs also requires closer collaboration between the International Maritime Organization and ICAO and between EMSA and the EU Aviation Safety Agency (EASA). Besides issues concerning the UAVs status, overflight rights and lawful pathways to collect marine data, the following section focuses on emergent surveillance issues of UAVs.

4.2 Nowhere to Hide: Emerging Surveillance Concerns

In the previous section, the author explained that UAVs might be equipped with a variety of sensors able to collect diverse data. From an environmental perspective, UAVs are used to monitor large and previously inaccessible areas and can provide valuable information concerning illegal and accidental ship discharges. However, marine areas could be extensive and effective monitoring requires overcoming current technical challenges, such as limited flight periods and "real-time communication data" between the UAV and enforcement authorities (Wich & Koh, 2018, 48). This information is crucial to engage promptly in enforcement activities. It is important to notice that UAVs help detect illegal ship discharges, but enforcement is still dependent on the competencies that international law endows on States and UAVs may not be used to advance excessive jurisdictional claims.

However, UAVs and other data-gathering technology could enhance current trends of territorializing extraterritorial violations by establishing territorial offenses (Marten, 2016; Ryngaert & Ringbom, 2016). Since there is no customary law right to enter into ports (UNCLOS articles 25(2) and 211(3)), (Churchill, 2014; de La Fayette, 1996), Port States may impose a series of conditions to grant access to their ports. In the case of ship source pollution, MARPOL prescribes a wide range of information requirements concerning operational discharges (e.g., Annex I: Regulations 17, 31 and 36; Annex II: Regulation 15; Annex V, Regulation 9; and Annex VI Regulation 12) that can eventually be requested and inspected by Port State authorities. One may argue that Port States, based on their legislative jurisdiction, can impose as a condition to enter ports stricter pollution standards than those prescribed at the international level (UNCLOS 211(3)9, (Argüello, 2019; Marten, 2016; Ringbom, 2008). Consequently, Port States may also request further information when ships are subject to Port State Control. However, extensive information requests are met with criticism against Port States for 'extraterritorial overreach' and could be construed as an indirect mechanism to regulate foreign ships (Marten, 2016). Nonetheless, the advent of UAVs will reduce the need for Port States to request information from ships lying in ports. This vast information can be used instead to:

> introduce a range of laws that relate directly to matters arising within its territory. In this way the sourcing of information is different from imposing a blunt requirement on visiting vessels … Information requirements are a tool that enables port states to investigate and influence issues that may arise en route to port. (Marten, 2016, 487)

UAVs are also part of extensive surveillance practices (Wich & Koh, 2018). As UAVs technology develops, shipping will be subject to constant observation. This state of constant surveillance is further intensified in cooperative arrangements, such as regional MOUs where port authorities share information between their members (Bang & Jang, 2012). SafeSeaNet (Directive, 2002/59/EC) is the EU traffic monitoring and information system that receives, stores and exchanges varied marine data, including information related to MARPOL. EMSA currently operates the voluntary data-sharing platform CISE, which seeks to enhance EU surveillance by promoting data sharing between public authorities, including marine pollution data. CISE is also an example of the turn to informality in maritime surveillance. This platform is not the result of specific legislation but rather a voluntary regional initiative that brings to the fore accountability and legitimacy issues. Even the environment may be negatively affected by the presence of UAVs. Evidence shows that UAVs' noise and silhouette change the behavior of several mammals, such as dolphins and pinnipeds (Raoult et al., 2020).

Being permanently observed in the name of environmental protection comes with a price. UAVs monitor busy port areas and even in remote sea areas, ships are still manned. While UAVs may be deployed to monitor marine pollution, one should not forget that these aerial vehicles collect a vast amount of data that can be misused (Storr & Storr, 2018). Data misuse may be more prevalent in informal surveillance practices. In these informal cooperation schemes, enforcing formal rights to privacy may prove challenging. Therefore, surveillance discourses should not be decoupled from privacy and human rights issues, especially for those in the most vulnerable position in shipping, i.e., seafarers (Storr & Storr, 2018; Wich & Koh, 2018).

5 Conclusion

The deployment of UAVs in the marine environment has been framed as a technological solution that enhances maritime domain awareness and facilitates environmental monitoring and enforcement. UAVs are assimilated as aircraft to ensure their smooth incorporation into the legal system. Such assimilation may be convenient for discussing overflight rights and jurisdiction over these devices. However, one should not forget that international aviation law is mainly concerned with transit or traveling from point A to B. UAVs used for environmental monitoring and enforcement are mainly data collection devices. This assimilation can overshadow important ethical and legal questions, including its intrinsic relationship with surveillance practices and human rights.

From a law of the sea perspective, Port State jurisdiction will continue to grow in relevance thanks to the UAV's data-gathering capacities. It is possible that UAVs' deployment and further territorialization of extraterritorial offenses represent laudable efforts to minimize ship source pollution and ultimately protect the global commons (Kopela, 2016; Ryngaert, 2020). However, such trends could trigger an imbalance between Flag and Port States. After all, UNCLOS does provide safeguards to avoid adverse consequences of enforcement against foreign vessels (UNCLOS, Part XII, Sect. 7). But with extensive territorialization practices, Flag States may not always succeed in protecting the rights and interests of their fleet. Overall, Port State authority over shipping may expand even in areas outside national jurisdiction because UAVs and other surveillance technology allow States to influence ship's behavior while en route to the port.

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CHAPTER 12

Digitalization and Cyber Physical Security Aspects in Maritime Transportation and Port Infrastructure

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1 Introduction

Ports play a vital role in global trade, by handling more than 80% of freight transferred all over the world, dealing with continuously growing demands on productivity and operational efficiency and concurrently contributing to sustainable development in accordance with the United Nations 2030 Agenda for Sustainable Development (Alamoush et al.,

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2021). A viable solution to the challenges faced by the wider maritime transport industry and related port infrastructure in handling increased volumes of goods and larger capacities of cargo can be provided by the expansion of digitalization in ports. Although currently both vessels and ports already rely on computers for communication, cargo operations, navigation, safety and security of operations, the adoption of innovative digital solutions such as Internet of Things (IoT), Big Data Analytics (BDA), Artificial Intelligence (AI), and blockchain, is still not widespread. The further integration of digital tools into ports can improve operational efficiency and encourage increased profitability. Considering the increased levels of digitalization of supply chains internationally, port infrastructures need to sustain their role as "nodes" within these chains by being converted into "digital nodes" (Dalaklis et al., 2020).

This chapter will review the cyber physical security aspects involved globally in the operations and infrastructure of the maritime transportation and port sectors, considering the influence of "digitalization" and integration of digital operational tools and applications. The most known cyber threats and vulnerabilities are discussed, to illustrate the current threat environment and cybersecurity posture. Important industry and government policies, directives, and standards are reviewed to indicate the effort undertaken by government, industry, and standardization organizations to issue policies, guidelines, directives, and standards that can be utilized by asset owners and operators. Key methods for the assessment of

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cyber physical security in the maritime transportation and port infrastructure sectors are also presented, illustrating the range of possible tools for the assessment of cybersecurity risks, threats, and vulnerabilities. The use of the Bow Tie Analysis method is demonstrated as an appropriate assessment method for the identification of proactive and reactive mitigation barriers and measures. Finally, necessary conclusions that will facilitate the way forward for the digital evolution of organizations and their operations in integrating physical and cybersecurity elements are provided.

2 Digitalization in the Maritime Industry

Industrial digitalization involves the technological evolution through the automation of business processes, operations, and information processing (Tijan et al., 2021). It is achieved through the incorporation of digital technologies such as the IoT, BDA, AI, cloud computing, and blockchain. In the general industry this digitalization evolution is known as Industry 4.0 while for the maritime industry it translates to Maritime 4.0 (Papageorgiou, 2020).

Digitalization in the maritime industry is aiming to the performance optimization of maritime assets, allowing for continuous and interactive monitoring of key technical and operational parameters and the realization of increased efficiencies and environmental compliance. Through digitalization, stakeholder communication is enhanced onboard the vessel and onshore at the port facility and related transportation infrastructure. Communication and data transmission and fusion are vital in this technological breakthrough and the process transforms the vessels to "digital ships" and ports to "digital ports" (Ben Farah et al., 2022). As the maritime industry advances, the optimization of operations and processes and increase of efficiencies are necessary to lead the industry forward.

Despite the prospective significant positive impact of digitalization in the maritime industry, its implementation depends on a number of organizational, technological, and external environmental barriers (Tijan et al., 2021). The maritime industry in general is characterized by its heterogeneous organization structures and lack of cultural integration (Tijan et al., 2021). In essence, the digitalization process is hindered by the varied capacity of stakeholders to adapt to the integration of new technologies, modification of current operations, and sustainment of capital and operational expenditure. The maritime transportation sector may also suffer from a lack of qualified labor force with digital skills. As human factors remain paramount in the operational level, their reduced cyber competency can affect the implementation of technical solutions and increase the cyber security attack surface. In fact, the operational complexity of the maritime industry and large number of technologically and organizationally diverse stakeholders can increase the possibility of a cyber security breach scenario.

3 Cyber Physical Security in Maritime Transportation and Port Infrastructure and Operations

Cyber physical systems can be defined as those that integrate IT (Information Technology) and OT (Operational Technology) functions/modules and are operated by humans. Infrastructure in the maritime transportation and port sectors is controlled by human operators and most usually includes an IT/OT interface that connects system processes, components, and performance (Progoulakis et al., 2021). Similar to the industrial sector, maritime port infrastructure contains complex processes and multiple Systems of Systems (SoS) platforms containing IT/OT equipment, enabling process automation and operational efficiency (Ben Farah et al., 2022). The maritime transportation and port sectors, as well as their IT/OT and cyber physical infrastructure are adopting new digital technologies such as the IoT, cloud computing, data analytics, robotics, and various other innovations, which are altogether shaping an always changing landscape (Zarzuelo et al., 2020).

The portfolio of operations carried out in the maritime transportation and port sectors include complex automated processes such as cargo management (e.g., storage, transportation, loading/offloading), supply chain data interchange, financial transactions, and contract management, as well as various aspects of maritime safety and security. The communication between the port and vessel systems and infrastructures is depicted in Fig. 1. The maritime port system architecture and some of the involved operations are depicted in Fig. 2.

These processes involve communication with multiple stakeholders, as illustrated in Fig. 3, such as port authorities, operators, service providers, customs officers, shipping companies, logistics providers, ship and cargo brokers, seafarers (vessel crew), and customers. In the security and IT sector this communication involves the Facility Security Officer (FSO),

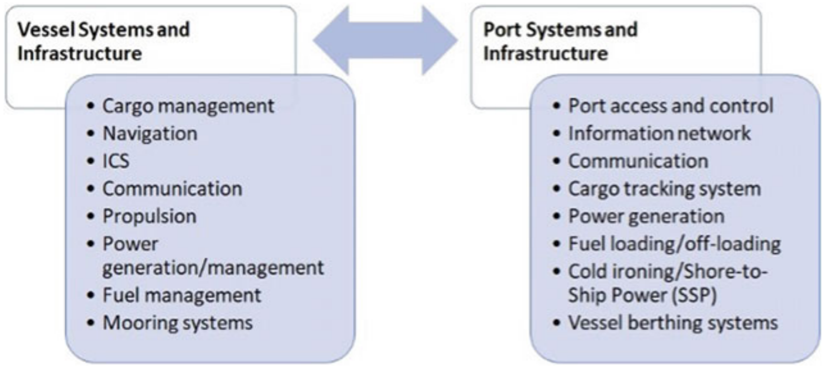

Fig. 1 Vessel and port systems and infrastructure communication (*Source* Iosif Progoulakis)

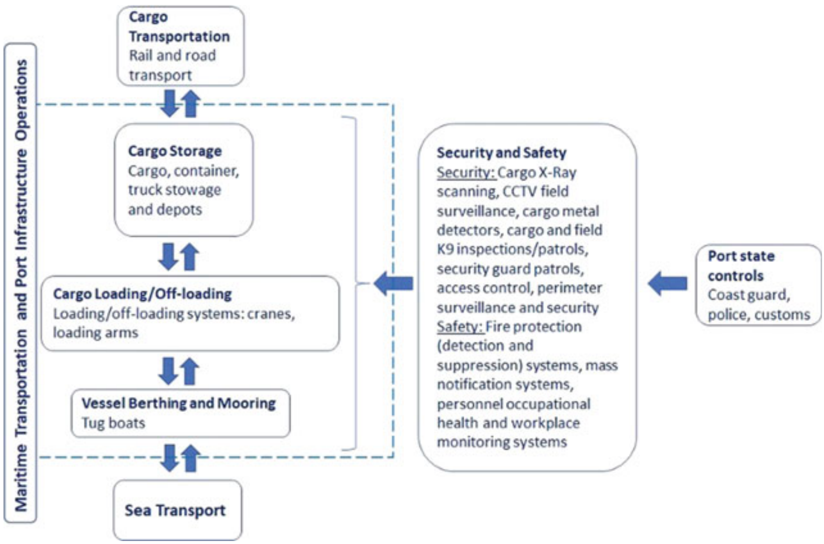

Fig. 2 Port architecture and operations (*Source* Iosif Progoulakis)

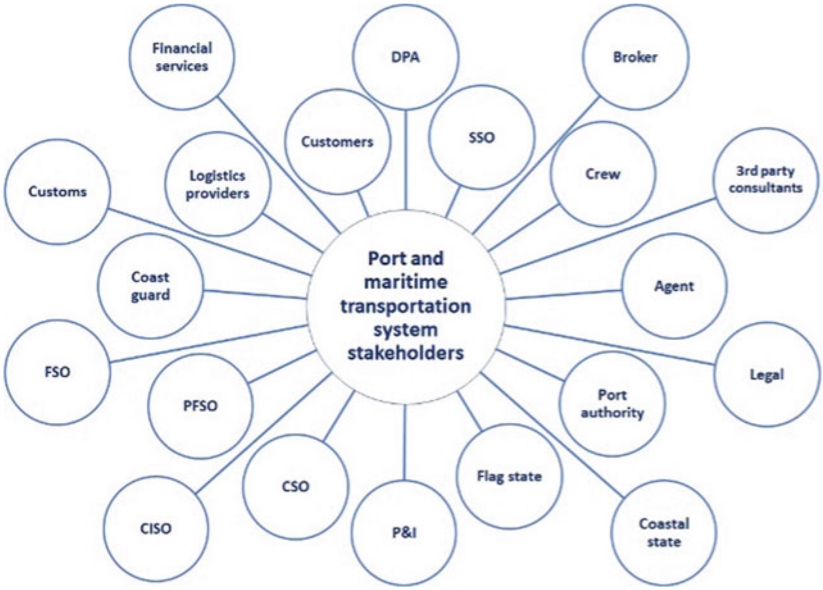

Fig. 3 Array of port and maritime transportation system stakeholders (*Source* Iosif Progoulakis)

Port Facility Security Officer (PFSO), Company Security Officer (CSO), Ship Security Officer (SSO), Company Information Security Officer (CISO), Designated Person Ashore (DPA), Coast guard, port authorities, etc. (Fig. 3).

The complexity and large number of operations as well as the variation and plethora of stakeholders involved translate into an increased attack surface in cyber physical security. Every path of communication between stakeholders constitutes a possible attack vector which is based on human factors and the use of technology and could lead to a security breach scenario. Secure information exchange and data transmission therefore are of great importance for the maritime transportation and port sectors. This safe and uninterrupted access to data can be achieved via confidentiality, integrity, and availability, as mentioned in the NIST Cyber Security Framework, which is a very effective model designed to guide policies for information security within any organization.

4 Cyber Security Threats and Vulnerabilities in Maritime Transportation and Port Infrastructure Operations

In recent years, the use of digital means is rapidly expanding throughout the whole world and the wider maritime industry is not an exception; a very extended number of shipping companies and ports are heavily relying on a computers and information technology (IT) applications to effectively support their business activities. There is now a new operating paradigm, often called "Digital Era" that is associated with significant cyber-risks. The term "Cyber Security" can be generally defined as "the collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment and organization and user's assets" (International Telecommunications Union, 2008). Within this description, the "cyber environment" encompasses standalone and interconnected IT/OT systems and devices utilizing wireless and hardwired technologies operating in cyberspace. Concurrently, the "organization and user's assets" consist of connected and isolated computing devices, operators, infrastructure, applications, services, telecommunication and data transmission systems, and the all-data-inclusive cyber environment. Cyber security (and associated risks) is not just about preventing cyber adversaries—such as hackers—breaching IT/OT systems. It also relates to the confidentiality, integrity, and availability of information and systems, safeguarding operational and technical business continuity and the operation of cyber assets. Maritime transportation and port infrastructure assets and corresponding risks include (US DHS, 2022):

a) Port facility access: This may involve the deprivation or disruption of IT/OT systems used in cargo, transportation, and personnel management, which may lead to a force majeure.
b) Port facility headquarters: This may involve the manipulation or destruction of sensitive cargo and customer data by cyber-attackers.
c) OT systems and components: The diminished or complete loss of operation of OT systems such as cargo handling equipment and fuel systems can potentially cause catastrophic safety and environmental-related incidents.

d) Positioning, Navigation, and Timing (PNT): The complete loss of PNT services can disrupt logistics systems and hinder vessel port maneuvering. It could also damage port infrastructure leading to safety and environmental incidents such as the release of hazardous material or waste, vessel collisions and grounding, human casualties, fires, and blocking of a navigable channel by damaged or sunk vessels.
e) Vessel at berth: The operational and technical incapacity of vessel or port infrastructure systems could lead to the damage of other shore- or water-based assets and systems. The data communication and interconnectivity of a berthed vessel to port facilities through Wi-Fi, network connections, USB storage devices, etc., could contribute to such a mishap.

Generally, sharing similarities with physical security, the cyber threats faced by ports' infrastructure and their OT/OT assets can be classified as internal, external, or colluded (Progoulakis et al., 2021). An insider threat may be a (disgruntled) seafarer or port operator, who maliciously compromises the related defenses, or even unintentionally causes the breach of preventive cyber security barriers by practicing poor cyber security hygiene. Poor "cyber hygiene" which refers to the routine practices for ensuring the safe and secure handling of IT systems and data, can be a result for example of malware infection of IT networks and OT devices through infected portable USB devices or emails; it can be detrimental to ports' cyber infrastructure and components. External threats comprise of those posed by industry competitors, cyber criminals, hackers, hacktivists, state adversaries, or terrorists, using highly advanced cyber tools to impair, destroy, or control IT/OT systems (UK IET, 2020). Finally, colluded threats are those imposed by external actors through internal adversaries.

5 Industry and Government Policies, Standards, Directives, and Guidelines

Cyber security in general, includes also the cyber physical security elements for maritime transportation and port infrastructure operations. A number of related publications, directives, guidelines, and standards from the industry and standardization organizations and various government agencies that are followed by the maritime transportation and port sectors, are presented below. It should be clearly noted however that this list is not comprehensive, as new regulations and guidelines are introduced, as well as revisions of existing documents are regularly released in ongoing effort to catch up with the evolving cyber threats, over the course of time.

5.1 Maritime Industry Organizations

The International Maritime Organization (IMO) through Resolution MSC.428(98) and IMO Guidance MSC-FAL.1/Circ.3 is dealing with the subject of cybersecurity, in the wider maritime transport domain. MSC.428(98) and MSC-FAL.1/Circ.3 complement the IMO ISPS (International Ship and Port Facility Security) code for vessels and port facilities and are working in unison with the ISM (International Safety Management) Code, which is a very influential risk mitigation tool for the specific sector.

5.2 Industry Standardization Organizations

The US National Institute of Standards and Technology (NIST) has published various standards applicable in different industrial sectors to include the maritime industry. The NIST Cyber Security Framework (NIST, 2021) encompasses five functions: (1) Cyber security risk classification for IT/OT systems, components, data, and operations; (2) The application of protective and mitigation barriers for the cyber security protection of IT/OT systems; (3) Detection of cyber security attacks; (4) Response and mitigation to cyber security attacks; (5) Recovery from cyber security attacks. The NIST Cyber Security Framework is accompanied by Special Publications 800–30, 800–37, and 800–82, related to cyber security risk assessment and management for Industrial Control Systems (ICS). Special Publications 1500–201, 1500–202, and 1500–203, containing the NIST Framework for Cyber Physical Systems, have also been released. The NIST Framework for Cyber Physical Systems is applicable to the maritime transportation and port sectors as it investigates IT/OT systems compiling the System of Systems (SoS) state of cyber infrastructure.

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) have published various standards on IT/OT systems and ICS cyber security for the maritime transportation and port sectors. ISO/IEC 27,001 can be used for cyber security risk assessment and management. The IEC-62443 series of standards covers cyber security for industrial communication networks of IT/OT systems. IEC-62443–4-2 specifies the technical requirements and measures for Industrial Automation and Control Systems (IACS) and control of cyber security vulnerabilities. IEC 62,443–3-3 explains the control systems security levels and ISO/IEC 21,827 defines the Systems Security Engineering—Capability Maturity Model® (SSE-CMM®), showcasing the security engineering process for organizations and assets. ISO/IEC 18,045 gives guidelines for IT systems security assessment. ISO/IEC 15,408–1 defines the Target of Evaluation (TOE) term and describes the cyber security assessment for IT infrastructure. ISO/IEC 27,032 provides guidance for the cyber security and protection of data and network infrastructure. Furthermore, the American Society for Testing and Materials (ASTM), has issued standards ASTM F3286-17 and ASTM F3449-20, covering the mitigation of and recovery from cyber security attacks following the NIST Cyber Security Framework and cyber reinforcement of the vessel safety management systems (SMS), in accordance to the International Safety Management (ISM) Code and IMO Resolution MSC.428(98).

5.3 Government and State Agencies

In the USA, the execution of cyber security protection policies and actions is entrusted to the US Cyber Security and Infrastructure Security Agency (CISA) and the Maritime Administration (MARAD) through the US Congress Bill S. 4023 “Enhancing Maritime Cyber Security Act of 2020.” The US Coast Guard (USCG) has published Navigation and Vessel Inspection Circular (NVIC) 01–20, titled “Guidelines for Addressing Cyber Risks at Maritime Transportation Security Act (MTSA) Regulated Facilities,” guiding MTSA-regulated facilities for their vulnerability assessment and management of their IT infrastructure. NVIC 01–20 adopts the NIST Framework for Improving Critical Infrastructure Cyber Security and Special Publication 800–82. The USCG has also released Vessel Cyber Risk Management Work Instruction CVC-WI-027 (rev.2, 2021), which covers cyber risk reduction through to the cyber risk and vulnerability assessment for Marine Transportation System (MTS) regulated vessels.

In the United Kingdom (UK), a Good Practice Guide in Cyber Security for Ports and Port Systems (UK IET, 2020) has been published through the collaboration of the Department for Transport (DfT), the Defense Science and Technology Laboratory (Dstl), the National Cyber Security Centre (NCSC), and the Institution of Engineering and Technology (IET). This guide supports the integration of cyber security into maritime ports and their systems, facilities, and general security planning activities. The operational risk management due to cyberattacks affecting vessel's safety and security is also covered by the released Code of Practice for Cyber Security for Ships (UK IET, 2017).

In the European Union (EU), the EU Maritime Security Strategy (EUMSS) Action Plan covers maritime cyber security, aiming in the reinforcement and improvement for security management, protection, and resilience against cyber threats in the maritime transportation and port sectors. Data protection for all industry sectors, is covered by Regulation (EU) 2016/679, called the General Data Protection Regulation (GDPR). EU-wide cyber security of IT infrastructure is handled by the European Union Agency for Network and Information Security (ENISA) through adopted EU directive 2016/1148/EU and the EU Cyber Security Act (2019/881/EU). Cyber security resilience, mitigation technologies, strategies, and policies are processed through the EU's cyber security strategy JOIN/2013/01. Other ENISA policy documents and reports cover port cyber risk management (2020) and cyber security (2019).

6 Cyber Physical Security Assessment for Maritime Transportation and Port Infrastructure and Operations

6.1 Introduction

The assessment and effective management of cyber physical security in the maritime transportation and port infrastructure operations requires versatile methodologies that can adapt in the operational and technical parameters of the maritime domain. This can only be achieved through the use of multidisciplinary methodologies deriving from different industrial sectors. The maritime transportation and port infrastructure sectors are part of the critical infrastructure sector, assimilating industrial, facilities, and maritime processes. This section will briefly present some applicable assessment methods widely used in various industrial sectors.

Such a method is the Security Risk Assessment (SRA) methodology, mostly used in the oil and gas industry, explained in much detail in API (American Petroleum Institute) standard (STD) 780. It can be used for security incidents to include theft, sabotage and terrorism for permanent and mobile assets. SRA can be also applied to various industrial infrastructure and operations including maritime transportation and port operations and infrastructure. The API SRA methodology manages security risks through a risk-based, performance-oriented procedure maintaining the safety and security of infrastructure, the environment, workers, and business continuity. SRA is applicable to maritime cyber physical security applications and the assessment of threats, vulnerabilities, and incidents for IT/OT systems (Progoulakis et al., 2021).

Another qualitative safety review method is the Bow Tie Analysis (BTA) which is utilized in Process Safety Management (PSM) for the petrochemical, and processing sectors. BTA defines risks, hazards, and consequences in safety incidents of systems, processes, and operations and the classification of security mitigation actions for assets and processes. BTA applies to the maritime transportation and port sectors, for the evaluation of operational and technical links between marine equipment, systems, and processes in safety and security scenarios. The use of the BTA in maritime cyber physical security has been shown by Progoulakis et al. (2021), Bernsmed et al. (2017), and Yang et al. (2021).

Another method stemming from the process and petrochemical industries is the Process Hazard Analysis (PHA), which identifies and assesses hazards related to operations and processes to enable their control (CCPS, 2016). This review method can involve the use of qualitative (HAZOP (Hazard and Operability Study), What-If, and quantitative (FMEA, Failure Modes, and Effects Analysis), FTA (Fault Tree Analysis) techniques to recognize and evaluate hazards' significance. PHA is used for PSM of complex industrial processes and adapted for cyber security applications in the form of Cyber-PHA (aeSolutions Inc, 2019). Cyber-PHA is focused in ICS security assessment and is aligned with ISA/IEC 62,443-3-2 (Security for industrial automation and control systems—Part 3–2: Security risk assessment for system design), IEC 61,511 (Functional safety—Safety instrumented systems for the process industry sector), and ISA TR84.00.09 (Cybersecurity related to the Functional Safety Lifecycle) standards. It should be noted that the implementation of cyber-PHA and the recognition of ICS and OT components and processes within the maritime transportation and port infrastructure can enable the reduction of operational cyber security risk and the strengthening of the organizational cyber security culture (aeSolutions Inc, 2018).

Finally, another tool for the assessment of cyber vulnerabilities, cyber-attacks, and organizational risks is the MITRE ATT&CK Threat Model. The MITRE ATT&CK Threat Model can assist in the evaluation of cyber adversaries' attack behavior, strategies, and methods enabling the collection and processing of such data (MITRE Corporation, 2020) by the Chief Information Security Officer (CISO) and his/her team. The MITRE ATT&CK Threat Model offers flexibility in the assessment of IT networks, cloud data storage, portable devices, and ICS. It also assists in the classification and certification of attackers' behavior in the IT/OT operational environment for the maritime domain.

6.2 Cyber Physical Security Assessment Case Study: BTA Method

Below and as shown in Fig. 4, a case study of the BTA method for the security compromise of a port access control system will be presented. The port access control system regulates the access of logistics and transportation providers for the conveyance of cargo containers and the personnel and vessel crews.

The hazard identified in this case study is the one imposed by malicious software penetrating preventive IT security barriers due to improper or poor cybersecurity practices and IT cyber hygiene practiced by port personnel. The top event identified is the compromise of the port access control system. This can result in delays in cargo management, cargo loading/offloading, and transportation through vehicles and cranes. Hindered access and exit of port personnel, visitors, service providers, and berthed vessel crews can also be caused by this incident causing further operational delays. In addition, without an effective port access control system, unauthorized stakeholders could also enter the facilities posing as possible terrorist, sabotage, or larceny threat actors. Hindered access by authorized stakeholders can also cause significant logistical and operational disruptions and delays leading to extreme situations where a force majeure may be enforced.

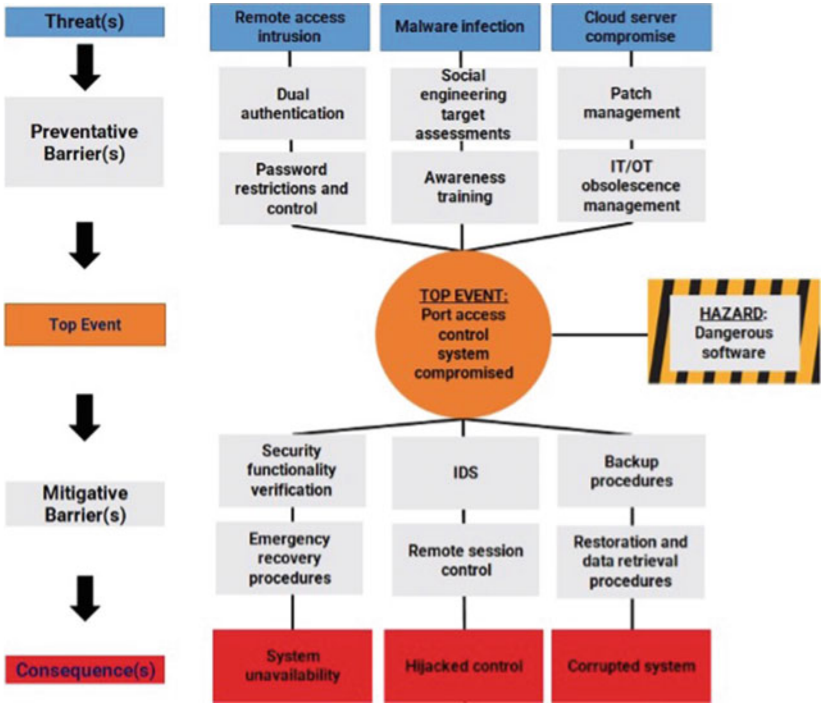

Fig. 4 BTA case study for security compromise of port access control system (*Source* Authors)

For such an event there are three credible threats identified for the specific case study: The system intrusion via remote access, the malware infection via the internet or internal corporate network, and the compromise of the port corporate business's cloud server. The malware attack can occur through the use of infected removable media and external hardware as well as targeted social engineering campaigns. Human error and sabotage can also be the reasons for either of the three threats. Finally, technical malfunctions in the IT infrastructure and systems and force majeure caused by uncontrolled parameters can also enable the threats noted. All three identified threats fall within the classified categories of those caused by internal, external, or colluded adversaries (Progoulakis, 2021).

The preventive barriers for the mitigation of the described threats can be common for many types of threats. For remote system access intrusion, the segmented and controlled access based on individual password restrictions and controls as well as dual authentication password protocols could be implemented. For the malware infection of port workstations and IT infrastructure increased cybersecurity training to raise operational and technical awareness could be carried out. Further target assessments of system and workstation operators for social engineering attack campaigns could also pre-emptively evaluate vulnerabilities and operational IT deficiencies of key personnel. Of course, the control or ban of portable USB devices and removable media and external hardware could also be implemented as another preventive barrier. For the security compromise of the port access control system cloud server, patch management and the abolition of obsolete software or applications could be implemented.

In the case of failure of all or some preventive barriers the top event would occur. At such an event, port operators will need to enter the damage control mode of operations relying on the post-event mitigative barriers which could reduce the severe consequences. Such mitigation barriers can include the frequent and random verification of system security functionality. The setup and implementation and frequent testing of emergency recovery procedures based on credible scenarios. Intrusion Detection Systems (IDS) and control of remote system activities for specific tasks and individuals could also be applied. The deployment of procedures for backup operations and the restoration and retrieval of data could also be implemented aiming in the reduction of data loss and the reactivation of system and recommencing of operations. It should be noted that mitigation barriers are not installed after the occurrence of the top event. These are already in place after a careful operational, technical, and security assessment of systems, which has taken place in a past chronology.

Finally in the worst-case scenario that mitigation barriers also fail to stop or reduce the effect of the top event, consequences such as the complete unavailability of the port access control system, the loss of control due to hijacking by external threat actors, and the corruption of the system leading to operational malfunctions and disruptions, would occur. In all cases a complete halt of operations can ensue leading to a force majeure implementation.

7 Discussion

The maritime industry is frequently viewed as inflexible in the adaptation of innovative or disruptive technologies, primarily due to the anticipated cost and operational implications. There are however, examples of maritime ports that have changed that and have been characterized as "smart ports." There are ports that have proactively adopted new digital technologies within their operations and technical infrastructure and enjoy financial, operational, and environmental benefits. For the maritime transportation and port infrastructure sector, and in line with other industrial sectors, the digitalization of port processes could improve efficiency, productivity, resource, and stakeholder (shipping companies, freight forwarders, rail operators) management (Acciaro et al., 2020). As it has been highlighted, the "cornerstone" of digitalization is the IoT (Yang et al., 2018). The adaptation of IoT can enhance data collection from all IT/OT assets and their components and contribute to operational and technical efficiencies and improvements through proper interpretation.

Furthermore, as the maritime sector is nowadays more and more digitally integrated making use of satellite internet connections and enjoying a global coverage, operational cost reductions, and optimized customer service provisions are realized. Concurrently modern ships are making use of new technological solutions such as voice over IP (Internet Protocol), email, and instant messaging, which are used by seafarers on a daily basis at a global scale, increasing the digital footprint of IT services on board vessels. This increased digital integration however comes with significant operational, technical, and security-related risks, which if not tackled in a timely manner can potentially lead to major disruptive results in the industry. The IMO has correctly and pre-emptively approved MSC-FAL.1/Circ.3 Guidelines on maritime cyber risk management aiming in the protection of the industry from existing and anticipated future cyber threats and vulnerabilities. The implementation of IMO Resolution MSC.428(98) has also further contributed to the increased cyber-awareness and resiliency of the industry. The standards, policies, and directives presented in this chapter also contribute to the implementation of cyber resiliency in the maritime sector.

Despite the positive steps forward in the reinforcement of the maritime industry to tackle the new challenges of the occurring digital evolution, vulnerabilities remain and threats are constantly re-emerging able to strike with precision and destructive results. These threats and their potential impact in the industry were made more obvious by the 2017 cyber-attack against the Maersk shipping company systems from the devastating NotPetya virus (Boyes et al., 2020), infected through a used tax accounting software in Ukraine loaded onto one unpatched workstation operating in a single local office connected to the company's global network. While Maersk was not the intended target for the attack, the consequences for the company were detrimental. The virus spread through the company's global IT infrastructure and incapacitated all their applications and data for several days, severely affecting worldwide operations, including the Rotterdam terminal, with $200–300 million of estimated financial losses. The Maersk cyber-attack example shows how IT infrastructure can fail at a larger scale through a system partially incapacitated by a cyber-attack. While Maersk's shipboard systems were unaffected, cargo management applications were completely forced to a halt unable to handle existing and new cargo shipments (Dalaklis & Schröder-Hinrichs, 2019).

Assessing the aftermath of the Maersk cyber-attack, business continuity was regained at a short period of time. That was made possible through (pre-existing) Maersk's internal policies and recovery action plans to regain operational capacity after a potential cyber incident. It is clear that sound pre-emptive planning is essential for dealing with the various cyber security risks and threats. The Maersk incident is a good example for the maritime transportation and port infrastructure sectors for the positive impact of pre-emptive mitigation measures when in place. Other examples of similar cyberattacks illustrating the negative implications of poor business cyber practices do exist, such as the 2021 force majeure in the major ports of South Africa caused by a cyber-attack (Stormshield, 2021). In any case, effectively dealing with cyber security should be a high priority issue, especially considering the fact that the world's economy is continuing its transformation toward a digital paradigm. As a result, dedicated professionals will be needed to cover whatever gap is created by the advance of the so-called "digitalization phenomenon" and the associated cyber-risks. This in turn is indicating a need for continuous training to add more resources in the workforce pool, who should be equipped with the "right" and most up-to-date IT skills.

8 Conclusions

The maritime transport industry and associated assets such as ports and seagoing vessels have entered an era of digital revolution. This new "digitalization era" known as "Maritime 4.0" is facilitating the tackling of the numerous and ever-evolving business challenges, the improvement of current business and operational procedures, as well as the introduction of new technical and operational-related capabilities, with automation and real-time monitoring standing out, among others. In the maritime transportation sector, data is generated daily at very large volumes from IT/OT systems supporting a vessel's navigation, propulsion, machinery, and related marine fleet management systems. This digitalization and data communication has been enabled by the interconnectivity of IT and OT components and systems and the adoption of new technological force multipliers, such as big data analytics, cloud computing, and Internet of Things (IoT). This digital trend, however, also creates various challenges, as in an "interconnected world" the whole security chain is as strong, as its weakest link. The concept of a cyber physical security incident remains rather abstract, with the industry remaining unprepared to deal with the emerging threats despite the positive initiatives from the IMO and the adoption of Resolution MSC.428(98) as well as other industry standards, directives, and policies.

Concluding, the following points are derived from the review of presented industry and government policies and standards, as well as cyber physical security assessment methods:

1) The review of presented industry and governmental policies, directives, and standards has revealed a lack of capacity in dealing with the OT systems in ports infrastructure. The interoperation of IT and OT systems and their plausible cyber threats are not handled effectively. Without such adequate guidance the owners/operators of maritime transportation and port infrastructure cannot adopt the right practical measures and procedures.
2) The physical protection of maritime transportation and port infrastructure assets, their operations, and IT/OT systems, vulnerable to mishandling and manipulation, must be improved. Considering that the majority of academic research, policies, and standards provide limited focus on the exact physical security state of certain cyber assets, this effort will assist in thwarting cyber threats by insider

malicious adversaries. Even though cyberattacks do occur remotely, the sabotage or poor cybersecurity practices are carried out in the field. The introduction of new policies for organizations and the cultural adjustment and training of users will also be necessary.

3) The identification of IT and OT vulnerabilities needs to be improved by maritime transportation and port infrastructure asset owners and operators. Internal and external operations, stakeholder communication channels, and IT/OT functions can be assessed so that existing mitigation measures can be evaluated. Potential vulnerabilities can be studied and tackled by the introduction of field practices for the containment of potential cyber-breaches, the segmentation of vulnerable systems, and the introduction of policies to field personnel.
4) The use of cyber security assessment methods from other industries should be considered. The API SRA and BTA methods can be valuable assessment tools for operational and technical risks, threats, vulnerabilities, and measures in IT/OT systems. Utilizing the MITRE ATT&CK Threat Model can improve the assessment and mitigation of the attackers' conduct, strategies, and methods and could be applied to ICS, IT networks, mobile devices, and cloud storage. The use of cyber-PHA can bridge safety and cyber security, dealing with OT and ICS components and assets utilized.
5) Training of maritime transportation and port infrastructure personnel (operators, vessel crews, etc.) needs to be increased. Increased integrity or failure of physical and cyber security measures relates to human factors and the level of cyber competency.
6) Maritime transportation and port infrastructure asset owners and operators should seek the convergence of cyber and physical security. The convergence of operations and stakeholder management could enable and improve the adoption of cyber and physical security policies, reduce cyber risk, and optimize threat mitigation.
7) Practices and policies for business continuity and infrastructure resiliency need to be pre-emptively implemented by all stakeholders in the maritime transportation and port infrastructure sectors. Back-up plans and protocols need to be in place to minimize the effect of cyberattacks. The industry should be capable to adopt policies and measures and adapt in new conditions causing major operational disruptions or surges. The Covid-19 pandemic should be such

an example to reinforce, technically and operationally, existing and future infrastructure and systems, ensuring cyber resiliency.

8) Digitalization and Maritime 4.0 require the implementation of dedicated policies and regulations, new IT/OT systems, and the upgrade or modification of physical and digital infrastructure. The industry and its stakeholders need to transform operationally and technically, investing in finance, infrastructure, and human resources, adopting cyber security where applicable.

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CHAPTER 13

Port Cybersecurity: Balancing Evolving Regulatory Compliance with Enterprise Risk Management

Andrew Baskin and Max Bobys

1 Cybersecurity Threat and Risk Landscape

Digital transformation in the port sector is on the march. The United Nations extols its benefits (UNCTAD, 2019). The World Bank is calling for more of it, particularly among the 33% of ports globally that have not begun the process of implementing electronic data exchange systems (IAPH, 2021b; World Bank, 2020). Analysts have projected 200% growth in the global market for it (BusinessWire, 2021). And there is little doubt that digitalizing both port operations and port-related trade processes can

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bring both efficiency and productivity gains (Fruth & Teuteberg, 2017; Gonzalez et al., 2021; Paulauskas et al., 2021; Xiao et al., 2021). Accordingly, ports and port facilities are adopting and integrating a wide array of sensors, technology platforms, and management systems that facilitate faster, more efficient, and streamlined operations. These, in turn, result in the faster movement, processing, and delivering of goods into and out of the port environment.

Yet, the benefits of this digital transformation also bring concomitant cybersecurity risks. Across the maritime sector, nearly half of the organizations were the subject of a cyber-attack during the period 2019–2021 (Chubb et al., 2022). This has been estimated as a seven-fold increase in the number of cyber-attacks over the 2010–2020 period (Meland et al., 2021). The costs of such attacks can be significant; the average ransom paid in a ransomware attack exceeded USD 3 million (Chubb et al., 2022). But why is this risk continuing to grow?

First, the increase in the number of interconnected systems and networks within a port or port facility means that a compromise of one system or network can cascade across the organization and bring serious consequences to a port or port facility's operations, safety, finances, and reputation. Further, as port stakeholders become increasingly interconnected with other members of their port community, such as via a port community system (PCS), a compromise of one port stakeholder's system or network can quickly lead to the compromises of the systems or networks of many port stakeholders (MTS-ISAC, 2021).

Second, the increase in digitalization, and the increase in the interconnection between various systems, means that ports and port facilities are core nodes of global trade and have become information hubs, receiving and processing data from terminal operators, shipping lines, logistics providers, and government authorities (OAS, 2021). These data are valuable to criminals looking to steal data or compromise data to facilitate fraudulent transactions or smuggling, as well as to competitors seeking commercial advantage. As a result, ports and port facilities need to safeguard the confidentiality, integrity, and availability of the data that reside in their systems and networks.

Nonetheless, port operations are particularly vulnerable to cyber threats. While the reasons vary, they include legacy systems, limited staff capability and awareness, and the numerous public and private sector stakeholders regularly accessing a port or port facility's physical operating environment, in particular its network and related management information systems (IAPH, 2021a). As a result, many ports and port facilities remain susceptible to attempts to compromise systems to steal money, pilfer and sell data, and facilitate fraudulent transactions and even drug, weapons, and human trafficking. Disruption, sabotage, and/or sustained exploitation of these vulnerabilities ultimately corrodes trust among all participants, degrades the confidence of shippers and trading partners in the integrity of the affected port facilities, and erodes reputations.

To manage these cyber threats and risks, ports and port facilities are investing resources—human capital, processes, tools, and funding—to safeguard the integrity and availability of critical data, ensure service delivery, and protect maritime infrastructure. In making these investments, ports and port facilities are guided by three sets of directions: government action, industry guidance, and insurance requirements.

2 Legislative and Regulatory Framework

First, both intergovernmental organizations and national governments are increasingly implementing legislation and regulations that attempt to establish minimum cybersecurity standards for ports and port facilities. However, the cyber threat landscape poses a challenge for government action, which is purposefully deliberate and consensus-driven, to meet the pace of technological development and cyber threat evolution. The requirements that currently exist are nascent and continuing to evolve and focus largely on the need for ports and port facilities to conduct cybersecurity self-assessments and to share with national governments information about cyber incidents.

2.1 International Maritime Organization

The International Maritime Organization (IMO) has yet to directly address cybersecurity in port facilities. The IMO has, however, addressed cybersecurity risks in the shipping industry. In 2017, the IMO adopted Resolution MSC.428(98) Maritime Cyber Risk Management in Safety Management Systems (IMO, 2017). This resolution, pursuant to the International Safety Management (ISM) Code, required vessel owners and managers to incorporate cyber risk management into their safety management systems (SMS) in advance of their 2021 annual verification. The Resolution further encourages national authorities to verify compliance with the requirements the Resolution describes.

The IMO's direct actions regarding port cybersecurity have thus far been limited. In 2020, the IMO issued a circular endorsing the industry call to action led by the International Association of Ports and Harbors (IAPH) to drive the acceleration of digitalization of maritime and logistics, including the need to address cyber risks in ports (IMO, 2020). In May 2022, the IMO Facilitation Committee (FAL) formally approved the addition of port-related cyber risk guidance from the IAPH (see Sect. 3.2) to the IMO's guidelines on maritime cyber risk management (IMO, 2022). The updated circular that will reference this change remains forthcoming.

Still, although the IMO has not taken direct action to implement a regulatory requirement for cybersecurity in ports and port facilities, such organizations do already have obligations under the International Ship and Port Facility Security (ISPS) Code to at least begin to address aspects of cybersecurity. Under the ISPS Code, port facilities are required to perform a port facility security assessment (PFSA) and prepare a corresponding port facility security plan (PFSP). PFSAs are required to identify possible threats to assets and infrastructure, including threats to radio and communications systems, including computer systems and networks, and the likelihood of their occurrence, and then establish and prioritize security measures to mitigate those threats. As port facilities digitalize, and in some cases automate, their operations, cyber threats are growing in importance, and accordingly such threats should be identified in revisions to an organization's PFSA and addressed in its PFSP.

2.2 United States

The United States government, for its part, has taken more assertive steps to regulate port cybersecurity. However, it has conscientiously done so without issuing new regulations. Instead, the United States Coast Guard (USCG), which has the authority to regulate port security in the United States, in early 2020 issued Navigation and Vessel Inspection Circular (NVIC) 01-20. The USCG has affirmed that the NVIC 01-20 is not itself a regulation on its own; instead, the NVIC 01-20's intent is to clarify the USCG's position that port cybersecurity is to be addressed similarly to other security and safety matters currently regulated under existing legislation (United States Coast Guard, 2020a).

In the United States, ports and port facilities are regulated under the Maritime Transportation Security Act (MTSA), which requires them to conduct vulnerability assessments and develop security plans. Consistent with the ISPS Code, the MTSA includes requirements to assess, document, and address computer system or network vulnerabilities. Facilities regulated under the MTSA are required to assess and document those vulnerabilities associated with their computer systems and networks in a Facility Security Assessment (FSA). If vulnerabilities are identified, the applicable sections of the Facility Security Plan (FSP) must address the vulnerabilities. FSAs and FSPs are to be renewed every five years.

When the USCG issued NVIC 01-20 in March 2020, it allowed a 1.5-year implementation period for regulated facility owners and operators to update their existing FSPs based on NVIC 01-20's clarifying language for addressing computer system or network vulnerabilities. Accordingly, facility owners/operators were required to submit updated FSPs or cyber annexes or addenda by the facility's annual audit date, no later than 1 October 2022 (USCG, 2020b). Thus, now all regulated port facilities are required to update their FSAs and FSPs account for cybersecurity vulnerabilities.

Nonetheless, this is unlikely to be the end of USCG's action on port cybersecurity. In December 2020, the United States released a National Maritime Cybersecurity Plan, which requires the USCG to develop a framework for port cybersecurity assessments (United States National Maritime Cybersecurity Plan, 2020). In addition, USCG is continuing to review and update NVIC 01-20, with the intent of evolving USCG's guidance.

2.3 *European Union*

The European Union (EU) has addressed port cybersecurity in an indirect way. In 2016, the European Parliament adopted the Directive on Security of Network and Information Systems (NIS Directive), which requires Operators of Essential Services (OES) to conduct cyber risk assessments that address the security, integrity, and resilience of network and information systems. The NIS Directive classifies port operators as OES (European Union Directive, 2016). These risk assessments and their corresponding mitigation measures are intended to instill a culture of risk management throughout the organization. Several EU member states have developed and introduced guidance to port operators regarding cyber risk assessments, but many operators have adopted one of the methodologies introduced in industry standards, such as the ISPS Code (ENISA, 2020). EU member states are responsible for determining penalties for non-compliance with the NIS Directive; Spain, for instance, has imposed a maximum penalty for NIS Directive non-compliance of one million euros (Government of Spain, 2018).

2.4 *Singapore*

Finally, in 2019, Singapore passed the Singapore Cybersecurity Act, which establishes a legal framework for the oversight and maintenance of cybersecurity in Singapore. Port terminal operations are included among the essential services covered by the Cybersecurity Act. The Cybersecurity Act requires that port terminal organizations furnish to the Singapore Cybersecurity Agency (CSA) certain information regarding the design, configuration, and security of their critical information infrastructure (CII); notify CSA within two hours of becoming aware of a cybersecurity incident; and conduct an annual cybersecurity risk assessment of their CII and undergo a biennial CII audit.

The Cybersecurity Act is considerably more prescriptive than the legislation and regulations that govern port cybersecurity in the United States or the EU. Even more, penalties for failure to comply with Cybersecurity Act obligations are relatively severe, including fines of up to S$100,000 and up to 10 years of imprisonment.

2.5 *Interim Conclusion*

Cybersecurity is a challenging topic and cannot be solved via regulation and financial penalties alone. Cyber threats are ever-present, constantly evolving, and manifest themselves at a pace that is much faster than a regulatory process. For this reason, prescriptive cybersecurity regulation is fleeting. Too often, by the time a regulation has been drafted, edited, reviewed, issued for public comment, revised, and implemented, it may no longer be as effective or relevant for addressing the cybersecurity threat it was intended to solve. Nonetheless, regulation does have a role. Codifying certain general cybersecurity requirements and minimum standards of care under law is a good idea. And harmonizing requirements across jurisdictions is an even better idea.

One way to achieve this would be to incorporate specific cybersecurity standards under the ISPS Code, similar to how the IMO introduced minimum cybersecurity standards for shipping under the International Safety Management (ISM) Code (Petta, 2021). For example, such standards might require that port facilities, at a minimum:

- Perform cybersecurity assessments and develop cybersecurity plans based on assessment results;
- Perform cybersecurity-related training, drills, and exercises;
- Update security and incident response plans to include cyber risk factors;
- Notify relevant authorities within a specified period of the occurrence of a cyber breach;
- Carry minimum levels of cybersecurity insurance.

3 Government and Industry Guidance

The increasing digitalization of port operations is accompanied by an increasingly complex cyber risk landscape. In light of this, some transnational organizations with port-sector interests have engaged industry stakeholders and operators to develop relevant cybersecurity guidance decoupled from regulations. Port stakeholders have developed and published guidelines and best practices to assist ports and port facilities with driving improved cybersecurity and cyber risk management, even in the absence of specific regulations. Many of these guidelines are geared toward understanding the financial risk of a cyber-attack and making decisions regarding investments in cyber risk management.

3.1 International Association of Ports and Harbors

One of the principal industry-driven responses to the need to both understand and manage cyber risk in ports is the International Association of Ports and Harbors' (IAPH) two recent publications on port cybersecurity: "Cybersecurity Guidelines for Ports and Port Facilities" and "Port Community Cyber Security White Paper." The guidelines are focused on the approach individual ports and port facilities should take in managing cyber risk, while the white paper is focused on how port communities that are increasingly digitally interconnected can take action to manage their collective cyber risk.

3.1.1 IAPH Guidelines

Developed in collaboration with the World Bank and port cybersecurity experts from around the globe, the guidelines were published with the objective to help senior port executives and decision-makers who are not cybersecurity experts to better understand how to:

- Effectively organize and determine and allocate resources to address cyber risk to their organizations;
- Deploy tools and methodologies to measure the financial, commercial, and operational impact of a cyber-attack to their organizations;
- Ensure that their organizations are prepared to prevent, detect, respond to, and recover from a cyber-attack.

As opposed to regulations that set minimum standards for cybersecurity in ports and port facilities, the common thread to these guidelines is the focus on the business imperative of managing cyber risk. These guidelines detail how to develop a port or port facility's individual business case for determining a reasonable level of investment for that specific organization's cyber risk management needs. For example, the guidelines recommend that ports and port facilities perform a business impact analysis based on realistic cyber loss scenarios against which to estimate financial valuations to determine and measure specific assets or systemic values at risk. By taking this analytical approach, ports and port facilities can establish the cyber-risk-to-money intersection that provides a financially informed risk management framework. This framework enables the efficient allocation of resources, the development of organizational constructs to facilitate operational resilience, and effective resource identification, allocation, and prioritization.

Once the port or port facility has established the business case for managing cyber risk, it can use the guidelines for direction on how to organize itself to manage cyber risk, including determining who is responsible for the management of cyber risk, such as a Chief Information Security Officer; the role of a board of directors in overseeing a port or port facility's organizational cyber risk management; and the imperative of driving cybersecurity across the port or port facility. The guidelines further discuss the need for port and port facilities to continuously grow and improve their cybersecurity capabilities, often by developing and following an organization-specific cybersecurity capability maturity model. Finally, these guidelines include PFSA and PFSP templates to assist port organizations with revisions required under the ISPS Code.

Ultimately, the IAPH guidelines recognize that effective cyber risk management is not compliance-driven, but instead requires continuous engagement, self-assessment, and improvement over time—and, critically, within the context of and consistent with the organization's performance objectives.

3.1.2 IAPH White Paper

In addition to those organization-specific guidelines, the IAPH's white paper on port community cybersecurity delves into the management of cyber risk in increasingly connected port ecosystems. The white paper references port authorities' emerging roles in coordinating the implementation of digital technologies within their communities, including the development of port community systems (PCS) to manage end-to-end trade logistics within a port ecosystem. This increasing interconnection brings with it increased cyber risk, in particular the risk inherent in individual organizations focused on protecting their own digital systems and not coordinating with other members of the port community. The white paper makes recommendations for managing this collective risk, including grounding port community cyber risk in financial terms, establishing intra-community information-sharing mechanisms, and managing responses to coordinated attacks that could cause supply chain disruptions across an entire port community.

3.2 European Union

To assist port operators with managing cyber risks under the NIS Directive, in 2020 the EU Agency for Cybersecurity (ENISA) issued, "Cyber Risk Management for Ports: Guidelines for Cybersecurity in the Maritime Sector." These Guidelines build on ENISA's 2019 report, "Port Cybersecurity – good practices for cybersecurity in the maritime sector," which described the primary cyber threats posing a risk to the port ecosystem and identified security measures ports and port facilities should take to protect themselves from such threats.

These guidelines are the result of extensive collaboration among a wide range of port and port facility stakeholders and industry experts. They offer actionable practices to address evolving cybersecurity threats and the required conduct of cyber risk assessments. Specifically, these guidelines introduce minimum requirements based on a four-phased risk assessment methodology that synthesizes the ISPS Code and the NIS Directive, EU Directive 2005/65 (Annex I) on enhancing port security and includes a component for analyzing organizational cybersecurity capability maturity. The methodology's four risk assessment phases can be adapted to various risk assessment methodologies, and include the identification and evaluation of organizational activities, cyber-related assets and services, cyber-related risks, and related mitigation measures. Finally, as with the IAPH guidelines, ENISA's guidelines recommend that port operators take a maturity model approach to guide them in their efforts to grow and evolve their cybersecurity capabilities and measures over time.

3.3 Organization of American States

Regionally focused organizations are also examining port-industry cyber risk and developing guidelines for its port and port facility executives. One example is the Organization of American States (OAS) Inter-American Committee against Terrorism (CICTE), which issued a set of guidelines to assist port and maritime stakeholders understand and manage cyber risk. Although adapted to the port and maritime sector in the Western Hemisphere, the guidelines describe a more general set of initial steps and best practices maritime organizations can take as they implement cyber risk management programs. The guidelines highlight the nascent nature of port-related cybersecurity regulation in the region and emphasize the need for organizations to develop and provide resources for their own effective cyber risk management and cybersecurity programs even in the absence of regulatory requirements.

3.4 United Kingdom

In 2020, the United Kingdom Department for Transport updated its Good Practice Guide: Cyber Security for Ports and Port Systems. Unlike the IAPH, EU, and OAS guidelines, which focus on executives and their need to oversee cyber risk management and cybersecurity at a high level, this guide offers specific advice on:

- Developing a cybersecurity assessment and plan for important assets;
- Handling security breaches;
- Ensuring the use of correct governance structures, roles, responsibilities, and processes.

This guide also includes detailed information for port security practitioners about developing a cybersecurity assessment, developing a cybersecurity plan, and establishing cybersecurity governance and management within a port facility. Unique among many of the guidelines and best practice guides, this guide reaffirms the importance of the role of the Chief Information Security Officer (or Cyber Security Officer) as the individual with ultimate responsibility for a port or port facility's cybersecurity. Finally, this guide provides a number of practical templates, including a process for developing a cybersecurity assessment, a definition of the contents of a cybersecurity plan, and the identification and implementation of mitigation measures.

4 Insurance

In addition to supranational political bodies, regional organizations, and national governments that issue regulations and/or guidance, the insurance industry is also helping to guide ports and port facilities' cyber risk management and cybersecurity approaches. Although cyber insurance serving the global port and port facility market remains fragmented, it is becoming an important part of many organizations' cyber risk management programs (Cremer et al., 2022). But cyber insurers want to know their risks, and often require a full assessment of cyber risk and the implementation of certain cyber controls before a port or port facility can be a candidate for cyber insurance (Hill, 2022). Required capabilities can include the implementation of firewalls, the performance of regular vulnerability testing, a cybersecurity training program for staff, and the performance of regular cybersecurity assessments.

Further, with the average cyber insurance claim rising from USD 145,000 in 2019 to USD 359,000 in 2020, and with trendlines continuing to increase, cyber insurers are paying ever-increasing attention to how to grow the cyber risk management capabilities of their insured (and potential insured) (Cremer et al., 2022) while protecting their financial bottom lines. In this way, as many ports and port facilities look to transfer at least some cyber risk off of their balance sheets, insurers are creating *de facto* cybersecurity and cyber risk management standards. Importantly, insurers are able to develop and renew cybersecurity performance standards and controls faster than regulatory changes occur and therefore have a better chance at adjusting to the market dynamics posed by cyber threat evolution. Annual policy renewals, in particular, drive this mechanism for adaptation.

Examples of areas in which cyber insurance is driving and evolving this organizational change include:

- **Governance**. Managing cyber risk begins at the top of a port or port facility with its executives and board of directors. This governance plays a critical role in the success of a port or port facility's ability to establish cybersecurity capabilities and achieve sustainable organizational cyber maturity. Effective cyber risk management depends on a common understanding of terms, financial grounding, and recognition of shared responsibility across both the organization and the port community overall.
- **Incident response**. A port or port facility should have pre-defined and accessible people, plans, processes, business practices, and technologies ready to detect, evaluate, and respond to confirmed cybersecurity events. The port or port facility should deploy its resources commensurate with the risk to its critical information technology (IT), operational technology (OT), and Communications assets and supporting infrastructure. The port or port facility should further ensure that cybersecurity incident response and recovery, preparedness, and/or contingency planning are harmonized and aligned with all compliance-based plans and activities, such as those mandated by the ISPS Code.
- **Business continuity**. A port or port facility should have a formal business continuity plan that considers its specific IT and OT operating environments. The plan should acknowledge the possibility of cyber threats and take proactive steps to organize its people, policies, procedures, technologies, and partners for responding to a cyber incident. The plan should provide guidance on the restoration of assets, systems, equipment, services, and organizational service delivery.
- **Training**. In 2021, more than 80% of breaches involved human-based causes (Verizon, 2022). A port or port facility should have a cybersecurity training program for all staff, as well as third parties

who will have access to a port organization's facilities and/or systems. Training staff and third parties help a port or port facility develop and sustain a culture of cyber risk awareness that supports overall cybersecurity capability and organizational cyber resiliency. Training should ensure minimum appropriate levels of cyber awareness and behavioral competence. A port or port facility requires levels of awareness commensurate with its cyber risk management objectives and efforts to protect its critical assets, systems, and infrastructure.

Critically, cyber insurance is driving the institutionalization of effective cybersecurity capabilities across ports and port facilities. The ports and port facilities that are able to obtain cyber insurance and therefore transfer certain cyber risks are those whose cybersecurity capabilities, processes, procedures, and/or tools are ingrained across the organization. In this way, cyber insurance more so than regulation will drive cybersecurity best practices across the port industry.

5 Conclusion

5.1 *Regulation and Guidance: Useful but Insufficient*

The regulatory and guidance approaches are significantly different, but both play a role in managing cyber risks in the port industry.

The regulatory process is slow and often lags the tempo of technological advancement and the evolving cyber threat landscape, but is useful for establishing minimum, baseline levels of cyber risk mitigation activities that port organizations must meet. The burgeoning regulatory regimes in the United States, EU, and Singapore are on the right track: without being overly prescriptive, they assure that ports and port facilities under their jurisdiction are performing cyber risk assessments and developing plans to mitigate the cyber risks they identify. The increasingly interconnected nature of the port industry necessitates this requirement for all ports and port facilities.

The guidance documents that both government and private entities have published are useful references for how ports and port facilities can take the actions necessary to meet regulatory requirements. Guidance documents set context, define steps ports and port facilities can take to develop cyber risk management programs, and identify best practices in cybersecurity processes and controls to consider as ports and port facilities implement their cyber risk management programs. These documents illustrate best practices and lessons learned from a variety of ports and port facilities across the globe who are leaders in port cybersecurity assessments, plans, and information-sharing.

5.2 *The Future: The Marriage of Legislation and Insurance*

The current regulatory regime and set of guidance documents are valuable. But cybersecurity assessments and plans conducted in a vacuum, and guidance that is not tailored to an individual port or port facility, will not be sufficient to manage the port industry's cyber risk. Regulators may want to instead look to another operational risk in the maritime sector: oil pollution, where the unique combination of legislation and insurance have delivered extraordinary successes in risk reduction.

After the Exxon Valdez oil spill of 1989, the United States passed the Oil Pollution Act of 1990 (OPA 90), which created a liability regime that identified the responsible party for an oil spill and required marine transportation providers to carry certain levels of related insurance. By holding the responsible party accountable for the costs of an oil spill, OPA 90 incentivized an insurance market that drove improvements in oil pollution risk mitigation that resulted in massive decreases in marine oil spills (Homan & Steiner, 2008).

Regulators tackling port cybersecurity should consider doing so in two ways. First, the IMO should strongly consider amending the ISPS Code to require ports and port facilities to conduct regular cybersecurity assessments and develop robust cybersecurity plans. This will create a global cybersecurity baseline for the entire port industry. Second, regulators either at the national level or at the IMO should consider creating a similar liability regime that mandates that ports and port facilities carry cyber insurance. The establishment of a requirement for ports and port facilities to have a specified level of cyber insurance will provide an incentive to motivate the port industry toward a desirable level of cybersecurity. A port or port facility's cyber risk will become its insurance carrier's cyber risk, and the insurance industry will require cybersecurity standards and controls that align with the evolving threat landscape. This continuous cycle of ongoing cybersecurity growth and development will benefit not only a specific port or port facility itself, but the connected port industry as a whole.

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CHAPTER 14

Opportunities and Challenges in Relation to Big Data Analytics for the Shipping and Port Industries

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1 Introduction

Over the course of time, the world has been dramatically transformed by several stages of the wider industrial revolution phenomenon. The first stage of this prolonged and multi-level change involved the invention and exploitation of steam power and its numerous relevant applications during the eighteenth and nineteenth centuries, and was the turning point of our

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society from an agrarian into a (highly) industrialized one. The second stage of this revolution was associated with the issue of mass production (assembly line and other associated concepts), as well as taking full advantage of electricity. Then, approximately since the mid-twentieth century, the third stage of the industrial revolution was a direct result of computers and the introduction of information technology applications that should be viewed as making the whole "western world" (including of course a certain number of Asian countries like Japan, South Korea, Singapore, and more recently China) more "intelligent" and quite reliant on digital means (Dalaklis et al., 2019). It is also clear that today we are already under the influence of the "Fourth (stage of the) Industrial Revolution," also described as "Industry 4.0" in the wider literature and by certain leading technology actors (IBM, 2022). The shipping and port industries are already transitioning into a new operations paradigm, often termed as "era of digitalization"; indicative examples are provided by advanced technology applications like Artificial Intelligence (AI), Big Data Analytics (BDA), Cloud Computing, and Internet of Things (IoT) (Ichimura et al., 2022).

Apart from operating under the strong influence of digital means, the contemporary shipping business environment is characterized by continuous changes and fierce competition. This situation is creating a pressing need for companies to identify and quickly adopt the right "tools" for ensuring their survival, as well as promoting their further development and consolidation within the sector of the market that they operate. Informatics, from the very beginning of their inception, has proven to be a powerful tool at the disposal of companies that want to improve their business model, since they can be used as the main strategic enabler for integrating changes in the company's internal structure, functions, and processes. Especially in the wider shipping and port sectors, an extremely large volume of data, commonly referred as "Big Data" (BD), is produced from a very extended pool of relevant sources (i.e., systems supporting the

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conduct of navigation and/or ship's machinery, as well as fleet and/or port management systems, etc.) The domain of BDA examines extremely large amounts of data to uncover hidden patterns, correlations, and other insights (i.e., market trends and customer preferences) that can help organizations make informed business decisions; it can be categorized as a special branch of the wider information technology (IT) domain and its main aim is to discover correlations and interactions between different measurable or non-measurable parameters, in order to identify non-clearly defined standards and patterns (Goyal et al., 2020).

With certain results being already presented at a relevant scientific Conference (Dalaklis et al., 2021), this chapter aims to clearly highlight that BDA has the potential to create a very positive impact upon the shipping and port industries. To achieve this, a qualitative approach is deployed, working in unison with a "Strengths, Weaknesses, Opportunities, and Challenges" (SWOC) analysis matrix. This combinatory methodology will allow to identify and briefly discuss the most relevant tools and techniques that are associated with effective BD management, indicating that the transition to a new era, characterized by the terms "smart shipping" and "smart ports," has already started. The influence of the notorious "digitalization" phenomenon upon the maritime transport industry and related port infrastructure is unfolding at a pace faster than anticipated, with the aim to improve operational efficiency and productivity, as well as to contribute into a more sustainable mode of operations. Before moving to a different direction, it is necessary to note that ports play a vital role in global trade, by handling more than 80% of freight transferred all over the world, dealing with continuously growing demands on productivity and operational efficiency and concurrently contributing into sustainable development in accordance to the United Nations 2030 Agenda for Sustainable Development (Alamoush et al., 2021).

2 Background

2.1 Big Data Concept

The contemporary era is frequently referred to as "the information age" (Tucci, 2014). It is therefore not a coincidence that economic activities like ship and port management are very highly dependent on data. It is also quite obvious that the volume of (stored and processed) data has grown exponentially over the course of time and this trend is recorded in literally all economic sectors and related activities. In order to provide a relevant definition, the McKinsey Global Institute, is approaching BD as those datasets with a size that exceeds the ability of traditional database software tools to collect, store, manage, and analyze these data (Al-Sai et al., 2019; Manyika et al., 2011; Saxena, 2016). This very significant growth in accessibility of data, storage capacity, and computational power has impacted businesses throughout the world. This change involves not only very popular and well-known businesses like Yahoo or Facebook that were "were born and function solely online," but also early adopters in more conventional industries such as banking, retail, and of course transport. In the near future, a really impressive data growth is expected because of the related developments in remote sensors, as well as functions like communications, computations, and processing activities of an "interconnected world" that will involve very large data collections/handling (Davenport & Harris, 2007; Goyal et al., 2020; Ichimura et al., 2022). It is also true that there are various definitions of BD and the prevailing version is usually different from one industry to another, and clearly depending on the type of available software tools and the sizes of datasets that are in common use within that specific industry (Al-Sai et al., 2019). BD is a potential research field receiving considerable attention from both academics and IT professionals.

In this digital era, the amounts of data generated/stored have expanded literally exponentially (Yaqoob et al., 2016). This very significant growth in the accessibility of data, storage capacity, and computational power has impacted businesses throughout the world (Davenport & Harris, 2007; Goyal et al., 2020). According to certain estimates, only 0.5% of globally generated data is analyzed today. In a world where "every 2 days we create as much information as we did from the beginning of time up to 2003," there is a need to cover the gap between data being analyzed and opportunities to improve business models currently in use. Today, approximately 20–100 billion connected devices are responsible for more and more data collection; on the positive side, understanding connections and patterns "hidden" in that vast pool of data can be achieved by applying BDA (GOS, 2014; Priestley, 2015). The three major motives for BD implementation are to minimize hardware costs, check the value of data before committing significant company resources, and reduce relevant processing costs. In addition, the implementation of new technologies for BD applications has contributed to performance improvement, innovation in business model products, as well as service and decision-making support (Carasso, 2012).

Size is the first characteristic that comes to mind when considering the question "what is big data?" Laney (2001) suggested that Volume, Variety, and Velocity (3V's) are the three basic dimensions in data management. That model provided a first common framework to describe BD (Chen et al., 2012; Kwon et al., 2014). Gartner Inc. defined BD in similar terms (Gandomi & Haider, 2015): "Big data is high-volume, high-velocity and high-variety information assets that demand cost-effective, innovative forms of information processing for enhanced insight and decision making." Similarly, the TechAmerica Foundation defined the term under discussion as "a term that describes large volumes of high velocity, complex and variable data that require advanced techniques and technologies to enable the capture, storage, distribution, management, and analysis of the information." Several studies, such as those by Manyika et al. (2011), Demchenko et al. (2013), Widyaningrum (2016), Bronk and Khan (2017), as well as Drus and Hassan (2017) have characterized BD by a multi-V (4Vs) model (volume, variety, velocity, and value). At the same time, other approaches emphasize the so-called 5Vs model (volume, velocity, variety, veracity, and value). This one is exhibiting certain differentiating characteristics that have been formulated by the difference between using traditional data and effectively exploiting BD (Chen & Zhang, 2014; Ishwarappa & Anuradha, 2015; Romijn, 2014; Saxena, 2016). Finally, according to Fouad et al. (2015), the BD concept is a cost-effective, and innovative technology used to describe the exponential growth and availability of structured and unstructured data for enhancing the processes of decision-making. This discussion is pointing out that there is a certain number of characteristics that distinguish BD from traditional relational database management systems (RDBMS); these characteristics can provide a complex descriptor, called the 6V's model (Volume, Velocity, Variety, Veracity, Viability, Value) (Ding et al., 2014), which is explained with the help of Fig. 1:

In summary, BD refers to a process that is used when traditional data mining and handling techniques cannot uncover the insights and meaning of the underlying data. Data that is unstructured or time sensitive or simply very large cannot be processed by relational database engines. This type of data requires a different processing approach called BD concept, which uses massive reliance on readily available hardware. BD enables organizations to store, manage, and manipulate vast amounts of disparate

Fig. 1 Big data—6Vs definition model (*Source* Authors)

data at the right speed and at the right time (Dhamodharavadhani et al., 2018).

2.2 *Big Data Analytics*

BDA is utilized by the various industries to describe, diagnose, predict, prescribe, and cognate the hidden growth opportunities and leads them toward gaining business value. Activities within that domain deploy advanced analytical techniques to create knowledge from an exponentially increasing amount of data (data mining, text mining, social media analysis, etc.), which will affect the decision-making process by decreasing the complexity of the whole process. BDA needs novel and sophisticated algorithms that process and analyze real-time data and result in high-accuracy analytics. Machine and deep learning allocate their complex algorithms in this process considering the problem approach (Harfouchi et al., 2017; Mavrovounioti & Yang, 2015; Wang et al., 2017). BDA can be viewed as a sub-process in the overall process of "insight extraction" from BD. The overall process of extracting insights can be broken down into five stages. These stages form the two main sub-processes: data management and analytics, which are shown in Fig. 2. The first sub-process involves processes and supporting technologies to acquire and store data, as well

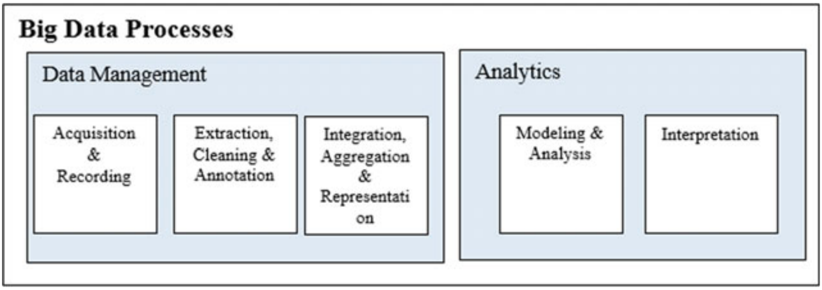

Fig. 2 Processes for extracting insights from BD (*Source* Authors)

as to prepare and retrieve it for analysis; the second one refers to techniques used to analyze and acquire intelligence from BD (Gandomi & Haider, 2015; Labrinidis & Jagadish, 2012) (Fig. 2).

BDA is required to efficiently analyze large amounts of data within a limited time period. The following techniques that were identified in the relevant literature represent a subset of the tools available (Bingham & Mannila, 2001; Chen & Zhang, 2014; Fan et al., 2014; Gandomi & Haider, 2015; Geng et al., 2012; Heer et al., 2008; Hinton et al., 2006; Keim et al., 2008; Li & Yao, 2012; Lin, 2005; Panigrahi et al., 2010; Sahimi & Hamzehpour, 2010; Tracy, 2010; Yaqoob et al., 2016):

- Data mining techniques: Used to summarize data into meaningful information. This includes cluster analysis, association rule of learning, classification, and regression. Machine Learning (ML) and statistical methods are also deployed in order to extract the "targeted" information;
- Text mining techniques: Used to extract information from textual data. Indicative examples include social network feeds, emails, blogs, online forums, survey responses, corporate documents, news, etc. Statistical analysis, computational linguistics, and ML can be involved;
- Web mining: Is employed to discover a pattern from large web repositories. It reveals unknown knowledge about a website and users. Web mining is classified into two different types: Web content mining (helps to extract useful information from the web content)

and Web structure mining (uses graph theory for analyzing nodes and connection structure of a website);

- Audio analytics: Used to analyze and extract information from unstructured audio data. For example, call-centers use audio analytics for efficient analysis of thousands or even millions of hours of recorded calls. When applied to human spoken language, audio analytics is also referred to as speech analytics. Speech analytics follows two common technological approaches: the transcript-based approach (Large-Vocabulary Continuous Speech Recognition, LVCSR) and the phonetic-based approach;
- Video analytics or Video Content Analysis (VCA): A variety of techniques to monitor, analyze, and extract meaningful information from video streams. Although video analytics is still in its infancy compared to other types of data mining, various techniques have already been developed for processing real-time as well as pre-recorded videos. Video analytics involve two system architecture types: server-based and edge-based;
- Predictive analytics: Techniques that predict future outcomes based on historical and current data, for example, predicting the failure of a ship's engine based on the stream of data from several sensors. The predictive analytics seek to uncover patterns and capture relationships in data. Predictive analytics techniques are primarily based on traditional statistical methods, but can be used for BD, too;
- Visualization methods: They are utilized to create tables and diagrams to understand data. Data presentation is important in dealing with BD. Also, relevant visualization is more difficult when compared to traditional small data visualization. Researchers have often applied a batch mode software to obtain the highest data resolution in a parallel manner;
- Machine learning (ML): Allows computers to "develop" behaviors based on empirical data. Existing ML techniques, both supervised and unsupervised, are required to scale up so that to effectively cope with BD. ML algorithms for BD are still in their infancy stage and suffer from scalability problems. Moreover, artificial neural networks can be utilized in pattern recognition, adaptive control, analysis, etc.;
- Optimization methods: Utilized to solve quantifiable problems. These methods are used in multidisciplinary fields; strategies used

are highly efficient, because they exhibit parallelism. These techniques provide optimization, but have high complexity and are time-consuming;

- Social network analysis: Employed to view social relationships in social network theory. It has gained significance in social and cloud computing.

2.3 Big Data in the Shipping and Port Industries

Big Data is gaining popularity in the shipping industry since large amounts of information are collected to better understand and improve issues like logistics, energy consumption, and maintenance, or even emissions. The shipping industry is key to global trade and currently operates under a complex set of different international and national regulations in terms of data collection and usage. Constraints to the use of BD include cost and quality of on-board sensors and data acquisition systems, satellite communication (availability, bandwidth and overall cost), data ownership issues and certain technical obstacles to the effective collection of the associated data. On a positive note, new protocol standards may simplify the process of collecting/organizing that data, including expected developments within the e-navigation domain (Rodseth et al., 2016; Zaman et al., 2017).

Further, it is important to explain the distinction of data into traditional and non-traditional. The term traditional data refers to the review of data from "standard" business support systems; indicative examples include fuel costs, transit times, wages, insurance, revenue per TEU, etc. These are data pools that can be used to determine the profitability of a trip. On the other hand, non-traditional data is time sensitive and is constantly changing, such as weather conditions, traffic delays, port strikes, etc. Usually, these data are generated by sensors, GPS services, and related traffic management systems (IEC, 2015; IMO, 2009, 2014; ISO, 2015a, 2015b; Rodseth et al., 2016). Finally, it is useful to note that there are various sources of data on the ship, with a high volume and associated with many possibilities for errors. To effectively remove these potential errors, Data Management (on the ship and ashore) has to be performed along three axes/dimensions: (a) Volume and storage, (b) Quality, and (c) Analytics. Volume and storage management can help to deal with large volumes of data in a structured collection on board and/or ashore. Volume management will help to consider the cost and capability of moving large sets of data between ship and the shore. Finally, quality control of the data needs to be considered as a separate activity and is clearly critical for the correctness of the analysis results.

The volume of data coming from vessels at sea is truly huge. Consider the large amounts of data from the Marine Traffic portal that indicate the exact locations of all vessels on a global scale, for example (marinetraffic.com, 2022). Also, effective implementation of existing maritime regulations requires continuous data from vessels, which must be collected, stored in a format that allows monitoring of the vessel, such as position/location, speed, course, the weather at the respective location or even data generated each time in real time and collected by sensors such as main engine telemetry data and many more. Data recording must be continuous and maintained in relation to various applications, offering detailed information that will contribute to "easier" decision-making. An additional feature of BD is its wide variety, as it is stored in many different formats. Data coming from seagoing vessels can be collected from dozens of different devices and with different formats. Accuracy and validity in ship management systems may have evolved considerably, but the risk of some data errors remains. An incorrect measurement, or an incorrect entry, can lead to erroneous results and consequently to the wrong decision (Rodseth et al., 2016; Zaman et al., 2017). Without the following list being exhaustive, sources of BD on board a vessel are (Rodseth et al., 2016): Bridge data network; Conventional ship's automation; New cyber-physical systems; Ship performance monitoring systems; Ship voyage monitoring and reporting systems; External ship monitoring (AIS and VTS); Weather data, among others.

As highlighted above, data associated with ship operations can be collected from various sources. However, in order to extract the "right" information and be able to make meaningful decisions, the stage of analysis is essential; a rigorous (Big Data) analysis is crucial. The BD value chain also consists, in the case of shipping data, of collecting, processing, and storing data, analyzing it with innovative and cost-effective technologies and techniques, and formatting it in such a way as to either create a better understanding, or improve insight and decision-making (Rodseth et al., 2016). The adoption of BDA is facilitated by the willingness of the shipping industry to move from a traditional culture to its operational management into a new Data Driven culture, as it is moving forward toward digitalization. According to various sources (IEC, 2015; IMO, 2009), indicative areas of interest include (but, are not limited to):

- Vessel Performance Monitoring. The vessel's energy efficiency management plan (IMO, 2009) requires vessels to collect information on the vessel's performance and conduct of navigation from various on-board systems and associated Data Acquisition Systems. These systems are designed to collect, store, and communicate large amounts of data relating to vessel performance and navigation data through complex processes. Data obtained from analytics allows a better understanding of the vessel's performance. Data on, for example, fuel consumption may show that in extreme weather conditions a significant reduction in speed can lead to disproportionate fuel reduction, leading the vessel to consume more fuel to move and indicate a change in speed at the point of optimal consumption. Data analytics in relation to a specific vessel might also "predict" a repair or a possible malfunction;
- Navigation Data. In 2000, the International Maritime Organization (IMO) defined the need for an Automatic Identification System (AIS), capable of automatically providing information about the vessel to other (nearby) vessels as well as to relevant authorities ashore. Since then, that data have been turned into a common object of research in the field of marine and/or maritime-related studies. This data mainly consists of the ship's identity, location, speed, and direction. BDA could provide a better understanding of the vessels' movements, indicating, for example, the most popular points of trade or helping ships to avoid congested areas/collisions and ensure a better level of safety at sea;
- Green Shipping. IMO has introduced several regulations regarding the reduction of emissions and improvement of energy efficiency. BDA can provide important information and lead to optimizations in relation to vessels' emissions, allowing a deeper understanding of the problem;
- Safety. Another area of interest in the world of Big Data analytics is that of safety in the operational management of the vessel. The information generated clearly creates new perspectives on maritime risk management and accident prediction;
- Autonomous or Remote Controlled Ships. BDA could provide a better decision-making for people performing remote control and allow for a smoother integration of these types of vessels.

Steering the discussion toward the port industry, the BD philosophy is an important factor for the future, often associated with the concept of "smart port." This "smart port environment" can be created via the integration of the various activities within the port and an indicative model is shown in Fig. 3. However, further details/explanations are outside the scope of this chapter (Fig. 3). In any case, BD from ports is derived from two major sources (Haidine et al., 2021; Heilig & Voß, 2016; Yau et al., 2020):

- The terminal operating system (TOS), the nerve center of any modern port operations. The TOS manages all processes, from documentation to planning and from execution of vessel operations to billing. It is a treasure house of rich data, especially on inventory changes, work plans, and sequences for dispatching jobs;
- From sensors and programmable logic controllers that have been built into cargo handling equipment.

It is also useful to note that the main applications of BD in ports are (Haidine et al., 2021; Heilig & Voß, 2016; Yau et al., 2020):

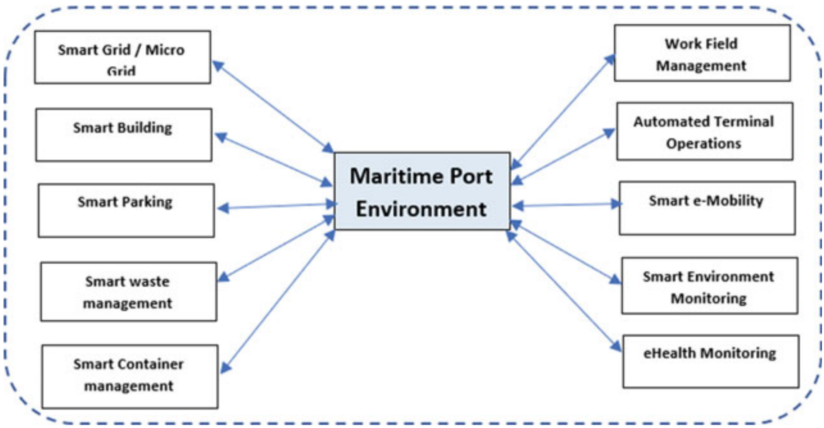

Fig. 3 Creating a "smart port" environment (*Source* Authors)

- Optimizing usage: Unlocking big data from port operations makes it easier to optimize the usage of resources and infrastructure;
- Preventive maintenance of cranes, and other machinery: Harvesting operational data from sensors placed inside machines makes it possible to predict when a part might fail, paving way for a more effective maintenance schedule as opposed to following the maintenance schedule recommended by the manufacturer;
- Accurate Predictions: BDA unlocks data hitherto not visible, and consolidates information from various sources, including vessels, machinery, and terminal operating software. Unlocking relevant operational patterns generates actionable, allowing decision-makers to not just optimize operations, but also anticipate events.

In addition, data from sensors placed in port equipment could help port operators design a predictive model for each type of machine, maximize the efficiency of port equipment, leading to cost savings. BDA also has the power to predict the demand and supply of port infrastructure, and thereby suggest new business models (Haidine et al., 2021; Heilig & Voß, 2016; Yau et al., 2020). Specifically, this concept (smart port) is a customer- and community-centric port that is distinguished by five main features:

a. smart port services and applications such as vessel and container management;
b. technologies such as data center, networking and communication, and automation;
c. use of sustainable technology to increase energy efficiency and reduce greenhouse gases emissions;
d. cluster management such as a shipping cluster that consists of geographically proximate companies and stakeholders with their main activity being shipping; and
e. development of hub infrastructures to foster collaboration among different ports.

From these features, BD methods offer significantly mainly with (i) (smart services & applications), (ii) (technologies supporting data center & communication—5G Smart ports), and (iii) (hub infrastructures for collaboration with different ports). A massive amount of real-time data and information is generated from heterogeneous sensing and detection devices in an unpredictable and dynamic environment. BDA can enable a better usage of data, from making essential decisions (e.g., identifying the quickest route and the preferred ports) to generating detailed statistics at a pace faster than human beings can do. This helps to improve the competitiveness and productivity of ships and ports. Accessing different kinds of real-time data, including traffic, weather, and currents, from different stakeholders (e.g., vessel owners and port authority) helps to visualize information (e.g., ship and container movements) and make optimal decisions, to predict the availability of resources (e.g., containers), and to optimize stowage and terminal operations, voyages, and coordination of the arrivals of vessels at ports in a real-time manner (Yau et al., 2020).

3 Methodology Framework

In this research effort, the methodology framework follows three basic steps: (i) data collection, (ii) Analysis with the help of SWOC tool/matrix, and (iii) exclude conclusions; it is summarized with the help of Fig. 4. Specifically:

- Data collection. This contains source identification, from international Databases (google scholar, science direct). Maritime environment-related keywords were used to search for articles (i.e., BDA in shipping, AIS, big data, etc.).

Briefly, the creation of the necessary pool of data follows the principles listed next: (i) Use of international search engines and existing printed versions of the literature, (ii) insert the keywords, (iii) Selection of texts (articles, studies, etc.), and (iv) their elaboration (challenges/opportunities/trends).

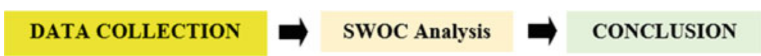

Fig. 4 Methodology framework (*Source* Author)

- SWOC tool. Categorization of findings (conclusions) according to the relevant SWOC variables. A SWOC analysis is a strategic planning tool and it can be used as a powerful framework. It contains: strengths, weaknesses, opportunities & challenges.
- Conclusion. We emphasize the opportunities and challenges in two fields: Big Data Concept, as well as Shipping (Maritime Transport) & Ports Industries (Fig. 4).

4 Analysis

A summary of the results is provided below (Tables 1 and 2). Briefly, these two tables concern all the relevant findings separately for the shipping and port sector, since the terms "shipping" or "port" were always included in the relevant search, along with the key terms "Big Data" and "Big Data Analytics." This analysis process was based on the search and collection of various articles that were deemed as relevant to the main field of research (shipping and post sectors). Input of relevant papers from google scholar and science direct databases was used, followed by a screening of the total inventory of the articles' data according to the axes of the SWOC tool (the selection of articles was made on the condition that they had a separate section on expectations and opportunities, or there was a visible analysis within the body of the article) and then, trimming further down that quite wide pool by selecting only those items that are either identical in many sources or deemed as adequately documented (for the later, the selected criterion was to be able to identify at least one contemporary bibliographic citation; to ensure relevance in terms of timeframe, the last decade was used as the selected benchmarking).

5 Conclusions

The contemporary era is very frequently referred to as "the information age." The further integration of digital tools into ship management activities and port operations/processes can improve operational efficiency, opening the path of increased profitability. Within the wider framework of the port industry, a "smart port" can have a very positive impact on issues like overall productivity, value added, and last, but not least, open up new opportunities of employment. Steering the discussion back to shipping, it is clear that the numerous computers supporting Information Technology (IT) and/or Operational Technology (OT) needs clearly hold a pivotal

Table 1 Results (BD + port sector)

	Strengths	**Weakness**
Inside view	Data quality Consistency Data reliability Data availability Data confidentially Data set scalability (Chen et al., 2012; Chen & Zhang, 2014; Ishwarappa & Anuradha, 2015; Rodseth et al., 2016; Romijn, 2014; Saxena, 2016)	Data management Data transfer Accidents (Haidine et al., 2021; Heilig & Voß, 2016; Yau et al., 2020)
	Opportunities	**Challenges**
Outside view	Smart marine traffic management Smart logistics Smart security service Business model Environmental legislation monitoring (Haidine et al., 2021; Heilig & Voß, 2016; IEC, 2015; IMO, 2009; ISO, 2015a, 2015b; Rodseth et al., 2016; Yau et al., 2020)	Devices that can measure different conditions (i.e., GPS) Sensors & RFID tags (an environment that transmits measures data reliably and in real time, mostly wi-fi connection) A system that can store and manage the transmitted data, and offer a platform to analyzed it Digital transformation (Smart ports) (Haidine et al., 2021; Heilig & Voß, 2016; Yau et al., 2020)

Source Authors

role in this digital era; along with human factors, they should be considered as critical for safe and secure operations. In any case, activities within the shipping and port industries generate a huge amount of data from different sources and in different formats; the volume and variety of that data continue to increase day by day and the expansion of remote sensors within ships and ports will complicate the whole issue of BD management even further.

Today, but also in the future, applications serving ship management needs require the integration of multiple technologies and two areas in particular will have a significant impact on vessel system design and operations: (a) the technology area originates from within the industry and includes ship building propulsion systems and the so-called "smart ship" (automation, intelligent machinery control, cargo handling systems, etc.)

Table 2 Results (BD + shipping sector)

	Strengths	**Weakness**
Inside view	Data quality Consistency Data reliability Data availability Data confidentially Data set scalability (Chen et al., 2012, Chen & Zhang, 2014; Ishwarappa & Anuradha, 2015; Rodseth et al., 2016; Romijn, 2014; Saxena, 2016)	Data management Data transfer Accidents (from IT errors) (Al Nuaimi et al., 2015; Al-Sai & Abualigah, 2017; Boyd & Crawford, 2012; Braun, 2015; Goyal et al., 2020; IMO, 2009, 2014; Malik, 2013; Manyika et al., 2011; Rodseth et al., 2016)
	Opportunities	**Challenges**
Outside view	Data protection Business model Human factors and practice AI using (machine & deep learning) IoT application Energy management Environmental legislation monitoring Performance management Autonomous ship (IEC, 2015; IMO, 2009, 2014; ISO, 2015a, 2015b; Rodseth et al., 2016)	Data analytics Big data security Data quality Data visualization Digital transformation, exploring the impact of digital technologies on business models and operations Applications of big data from AIS, addressing how data analysis, particularly AIS data, can be applied to improve safety, security, and both environmental/commercial efficiency Energy efficiency, covering topics such as speed optimization and route/crane planning predictive analytics, focusing on ship systems maintenance, traffic and accident scenario analysis and other decision making and forecasting challenges (Al Nuaimi et al., 2015; Al-Sai & Abualigah, 2017; Boyd & Crawford, 2012; Braun, 2015; Goyal et al., 2020; IMO, 2009, 2014; Malik, 2013; Manyika et al., 2011; Munim et al., 2020; Rodseth et al., 2016)

Source Authors

or "smart port" (a collaborative environment created by the digital integration of all activities within the port) and (b) technology influences that will come from other sectors and include issues like remote sensors, BDA, as well as AI, IoT, and cloud computing. In the port sector, such transformation would be heralded by harnessing BD to improve the efficiency of port equipment, TOS operations, and for boosting the overall logistics process.

In the wider maritime transport sector and related ports, huge volumes of data (from various sources) are being processed and analyzed in relation to topics like operations of vessels at sea, loading/unloading their cargo, as well as to serve the needs of effective management. Truly vast volumes of data are obtained from both in-vessel systems and the related port systems and relevant cargo handling operations. That data should be collected, processed, analyzed, and stored in such a way as to provide the "right" information and this can be facilitated by a rigorous BDA. However, with standards and performance of relevant algorithms varying significantly, certain regulatory interventions to ensure a uniform approach by the concerned actors are needed. Following the BDA path, shipping companies can extract, with a relatively low cost of implementation, meaningful information and improve their decision-making in areas like reduction in fuel consumption and improving the vessels' environmental footprint. In addition, the use of spatial–temporal data (i.e., vessel identity, location, speed, direction, etc.) can provide opportunities for a better risk management and even contribute to accident prediction. Similarly, port management can have a better understanding of what exactly is happening within the various areas of operations and boost the tempo of operations and maximize profits.

The exploitation of BD and the role of certain software applications in accessing and managing this large volume of information are key factors for improving/optimizing the conduct of maritime transport activities and port management; establishment of a "Data Driven Culture" within the concerned organization can clearly improve the current business model and at the same time promote sustainability. It is crucial to highlight that this new technology paradigm goes hand by hand with certain cultural challenges that must first be fully overcome in order to achieve a smooth upgrade of port operations, and then enjoy all related benefits in terms of effectiveness and boosting profits. BDA can be deployed as a powerful tool and facilitate the transition toward "smart shipping" and/or "smart ports." There is also the opportunity to help shipping companies/ports that perform the investment and effort to enjoy the benefits of a more "safe" and "greener" operating environment. In any case, topics such as optimizing the conduct of all relevant activities on-board the vessel at sea and in the port, as well as contributing to the numerous elements of sustainability by achieving reductions in energy consumption and/or a better overall environmental footprint, should be researched further.

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PART IV

Remote Inspection Techniques

CHAPTER 15

Remote Inspections Scheme on Tanker Vessels During Covid-19 Pandemic

Anastasios Kartsimadakis

1 Preliminaries

All ships, including, where applicable, relevant construction material and equipment/installations, and onboard safety management system and security measures, shall be surveyed/verified by officers of the flag State Administrations or the recognized organizations (ROs)/recognized security organizations (RSOs)/nominated surveyors, authorized to carry out surveys/verifications and issue relevant certificates on behalf of flag State Administrations. This is so that relevant certificates under applicable International Maritime Organization (IMO) instruments can be issued to establish that ships are designed, constructed, maintained and managed in compliance with the requirements of IMO Conventions, Codes and other instruments.

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Within the legal framework under IMO Conventions, i.e. International Convention for the Safety of Life at Sea (SOLAS) 1974 regulation I/6; International Convention for the Prevention of Pollution from Ships (MARPOL) Annex I regulation 6, Annex II regulation 8, Annex IV regulation 4 and Annex VI regulation 5; LL 1966 article 13; International Convention on Tonnage Measurement of Ships (TONNAGE) 1969 article 7; International Convention on the Control of Harmful Antifouling Systems on Ships (AFS) 2001 article 10 and annex 4; and Ballast Water Management Convention (BWM) 2004 regulation E-1, stipulate that the inspection and survey of ships shall be carried out by officers of the Administration (IMO, 2019). The Administration may, however, entrust the inspections and survey either to surveyors nominated for the purpose or to organizations recognized by it.

At the time these provisions were adopted in the 80s, technological means had not been developed to an adequate level to enable inspections to be conducted remotely. The physical attendance of the inspector was a prerequisite. Evidence that the inspection had been conducted was the report prepared by the inspector in handwriting and delivered to the Master. The only technologies used by that time were a voice recorder for keeping voice notes during the course of the inspection to transcript them later in the report, and a photographic camera to make a limited set of pictures that could only be developed after the completion of the inspection, with the aim of maintaining records.

Digital photography was the first major technological development that enabled inspectors to make practically unlimited high-quality photos that could be viewed on the spot, erasing all constraints previously imposed by the film development procedure. In addition, internet connectivity and the speed of data transfer have significantly increased worldwide within the second decade of the twenty-first century, allowing the sharing of digital photographs and short videos through email or through file sharing platforms.

Nevertheless, major technological developments alone were not enough to mandate remote inspections as a true necessity. PSC & SIRE inspections until 2019 were still conducted with the physical presence of inspectors onboard.

The pioneers in implementing remote inspections were the Classification Societies, which allowed the close-out of minor outstanding issues without the physical attendance of the surveyor. The submission of supporting photos, video recordings and documents indicating the rectification of outstanding issues was sufficient to be considered as closed.

However, the limited internet bandwidth available offshore and the increased charges still acted as a major barrier to the establishment of remote inspections, and to that end, no major change had been noted until the year 2020.

2 PSC and Remote Surveys by Classification Societies

2.1 Introduction

Port State Control (PSC) is the inspection of foreign ships, in national ports, which is conducted by PSC authorities that aim to verify that the condition of the ship and its equipment comply with the requirements of international regulations and that the ship is manned and operated in compliance with these instruments and ensure maritime safety and security and prevent pollution. PSC provides a "safety net" to catch substandard ships, especially if the inspections are managed on a regional basis.

Classification societies and flag Administrations, on the other hand, carry out various surveys on behalf of governments, particularly in order to ensure that the vessel complies with relevant standards that are required to be met for the issue of essential certificates.

They also carry out annual and other periodical surveys on behalf of the governments to ensure that the vessels are still entitled to hold valid certificates. In addition to these surveys, the societies also require certain surveys to ensure that the ships classed with them are still entitled to retain their class. Surveys may be carried out when it is intended to build a ship for classification these are new construction surveys. Surveys may also be carried out for existing ships, e.g. when they are transferring between societies or when they are being reclassified either after suspension or cancellation of their original classification certificates. If any damage or casualty occurs to a vessel, repairs and alterations may be carried out. These are also surveyed.

2.2 *Remote Classification Surveys*

The significant impact of the Covid-19 pandemic on the maritime industry resulted in an increase in the deployment of remote surveys by the International Association of Classification Societies (IACS) Members to ensure the maritime industry was able to continue functioning in as smooth and efficient a manner as possible (ABS, 2019).

Many classification societies are offering the possibility of remote surveys for some inspections under their responsibility (ABS, 2019). This means that for a range of surveys, a Class surveyor will not be required to travel to the vessel. Instead, by using an online connection or video streaming link, a dedicated team of remote surveyors can provide support to vessels anywhere in the world with documentation, images, video (streaming or recordings) and input provided by the customer and crew.

When a customer makes a survey request through Classification Society fleet portal, they may, for some survey types, be given the option by the system to choose to carry out the survey remotely. All such survey requests are then evaluated by a remote surveyor to make sure that the survey can be offered remotely. The remote survey regime has been constructed to ensure that the level of assurance is equivalent to an onboard survey.

The types of surveys able to be offered as remote surveys include occasional surveys that fall between periodical surveys, documentation-based surveys, testing and witnessing systems during normal operation and surveys not ordered together with annual surveys. Periodical surveys like the annual survey of a vessel are not part of the remote survey programme as they require a surveyor onboard.

As noted by Knut Ørbeck-Nilssen, Chief Executive Officer of Det Norske Veritas (DNV)—Maritime: "This is another big step forward in using the power of digitalization and increased connectivity to deliver smarter and more efficient services… Remote surveys allow us to free up time for our customers, while delivering our services with unparalleled response time. In addition, cutting down on unnecessary travel can result in lower costs, less waiting, and more operational up-time. We've had a great response from our customers and support from major flag states, and we are deeply appreciative of the feedback provided to us to make this project a great success" (Späth, 2019).

3 Remote Assessment and Inspections During Covid-19

It is evident that the prolonged restrictions and social distancing measures, imposed by the majority of nations across the world to contain the spread of Covid-19, had a major impact on the inspections conducted onboard ships. The inspector's physical attendance onboard emerged as a true challenge for both the inspectors and the seafarers. Many individual inspectors were reluctant to attend vessels to protect themselves and their families from any possible infection that may occur onboard. On the other hand, seafarers also had serious concerns over people attending the vessel from the shore and the significant risk of contamination to the isolated community on the vessel. This could create severe complications in the event of a Covid-19 outbreak, particularly when the vessel is sailing hundreds of miles away from the nearest coast and at a time when the provision of medical care to onboard marine personnel was limited due to lockdown restrictions.

The immediate crisis management reaction from all parties, in the first quarter of 2020, was to withhold any inspection activity and temporarily extend the allowed time frameworks between two consecutive inspections until health conditions were stable. As the pandemic crisis persisted with intensity for several months, and development and testing of vaccinations took time, the need for enabling remote inspections became evident via the expanded utilization of available technological means which were already available in the pre-Covid-19 era.

3.1 Actions by Shipping Companies and Vessel Operators

Covid-19 restricts the travel of operators' Marine and Technical Superintendents, which affects the inspection and audit programmes of companies' fleet vessels. In view of this arising complexity, remote audit programmes were developed and implemented by the vast majority of shipping companies. The aim was to minimize arising disruption and to re-establish the fleet vessels' monitoring process and the implementation of the company's Safety Management System onboard.

As an example, Tsakos Columbia Shipmanagement (TCM) promptly recognized the need for an effective remote inspection scheme and developed procedures and remote virtual capabilities and software tools aimed at facilitating remote inspections and audits to ensure process integrity.

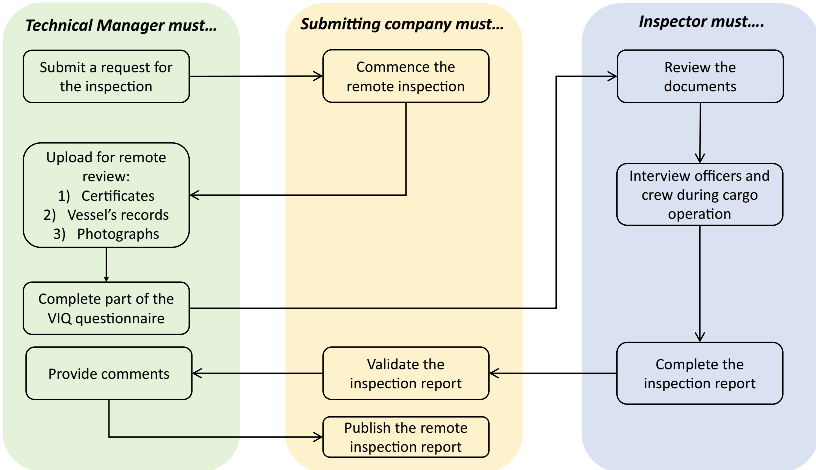

Fig. 1 Remote SIRE inspection process (*Source* Author)

Remote audits are carried out by Marine and Technical Superintendents in cooperation with Masters and Chief Engineers onboard.

During the process of the remote inspections or audits, the Superintendent requests equipment tests to be carried out by the crew and video and photos to be sent to the office as supporting evidence. Upon completion of the audit, a teleconference is carried out with the auditor and senior officers, and all findings are discussed with the Master and responsible officers. All findings are uploaded into the Company's inspection module for follow-up along with all the supporting documentation (Fig. 1).

3.2 Actions by INTERTANKO

INTERTANKO (the International Association of Independent Tanker Owners) is a trade association that has served as the voice for independent tanker owners since 1970, representing the interests of its members at national, regional and international levels. The organization champions an industry dedicated to support global energy networks by delivering safe, efficient and environmentally sound transport services.

INTERTANKO actively works on a wide range of operational, technical, regulatory and commercial issues affecting tanker owners and operators around the world. It draws on regular and direct contact with its members and other industry stakeholders to develop and disseminate information and best practice, essential to the tanker industry.

During a four-month period, INTERTANKO collected and disseminated more than 100 entries detailing information regarding restrictions surrounding the conduct of OCIMF, SIRE and Chemical Distribution Institute's (CDI) marine inspections. In addition, and in collaboration with OCIMF and CDI secretariats, INTERTANKO developed temporary guidelines for conducting vessel inspections during Covid-19 (INTERTANKO, 2021).

4 Remote Assessment and Inspections Post-Covid-19

A partial return to past normality has gradually been established with the lifting of travel restrictions, the growing availability of vaccines [in developed countries] and improved and accurate Covid-19 testing processes. Physical attendance became feasible again under strict health frameworks, thus offering a certain degree of safety during a possible physical inspection. Consequently, the number of remote SIRE and PSC inspections have decreased.

The trends for all types of PSC inspections have been similar, with a gradual return to physical presence, although the pace of return to physical inspections differs according to different geographical locations and regimes.

As indicated in the following graph (see Fig. 2), the number of PSC inspections worldwide were significantly increased from May 2020 and onwards, mainly because a great number of physical inspections were conducted along with the existing remote scheme (Fig. 2).

5 The Future of Remote Inspections and Risk Assurance

The outbreak of the Covid-19 pandemic was an extraordinary situation in which the maritime industry had to adjust swiftly and efficiently whilst ensuring that the global maritime supply chain remained undisrupted. With inspection regimes continuing to apply, the implementation of remote inspections was introduced as a temporary additional resource

Fig. 2 Number of PSC inspections 2019–2020 (*Source* Author)

to ensure a vessel's safety and reliability. Along the way, it was evident that we should all leverage on lessons learned and adapt to changing conditions by integrating new ways to operate.

It became evident that remote inspections did present a number of benefits, beyond the pandemic mitigation conditions. A major benefit was the reduction in workload for the crew: providing a substantial part of the documentation through an electronic database simplified the process of finding and exhibiting documentation onboard, often in various repetitive cases. This could potentially reduce the time in port and also reduced overhead costs. A vessel's deviations could also be avoided whilst transparency would be encouraged through closer online communication between all parties involved. However, the principal objective of any type of inspection is to ensure that all stakeholders maintain confidence in the credibility of the process. The ultimate objective of an inspection is to assess vessel reliability and standards beyond the time that an inspector is onboard. It is also a fact that a remote inspection will never provide the same type of "feel" that the inspector has upon stepping foot on the vessel and throughout the inspector's communication with all crew members.

Now that the industry is gradually transitioning to pre-pandemic physical inspections, we observe that many elements adopted during the remote inspection period will remain as the way forward in the future. For example, it is expected that allowances will continue to be provided for certain preparation and work to be done in advance, with less pressure throughout the process, whilst the physical inspection will concentrate on critical areas onboard the vessel and the interaction with a crew to assess human performance. It is a fact that technologies that had been utilized during remote inspections are now being applied to support and complement physical inspections. As an example, certificates' review is presently conducted remotely while the review of the vessel's record books and crew certificates is preferred to be conducted onboard the vessel.

The new tanker inspection regime OCIMF SIRE 2.0 (launching Q4-2022) is following the same path by creating a dedicated website/database to complement the online preparation of physical inspections and requiring vessel operators to upload similar information that was originally required under the remote inspection scheme to their respective OCIMF SIRE 2.0 website, as depicted on the following figure (Fig. 3).

Part of the SIRE 2.0 process will entail the upload of documentation in the form of a series of photographs, indicating the overall condition of the vessel and equipment, before an inspection is booked, in addition to the vessel's main certificates. This process is expected to significantly increase

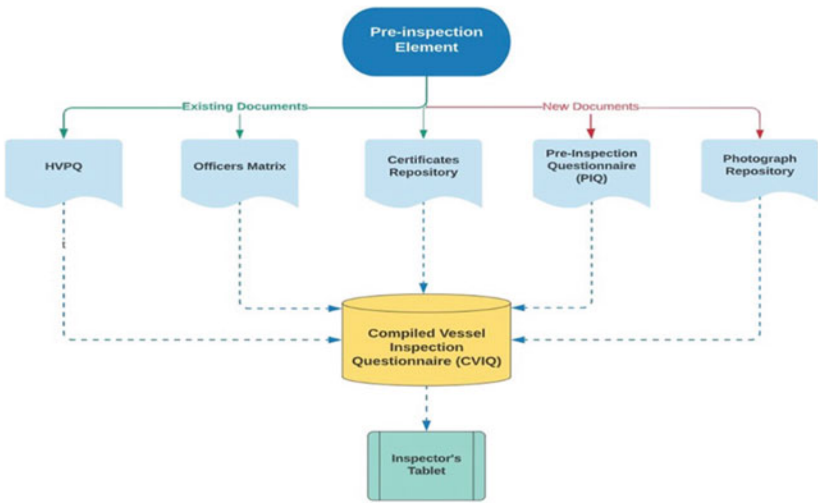

Fig. 3 The SIRE 2.0 pre-inspection process (*Source* Author)

the administrative burden prior to the inspection. On the other hand, it aims to ease the review of the vessel's condition and provide insight into how well the ship is managed on a long-term basis. Indicatively European Maritime Safety Agency (EMSA) is also moving towards the direction of paperless documentation by creating a favourable environment in which the framework for the use of e-Certification will be strengthened.

Technology plays an instrumental role during this transformation. The pandemic has forcefully exemplified the criticality of digitalization, and thus, the maritime industry will have to embrace change and navigate through the smart era beyond the business continuity issues that arose during the pandemic. Moving towards to this direction, vessel visibility can be significantly enhanced from the shoreside with the utilization of:

I. Control & Operations Rooms which provide a 24/7 management and visual access onboard, navigation monitoring, route optimization and vessel optimization (fuel consumption, weather, etc.);
II. Live Video Feeds and cameras monitoring operational activities, navigation, security threads and fire-sensitive areas.

The use of Remote Inspection Technologies (RITs) enabling a Remote Inspection Vehicle (RIV) including Unmanned Aerial Vehicles (UAVs), Remotely Operated Underwater Vehicles (ROVs) and Robotic Crawlers are increasingly becoming a reality as means of assessing vessel structures and reducing operational intrusiveness.

6 Conclusions

Through the ongoing technological transformation, ship managers and shipowners will need to embrace change and invest in a diverse range of emerging technologies, whilst also focusing on optimal vessel-to-shore connectivity levels. Ship managers will need to ensure that the pace of technological change is supported in full, from both onboard and shore personnel, in terms of familiarization, awareness and effective training. Similarly, training will be required for all other stakeholders involved in the processes, such as surveyors, inspectors, PSC personnel, etc.

For a change to be successful, consensus and coherent guidance is mandatory. As such, for the range of remote inspections to be truly efficient, global uniform guidelines will need to apply and be adapted by all stakeholders. The attempts to establish a specific framework for remote inspections within the framework of IMO have, so far, faced a degree of scepticism from the majority of governments and has been considered—at this stage—rather unsuccessful.

The maritime industry historically has proven to stand out as a very agile industry, easily foreseeing and adjusting to a fast-moving global landscape—and this will need to continue with the capitalization of positive lessons learned during the Covid-19 pandemic. Digital strategy and transformation will be an essential element of setting, assessing and maintaining reliability and safety standards in the industry.

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CHAPTER 16

Techno-Regulatory Challenges for Remote Inspection Techniques (RIT): The Role of Classification Societies

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1 Introduction

In this chapter, Remote Inspection Techniques (RIT) will be explored to determine their status and explore the possibilities for extending their use in light of the digital transformation of the industry and the discussion of autonomous features at various levels onboard ships.

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Since the early 1990s, the use of RIT such as drones and remotely operated vehicles (ROVs) in shipping has been reported. These Remote Inspections are conducted in the presence of a surveyor who uses RIT to gather the required information without physically inspecting the construction.

Until now, the trend toward using RIT has been mostly driven by the digitalization of the industry. In the future, underwater vehicles, drones, and other optimization tools and procedures will become increasingly important due to their cost, time effectiveness, and improved safety for both surveyors and crew/people onboard.

Conventionally, the term "inspection" refers to a set of activities that can be carried out based on professional judgment or general requirements. "Survey," on the other hand, is conducted in compliance with the rules of a classification society and/or in adherence to statutory requirements. Notwithstanding, at the outset, it is crucial to define the terms "inspection," and "survey" as these terms will be used within the context of the chapter.

Additionally, the chapter emphasizes remote inspections using Unmanned Aerial Vehicles (UAVs) due to their growing popularity in the maritime space. These are highlighted in light of Scout Drone Inspection's (ScoutDI) drones, which will be discussed in further detail later. The procedure of using drone-assisted RIT, on the other hand, might be extrapolated to the other techniques listed in the following paragraph. Also, it is essential to note that in this chapter, RIT and remote surveys are assumed to be separate entities, each existing through a standalone and distinct definition. Table 1 provides reference to the definitions used in the chapter.

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Table 1 Definition of terms

Term	*Definition*
Inspection: ISO/IEC 17,000 (2020)	An examination of a product, process, service, or installation or their design and determination of its conformity with specific requirements or, on the basis of professional judgment, with general requirements
Survey: DNV GL (2015)	A systematic and independent assessment of a vessel, materials, components, or systems in order to verify compliance with the Rules and/or statutory requirements
Remote Inspection Techniques (RIT): IACS (2019)	A means of a survey that enables examination of any part of the structure without the need for direct physical access of the surveyor
Remote Survey: IACS (2022)	A process of verifying that a ship and its equipment are in compliance with the rules of a Classification Society where the verification is undertaken, or partially undertaken, without attendance onboard by a surveyor

Note Quoted from ISO/IEC 17,000 (2020); DNV GL (2015); IACS (2019); and IACS (2022)

2 In View of the Covid-19 Pandemic

A new need has emerged during the last couple of years. Travel restrictions and lockdowns due to Covid-19 highlighted the need for remote surveys to keep the maritime industry operational while assuring compliance and safety. Stakeholders published the IACS Unified Requirements (UR) Z29, which contains the principles and minimum requirements for conducting remote surveys. In general, a remote survey will only be appropriate when the level of assurance is not compromised, and the survey is carried out with the same effectiveness as and is equivalent to a survey carried out with physical attendance on board by a surveyor. The requirements for equivalency of a remote survey to a survey attended on board by a surveyor include:

- eligibility of the remote survey;
- qualification of surveyors;
- planning of the remote survey;
- performance of the remote survey—assessment of the remote survey; and
- reporting.

It is also noted that equivalency is obtained when, with the use of available Information and Communication Technology (ICT), a surveyor can perform a survey remotely by being able to:

- obtain the supporting and technical evidence required according to the applicable rules;
- verify applicable survey items and relevant tests; and
- ensure that the results of the remote survey provide the same level of assurance as that obtained by an attending surveyor.

The findings of the UR Z29 could be applied from an RIT setting. It is noteworthy that a variety of organizations, including flag state authorities, port state authorities, classification societies, protection and indemnity clubs, insurance firms, and cargo owners, conduct inspections on board ships. For a traditional close-up examination and survey—human surveyors are required to be quite close to the surface they investigate so that they could almost remain in close proximity so as to be able to touch the surface. The most costly and time-consuming component of the inspection procedure is gaining access to the inspection locations in ship compartments, which can take several days to weeks depending on whether rafting, scaffolding, or cherry picker cranes are used to obtain access to structural sections, such as bulkheads (Poggi et al., 2020). On average, dry bulk carriers receive six inspections per year, tankers receive eleven, and passenger ships receive even more, with at least 50 hours per year spent on board to conduct inspections (Knapp et al., 2006).

Preparing and completing the above inspections in a safe mode could take a longer time; the owners could lose a lot of money in lost opportunity costs (e.g., chartering, operating profit, etc.) while the vessel is out of service or demurrage fees incurred while the examination takes place. The expenses and safety risks might increase considerably when examining offshore vessels and structures. Even a single-day delay on such vessels may cost hundreds of thousands of dollars, and the inspection could result in days, weeks, or even months of downtime. Hazardous environments are another concern, such as a lack of oxygen, hot climates, and the ship's swaying motions in question. In the case of a very large crude carrier vessel (VLCC), rafting costs may be paid to remove oil-contaminated water from cargo tanks and ballast the vessel by filling some cargo tanks with seawater to allow surveyors to raft through the interior structure. Surveyors conduct inspections that generally reach and evaluate most parts of the ship, including potentially dangerous areas. All of these come at a high price.

Although the adoption and acceptance of new digital technologies in shipping are slow, remote inspections are gaining interest due to their cost mitigation, safety enhancement, flexibility, and effectiveness compared to traditional methods. According to the authors, this may be an opportunity to expand the use of RIT to remote surveys, taking advantage of the experiences gained already in that field during Covid-19.

3 Regulatory Challenges

The definition of terms and their corresponding effects on the scope of activities is a major regulatory challenge. Prior to the development of IACS UR 29, IACS had issued the following recommendations as requirements, which served as the plinth for all major classification societies when developing respective guidelines/rules:

- IACS Recommendations No. 42, Guidelines for Use of Remote Inspection Techniques for Surveys
- IACS UR Z7, Hull Classification Surveys 1.6 Remote Inspection Techniques
- IACS UR Z17, Procedural Requirements for Service Suppliers

In general, IACS has made a significant effort to align itself with the industry and existing regulations by inserting the definition for RIT in its Recommendation 42, allowing the use of RIT for close-up surveys and describing the requirements that need to be followed. Furthermore, the 2019 Amendments proposed by IACS to the ESP Code (2011) have indeed aligned the Code with the IACS Unified Requirements.

Nevertheless, with the IACS recommendation and URs in place and without any intervention from the International Maritime Organization (IMO), many grey areas remain, which need to be addressed broadly because Classification Societies and Flag States continue to use the terms according to their interpretations, and as they see fit. This has the potential to lead to deviation. Harmonization is in order. In IMO's Circular Letter No.4241/Add.4 (5 January 2021, from Greece), the use of RIT is viewed as being connected to remote surveys. The same can be found in IMO's Circular Letter No.4231/Add.6 (15 May 2020, from Italy) and IMO's Circular Letter No.4251 (3 April 2020, from Cyprus), *inter alia*. The above references depict the ways in which various flag States perceive the terms RIT and remote survey, which, in turn, stresses the need to establish a singular and harmonized terminology. As described in the previous section, IACS UR 29 has developed the principles and minimum requirements for carrying out remote surveys.

Furthermore, there are liability issues, such as data security and data governance. Currently, RIT data handling falls outside the scope of the EU General Data Protection Legislation (GDPR, 2016), and therefore RIT data protection concerns need to be addressed. Various Committees of the European Union (EU) are conducting intensive work to deal mainly with liability issues to establish trust in Artificial Intelligence (AI) by creating a trustworthy ecosystem among the product, the producer/manufacturer, and the end-user. Furthermore, a number of items require further clarification from a European Union (EU) RIT horizontal policy standpoint so as to remain prepared to resolve collateral problems arising from the deployment of RIT. "Liability" is viewed by authors as one such grey area that could impede the smooth integration of RIT within the EU maritime domain (Alexandropoulou et al., 2021). Increasing use of data leads to new emerging risks on safety and security. Although IACS has the standard requirements for the deployment of RIT, liability issues nevertheless need to be addressed. On the data governance issue, IACS standards are considered by Johansson et al. as "insufficient, unsettled, and incomplete" (Johansson et al., 2021), as data security, storage, and ownership are overlooked. In the case of data ownership, this is left with suppliers, which creates another sensitive issue to address, and that is vessel structural information deriving from the use of RIT. Such information, if mishandled, could lead to unforeseen negative events. Therefore, the need to address copyright issues and third-party liabilities for suppliers is eminent.

4 Technological Challenges

Despite its benefits in terms of human safety and cost savings, RIT does not appear without flaws. For example, in the case of drones—they are only capable of providing visual information. Taking ultrasonic thickness measurement is difficult, and using other senses (e.g., a surveyor's touch and hammer) is not possible. One of the significant difficulties is the environment in which RIT must operate and capture quality data. Ships and marine platforms are increasingly digitalized, and electromagnetic field disturbances between RIT platforms and onboard electronic equipment can be a problem for both vessels and drones. Global Positioning System (GPS) signal cannot be received inside the hull because the surrounding environment is composed of steel. Drones use technologies such as light detection and Ranging (LiDAR) based on simultaneous localization and mapping (SLAM) for traversing inside vessel tanks with a view to providing high level of precision required for these checks. Problems with object detection, such as a thin crack, or maintaining position on a visual reference occur in environments with low lighting, e.g., in ballast tanks, where cameras' visions usually suffer motion blur. Smooth metallic plates of structures, such as stainless-steel tanks, have reflective surfaces, preventing lasers and cameras from properly detecting the appropriate distance. Furthermore, rising dust in restricted and dusty spaces disrupts camera vision and results in blurred images. Dust and debris could also impact the performance of electric propulsion motors.

Most modern drones have operational and maneuverability limitations in harsh environmental conditions, such as heavy rainfall, strong wind, extreme temperatures, confined spaces, etc. Currently, batteries used to operate drone technology have charge-related limitations and necessitate early detection of low power and swapping of batteries for extended continuous operation. Notably, the strength and quality of Wi-Fi and radio networks are also crucial for communication. Depending on the nature of the inspection, tethering the drone to a power supply and data link can solve the above problems. Precautions must be taken to prevent the damage or loss of equipment during the survey. Recovery procedures can be dangerous or difficult, especially on board ships in service, whereby damaged drones are often declared as missing-in-action. It is also necessary to assess the safety and reliability of such technologies. At present, fail-safe systems are primarily concerned with averting threats to operators.

Additionally, adequate RIT testing, pilot training, and teamwork assessments are required to apply RIT-assisted inspections successfully. However, pilot training is less of an issue for more advanced drones such as ScoutDI's Scout 137 Drone System, which are equipped with advanced navigational and flight control systems (ScoutDI, 2022). ScoutDI is now partly owned by DNV (ScoutDI, 2021). Such technological preparedness highlights the importance of standards and controlled testing environments to demonstrate capabilities prior to ship boarding. All of which call for significant investments.

The effectiveness and quality of remote inspection techniques and practices of ships and marine constructions are critical since they substantially impact both safety and commercial activities. While current RIT technologies are ready and promising, they must be assessed and adapted to the characteristics of ships and offshore buildings, as well as the shipping community in general. This will yield positive results in acceptance and efficient utilization. For it to be successfully applied, the information obtained by RIT must achieve at least the same degree of inspection quality as that collected by a human inspector. As an advantage, it may also come with the capability of data processing and automatic result output for further human decision-making and engineering judgment. Table 2 shows a list of advantages and disadvantages of drone-assisted RIT inspections compared to human inspections (Table 2).

It is of utmost importance to ensure that drone-assisted RIT inspections are as effective as human inspections and that a third party is present to verify this equivalency. To do that, it is preferable to collect all relevant data in a controlled setting where well-defined and repeatable experiments are conducted. To this end, testing protocols have developed within research and development initiative programs such as MINOAS (Marine INspection rObotic Assistant System), INCASS (Inspection Capabilities for Enhanced Ship Safety), and ROBINS project (ROBotics technology for INspection of Ships). MINOAS and INCASS (completed in 2012 and 2017, respectively) were two pioneering EU-funded Community Research and Development Information Service (CORDIS) that involve several shipping stakeholders, including classification societies, ship owners, and service providers, as well as robotic systems developers to develop robotic devices to assist and simplify the inspection of vessels. The ROBINS project was a three-year EU joint initiative co-founded under the auspices of the Horizon 2020 EU Research and Innovation Programme, and was launched in 2018 to bridge the technological and regulatory gap between present ship inspections and accessible robotic technologies. The project evaluated the efficiency of robotics and automated systems (RAS) in performing specific tasks, such as thickness measurements. Project outcomes include developing testing methodologies and designing a testing facility for analyzing RAS capabilities to

Table 2 Advantages and disadvantages of drone-assisted RIT inspections as compared to human inspections

Advantages	*Disadvantages*
• Save on cost and time by eliminating the need to gain access to the inspection locations by traditional means such as scaffolding, water filling for rafting, cherry picker, etc • Improved safety by eliminating the need for inspectors to enter hazardous environments, such as lack of oxygen, locations at a height, etc • Possible data processing and automatic result output capabilities reduce overall time and effort in inspection and reporting • Artificial intelligence can identify, record, and log cracks, corrosion, and deformations in real-time • Able to take and record 3-D environmental scans and compare with the original or previously scanned 3-D models to detect anomalies in real-time • Able to detect what humans cannot with the naked eye, e.g., Hyperspectral imaging (HSI) and analysis software accurately detects and classifies the chemical composition of paintworks • Data can be automatically processed for the machine learning systems • Micro-drones can reach into tight and confined spaces • Inspection process is more transparent	• RIT inspection is a new trend in the industry and may not be perceived with the same level of confidence as traditional inspection • Extensive pilot training is required for drones without advanced autonomy systems • Potential cybersecurity, data security, and data governance issues and liabilities • Connectivity and power issues under certain conditions. However, it could be solved by tethering • Most RIT drones only provide visual information. Difficult to take ultrasonic thickness measurements, and using other senses (e.g., a surveyor's touch and hammer) is not possible with a drone • Electromagnetic field disturbances between RIT platforms and onboard electronic equipment may be a problem for both vessels and drones • High cost of advanced equipment. High-tech sensors allow RIT to achieve the same degree of inspection quality as a human inspector

Source Authors

establish a foundation for proposals with regard to international standards that would be widely recognized and accepted by stakeholders and authorities.

5 The Role of Classification Societies

While the IMO and flag administrations rely on classification societies to regulate standards, the classification societies themselves do not enforce any regulations or standards. Classification organizations are authorized to offer advice on requirements to vessel owners on topics such as maintenance and safety, which the owners must follow for the vessel to remain "in class" (Koch Marine Inc, 1980). Without endorsement from a classification society, obtaining insurance for the vessel, along with any cargo it carries, may prove to be difficult. Failure to obtain class certification could also be a breach of the charter party, in which case a charterer is entitled to terminate the charter party and sue the vessel owner and/or counterparties for damages. In addition, failing to provide proof of class certification could limit or prevent entry into ports of a country's territorial seas. As a result, classification surveys are necessary for the maritime industry, shipping, and modern trade and commerce.

Having described the regulatory and technological challenges, the role of classification societies in the area of RIT would be to help mitigate the myriad of challenges, which could deem RIT as safe as well as a sustainable alternative. At this early stage of RIT technological evolution, many companies claim their products are technologically superior compared to those endorsed by their competitors. One of the difficulties confronted by classification societies around the world is the absence of adequate regulations in the RIT sector. There is still insufficient regulation to evaluate such products for RIT suitability at the time of writing. However, there are existing guidelines on the use of RIT on board vessels. According to IACS UR Z17 and IACS Guidelines NO 42, for RIT to be acceptable for use on board a ship, several conditions must be met:

- The results of the surveys by RIT are to be acceptable to the attending surveyor;
- Inspections should be carried out in the presence of a surveyor;
- Confirmatory surveys/close-up surveys may be carried out by the surveyor for verification purposes;
- The use of RIT may be restricted or limited in case of abnormal deterioration or damage;
- The inspection with the use of RIT is to be carried out by qualified personnel (Pilots,
- supervisors, operators);
- An inspection plan should be agreed upon and in place beforehand; and
- Visibility and surface cleanliness should be such to allow for the use of RIT.

DNV and other major classification societies consider RIT effective and safe alternatives for close-up surveys. Several IACS Unified Requirements (UR) support this, allowing RIT to be an alternative to traditional close-up surveys. The same is also included in DNV Rules for classification. At present, maritime surveyors working in classification societies must make the determined choice about the appropriateness of remote procedures on a case-by-case basis based on their own experiences with inspection results only acceptable if the attending surveyor is satisfied. Traditional survey techniques may be necessary if the surveyor is dissatisfied with the RIT inspection results, according to IACS Rec. 42. The rules describe further that RIT surveys shall be carried out in accordance with the requirements given in the rules and the requirements of IACS Recommendation No. 42 (IACS, 2016). As an example, for DNV, the following applies in addition to the existing requirements stipulated by IACS:

- Equipment shall not be hazardous to the involved personnel, and the structure inspected.
- Specifications to be met, i.e., high-definition live video monitoring, 4 K definition video recording device, and 4096 × 2160 still image capture device.

The American Bureau of Shipping (ABS) has produced Guidance Notes (ABS, 2019) on the use of RIT, covering Drones, ROVs, and Robotic Crawlers, stressing that such technologies reduce the need to access potentially hazardous locations or inspection areas, facilitating safer, more effective and efficient use of technology. Lloyd's Register (LR) issued an assessment standard for Remote Inspection Technique Systems (RITS) in which indications for the performance requirements, performance test, and certification of RITS are indicated (Lloyd's Register, 2018). According to Bureau Veritas (BV), remote inspections are carving a path through the next phase of marine digitalization, providing owners and operators with new ways to survey newbuilds and in-service vessels. Still, remote inspection techniques are subject to certain limitations: they are only applicable to certain regulatory backgrounds and must be managed by qualified operators. Nonetheless, they have enormous potential. With a clear understanding of how RIT can be used—and by dispelling common misconceptions about RIT—ship managers can reap both the benefits available today and those coming down the line (BV, 2021). Furthermore, Registro Italiano Navale added in their services "Surveys with Remote Inspection Techniques," listing the types of surveys that can be managed with RIT and the required equipment (RINA, 2020). Table 3 shows the DNV, BV, ABS, and Lloyd's Register suggested processes for planning and executing remote inspections (Table 3).

6 Case Study—Development of RIT Drone for Vessel Inspection

DNV GRD (Group Research and Development) has been a collaborative worldwide research platform for many years. Many technological solutions, rules, standards, and guidelines have been developed in close cooperation with industries and institutions worldwide (DNV, 2021b). Since 2016, DNV has used drones as an alternative to traditional close-up surveys in enclosed environments resulting in cost savings and improved worker safety. This led to the creation of the Autonomous Drone-based Surveys of Ships in Operation (ADRASSO, 2018) research project, which later expanded into the ongoing REmote Drone-based ship HUll Survey (REDHUS) project in 2021, intending to improve remote inspection technologies in ship inspection. Both programs are part of a global effort, bringing together research teams worldwide.

The ADRASSO project was a collaboration among DNV, Scout Drone Inspection, Norsk Elektro Optikk (NEO), Jotun, Idletechs, and the Norwegian University of Science and Technology (NTNU). It investigated and developed semi-autonomous drone navigation functionalities (ADRASSO, 2018). ADRASSO also investigated an AI-based computer vision for automated defect detection, hyperspectral imaging, and software for fast analysis of large hyperspectral data to constantly evaluate the condition of the protective paint used in steel tanks and their chemical composition. The project aimed to create and demonstrate an intelligent, self-flying drone for ship and offshore vessel inspections. Its long-term objectives are to reduce the necessity for surveyor tank entry, lower survey costs, increase safety, reduce environmental impact, and improve inspection quality (The Research Council of Norway, 2021). The inspection drone is tethered to a power supply and data link, giving it an unlimited operating time. It boasts sturdy physical construction, a powerful illuminating light, and a 4 K resolution camera. With an onboard 3-D laser scanner and anti-collision systems, it can navigate itself in constrained

Table 3 Process for planning and execution of remote inspections for various classification societies

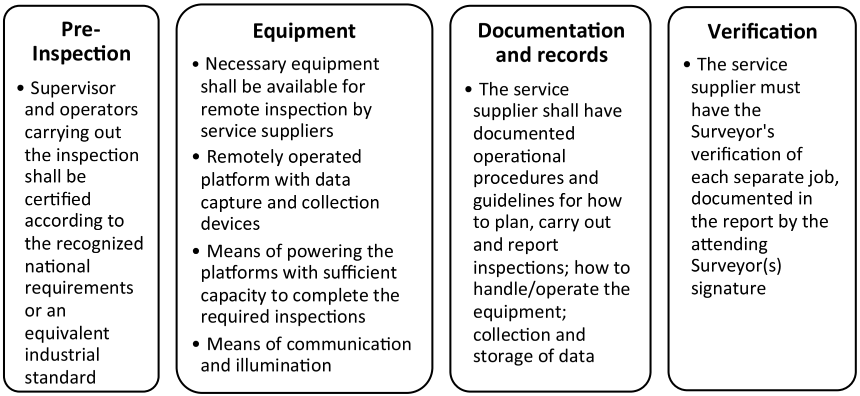
Classification Society	*Type*
DNV	RIT (DNV, 2021a)

Submission of documents	Work procedures	Job preparation and cleaning	Examination process	Reporting
• RIT qualification (document review, function and performance test) • Work procedures on use of RIT • Record of equipment used • Competence and training for RIT supervisor and operators	• Information to ensure a reliable and efficient examination process • Evaluation of conditions according to operational criteria and limitations • Communication between RIT operator and supervisor or other responsible person • System for tracking the examination and findings according to applicable rules and standards and acceptance criteria	• Preparation meeting (kick off) • Selection of tools and equipment • Maintenance and calibration (tools and equipment) • Work process planning, resources and time schedule • Operational criteria and limitations • Cleaning of components for inspection	• Describe the necessary information enabling a qualified individual using required tools and equipment to perform a safe and complete examination • A step by step process, covers inspection activities that shall identify all common problems related to specific system components	• Report based on standard electronic template format accessed through e.g. a web portal • All examination reporting/records be documented and retained in such a way that the performed examination may easily be re-traced later

(continued)

Table 3 (continued)

Classification Society	*Type*
Bureau Veritas	RIT (Bureau Veritas, 2021b)



Classification Society	*Type*
ABS	Remote Inspection Vehicles (ABS, 2019)

Pre-operations

- Confirm the opeartion work scope
- Assess the field condition
- Verify the responsibilities of personnels involved
- Review risks, emergency paln, work permits, RIV maintenance records, weather forecast
- Verify proper personal protective equipment (PPE)
- Confirm the inspection area/tank surface and enclosed space is clean

In-operation

- Checklist clearance
- RIV launch and recovery zones
- If communication signal is lost or experiences significant interference, abort operation
- Documentation for final reporting
- Visual line of sights for UAVs be maintained throughout the operation
- De-confliction for UAV in place

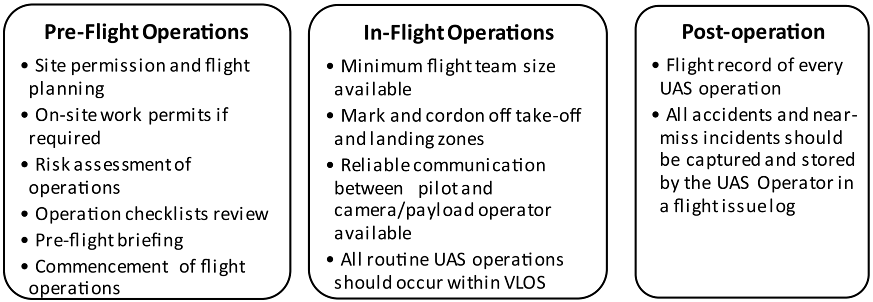
Post-operation

- Logging (RIV operational details, maintenance or technical adjustments, any accidents or near misses observed)
- Maintenance of equipment
- On-site battery handling: check, maintain, recharge and store
- Review of collected data
- Data post-processing for further evaluation
- Report on the asset and structure inspected

(continued)

Table 3 (continued)

Classification Society	*Type*
Lloyd's Register	Unmanned Aircraft Systems (Lloyd's Register, 2016)



Note Quoted from DNV (2021a, 2021b); Bureau Veritas (2022); ABS (2019); AND Lloyd'sRegister (2016) interiors. It can map its surrounding space and locate its position. It is controlled by high-level commands with a user-friendly graphical user interface rather than a joystick. Using a cloud system, 3-D map data and the drone's position can be captured in real-time. This enables BLOS control of the drone from outside the tank.

The drone capabilities are beneficial for surveying locations where close-up examination is required but access is constrained and lighting poor. The computer vision system powered by deep learning software can automatically detect cracks from videos and images. Thousands of photos have been collected and processed from DNV's databases to train the deep learning system. The AI can perform crack detection in real-time. Inspectors can review the results and correct detection errors with a video inspection tool. Figure 1 shows software recognizing a crack fault. Hyperspectral imaging (HSI) and analysis software accurately detect and classify the chemical composition of paintworks (Fig. 1). Investigated elements as part of the project are the assessments of surface conditions, corrosion severity, corrosion under paint, condition or age of the paint, the thickness of remaining zinc coating on galvanized steel, and contaminants on the tank surfaces. The drone may also carry an ultrasonic thickness measurement sensor to measure steel thickness. Two successful demonstrations were carried out onboard FPSO ships during the project, and an additional trial in a stainless-steel tank onboard a chemical tanker (Stensrud et al., 2021). ADRASSO has demonstrated favorable technological feasibility and provided a strong case for the technical proof-of-concept. The ADRASSO project is currently being continued as part of the Research Council of Norway NFR-funded REDHUS project, which began in January 2021 and is set to complete by 2024.

REDHUS expands on ADRASSO, taking a step closer to enhancing remote inspection and toward no human intervention. To achieve this, DNV AIRC (Artificial Intelligence Research Centre) has been focusing on developing artificial intelligence detection technologies. Artificial intelligence detection algorithms, named Corrosion.ai (Wei and Chen, 2021) and Deformation.ai, have been developed. Corrosion and deformation irregularities can be detected automatically. The corrosion detection algorithm aims to automatically assess and rate corrosion conditions "GOOD," "FAIR," and "POOR" according to IACS 87 standard. The algorithm is built upon image segmentation algorithms, which identify pixels representing corrosion from an image. Together with DNV Maritime, an image qualification pilot is conducted to investigate the

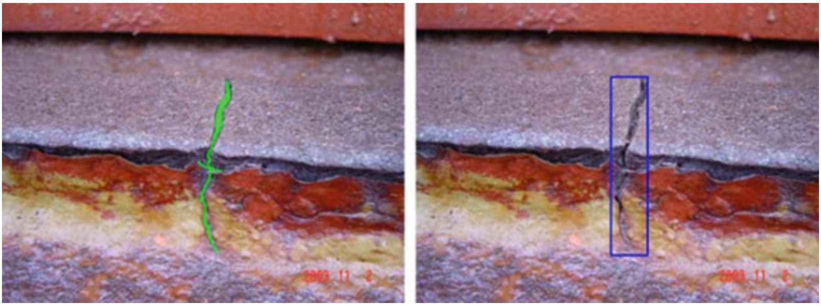


Fig. 1 Annotations for the pixel-level classification (left) and bounding-box (right). Models have been trained to provide annotations on new images automatically (*Source* DNV AS)

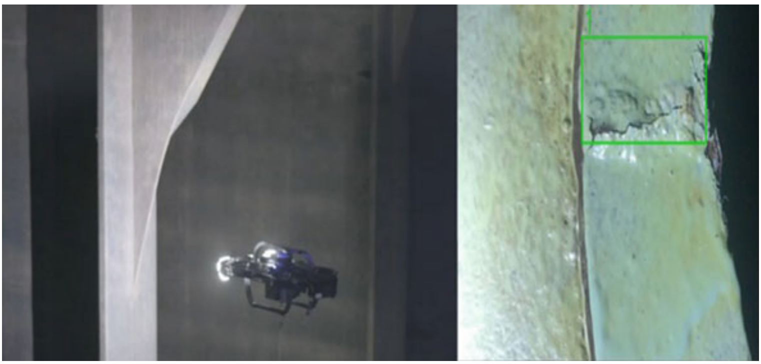


Fig. 2 REDHUS—Drone-based ship hull inspection (left) crack and damaged paintwork identified by drone (right) (*Source* DNV AS)

algorithm's performance against surveyors' rating results. Figure 2 shows a drone developed by Scout Drone Inspection (partly in REDHUS and partly through other projects) in flight and identifying structural anomalies (Fig. 2).

For the work on deformation detection, DNV AIRC has proposed a technology solution by utilizing an RGB-D sensor, which comprises an RGB sensor and a depth sensor. The basic idea is to train a deep learning neural network to detect deformation defects in 2-D RGB images to locate the deformation in the image by bounding boxes. A depth sensor can measure the deformation by comparing the difference between the sensed 3-D point cloud and the original 3-D model or previously scanned intact model. At the time of writing, the corrosion detection algorithm is under pilot with DNV maritime class, while the deformation detection and measurement algorithm are still under development.

Many novel RIT capabilities have been developed, both by DNV GRD and ScoutDI, particularly in the area of computer vision-based defect detection algorithms. REDHUS plans to do demonstrations for an automatic pre-survey planning and onboard inspection in the near future. With the advent of automatic detection technologies, which greatly improve the quality and speed of vessel inspections, drone-based inspections may become increasingly common in the industry.

7 Conclusion

The development of RIT inspections has been ongoing for some time. The technology has proven that it can facilitate external and internal inspections, removing the need for human inspectors to physically inspect the area of concern. Surveyors can remotely monitor routine examinations in real-time, particularly on new ships, where digitalization is more prevalent and accessible. All that is required are accurate virtual representations of onboard spaces from earlier inspections and scans, 3-D reconstruction, advanced image processing, point clouds, thickness measurements, and data about the stresses the vessel was subjected to. As a result, cost reduction with higher efficiency while considerably lowering the risks to human surveyors can be achieved.

However, before the industry and classification societies can adjust to meet the RIT challenges in application and regulations, they may face another technological disruption. The advent of autonomous drones poses a new conundrum for regulators and policymakers. By overcoming the limits of human pilots, the development of autonomous drones equipped with artificial intelligence has the potential to revolutionize the quality assurance sector once more.

More legal difficulties may arise as drone technology transits into full autonomy, but their analysis falls beyond the scope of this chapter. An example of this transition is related to hybrid aerial underwater vehicle drones that are capable of operating in air and water. Such abilities are useful for a multitude of tasks and applications, especially for offshore oil platforms. However, because aviation and admiralty laws are formed pertaining to an "object," instead of a "venture," the problem arises in its classification, i.e., a "ship," an "aircraft," or a "vehicle." This is a complication for maritime insurance legislation around the world. There will be a need to address how this area of law is influenced and possibly altered in the age of drones and autonomous vehicles. Many governments, international regulatory authorities, and organizations are also examining how this technology may affect their respective industries.

Before fully integrating RIT in shipping, issues like liability, data governance and management, cyber security, ownership of data, harmonization of services and frameworks as well as legal and technological challenges need to be addressed. This should be done before trust in RIT technology is compromised by "accidental" misuse.

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CHAPTER 17

Remote Inspection Schemes: Past, Present, and Future

David Knukkel

1 Introduction

Inspection using Remote Inspection Techniques (RIT), for example borescope-inspections, is not a new phenomenon. RIT, today, are commonly referred to as disruptive technologies that are deployed for inspections of ships' structures. In other words, crawlers, unmanned aerial vehicles/flying drones (UAV), and remotely operated vehicles/underwater drones (ROV) are being used to inspect different structures, such as hulls, ballast tanks, cargo holds, void spaces, propellers, stern seals, and thrusters to enhance surveyor's and owner's employee's safety (Alexandropolou et al., 2021; Johansson et al., 2021; Pastra et al., 2022). RITs are based on a human–autonomy interaction where

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two parties (i.e., human and autonomous digital agents) work interdependently toward the achievement of a common goal (O' Neill et al., 2020).

While many today would consider RIT as emerging technologies, in retrospect, it was around 2010 that research institutions began experimenting with robot arms, crawlers and UAVs, and other concepts for the conduct of inspection of ships' constructions remotely. ROV have existed for quite some time. New developments have made ROV more suitable to inspect smaller areas. The robot arm drove on a rail which was fixed in the tanks and was able to carry out visual inspections and thickness measurements. However, the fixed rails made human access to tanks more complicated and were unsuccessful in the market as it was too sensitive, too large, and inflexible in terms of usage. The first crawler that was developed to maneuver in tanks posed the following challenges when deployed in ballast tanks:

- The ships construction was too complicated to pass (longitudinal, web frames). Only large bulkheads were suitable for crawler technology;
- Dirt which is magnetic got stuck in the wheels; and
- Areas which are corroded are less magnetic and the crawlers have tension to fall down.

Also, this technology was considered not good enough for visual inspections.

It is noteworthy that over the years the crawler technology has witnessed improvement. Over time, technology has become more robust, especially in the oil and gas industry. In the maritime industry it, however, did not lead to a large breakthrough.

Around 2015, the first companies and Classification Societies started to experiment with UAVs, first focusing on the outdoor inspections. For outdoor inspections, the usage of drones seemed obvious, although there were many hurdles to overcome:

- National regulations (Civil Air Association) to obtain flight permits;
- Rules toward equipment (outdoor UAVs were considered as airplanes);
- Client safety regulations;

- Magnetic Interference;
- Lines of sight; and
- Skilled pilots who knew what to inspect.

Also, UAV experimentation commenced with test-flying in ballast tanks and cargo holds. Since these were drones typically designed for outdoor usage only, manufacturers faced a number of challenges (Pastra et al., 2022) which among others include:

- No protection of the propellers;
- No GPS-stabilization;
- No vision sensors installed yet;
- Magnetic interference influencing the controls and led to many crashes of the drones; and
- Lighting and exposure issues of the camera.

In 2015, Global Drone Inspection (GDI, 2022) completed a successful test (with the Elios 1) in a ballast tank and duct keel. No tank entrance was required as both signal receipt and video transmission and footage were of good quality (see Fig. 1).

The above being said, challenges with UAVs surfaced from different angles: stability of the flight (only kept the height by barometric pressure); manual control of light and exposure; and case visible on video footage.

Fig. 1 GDI 2017 (*Source* Author)

ROV have been used extensively in the offshore oil and gas to inspect, maintain, and repair of their infrastructure (Mc Lean et al., 2020). Special survey vessels were used to handle the equipment. However, this technology was not suitable or considered too expensive to carry out a relatively simple in-water survey of a hull, a quick stern seal, and inspections of propeller or ballast tanks (with the requirement to sail through manholes of 600*400).

In the last years, mini ROV have gone through a tremendously swift development phase, novel shapes can be found commercially and the number of sensors utilized on inspection-class ROV has increased (Capocci et al., 2017). Mini ROV are now suitable to carry out visual inspections and have the capacity to conduct measurements on the outer and inner area of the hull and tanks.

Generally speaking, there are many challenges that the industry faces when it comes to development and employment of innovative digital equipment. It is observed that every product and service go through a number of learning curves:

- Unawareness of the manufacturer regarding the technical requirements of the market and the field (lighting, right video footage, signal losses, only a visual inspection but no option to do thickness measurements, data reporting);
- Unexperienced pilots;
- Limited flexibility in logistics;
- Limit knowledge of variation of legal requirements (right permits, import/export limitations) etc.:
  - CAA (local flight permits);
  - Classification Societies (survey requirements);
  - Customs (im- and export of equipment when traveling);
  - Airlines (limitations of flying batteries); and
  - Local port authorities.

In nearly all cases, the chain of stakeholders is not aligned and after failure to launch after the first trial—clients tend to place distrust on the system, and become skeptical toward RIT usage. This unalignment impacts the successful deployment and usage of the equipment.

Fortunately, however, over time manufacturers, service suppliers, and Classification Societies have regrouped through a number of state-of-the-art techno-regulatory projects (ADRASSO, 2018; BUGWRIGHT2, 2020; ROBINS, 2022). Addressing specific challenges for mass deployment resided at the crux of the above projects. Notwithstanding, these projects met with quite a few challenges:

- Keeping all stakeholders on board and being transparent until the end of the project;
- Obtaining a deeper understanding and translation of what is really required and needed to get there without someone that is able to bridge people coming from different domains;
- Commercialize the knowledge on large scale although the knowledge is financed with European subsidies. Every stakeholder has its own commercial interests and wants to protect their share of the pie; and
- Stakeholders claiming the spotlight for the achievements for themselves.

The picture of the puzzle is visible and clear. Many pieces are missing and/or are not commercially interesting, except for the high-end market which might be a feasible market/platform with low volumes.

2 Inspection and Certification

There are three important areas with regard to inspection and certification in shipping:

1. Inspection and certification of vessels in relation to:
    a. Safety and seaworthiness (requirement from Flag States and Classification Societies);
    b. Condition assessment program (requirement from charterers/cargo owners); and
2. Certification of those organizations who carry out the inspections to ensure a quality level: Approved service suppliers.

The above areas are briefly examined in the following sections.

2.1 *Certification of Safety and Seaworthiness of Vessels (1a)*

To ensure safety of ships and crew at sea, vessels are inspected and certified by Classification Societies, such as Lloyds Register, Det Norske Veritas, and Bureau Veritas. The process of inspection and certification takes place on a 5-year basis, with intermediate inspections/validation of the certification taking place on a yearly and 2,5 yearly period respectively.

For the inspection of the ship's structure, the International Ship Construction Certificate is important to ship owners. The requirements for inspection are described in the Rules of each Classification Society, which are nearly the same, but might differ in minor details. In general, the inspection consists of two parts: close-up visual survey and thickness measurements. The actual methods used to carry out these inspections are:

- Human entrance of the tanks and holds;
- Building scaffolding;
- Usage of rope access; and
- Usage of cherry pickers.

The choice of method out can vary based on different criteria:

- Actual work scope of the survey, which is based on:
  - Type of vessel;
  - Age of the vessel;
- Condition of the vessel;
- Location of the vessel;
- Available time;
- Requirement of additional work;
- Availability of approved service suppliers;
- Balance of costs between different inspections methods;
- Personal preferences surveyors.

In general, RIT could be integrated:

- During inspections of enclosed spaces and work on heights to increase safety of crew and surveyors due to potential:

  - Lack of oxygen;
  - Polluted vapors/cargo in the atmosphere;
  - Chance of being lubricious
  - Dangers related to work on heights;

- When the condition of the vessel is still good (for heavy corroded vessels additional surface preparation is required to find out if the integrity is still good);
- To identify the areas of concern in preparation of the dry docking; and
- When options like scaffolding, cherry pickers, and rope access are not available (i.e., inspections during port stays while alongside the terminal).

2.2 Condition Assessment Programs (1b)

Ship owners/managers are keen to demonstrate to their clients the operational reliability of their ships, regardless of their age. A Condition Assessment Programme (CAP) highlights to charterers that the critical quality areas have been assessed and certified.

Although these types of inspections do not form a part of flag State or class surveys, those inspections are usually carried out by class surveyors that play the role of an external consultant. In the case of class and cap surveys: two surveyors of two different Classification Societies will need to be present on site.

Although Classification Societies approve the usage of RIT, large oil majors defining the cap-rules are yet to not approve its usage.

2.3 Certification of Approved Service Suppliers (2)

The regulation and certification of service suppliers started around 2015. At that time there was no legislation regarding RIT in place. It was a time for experimentation with new technologies to explore opportunities and limitations. In 2015, GDI developed its own Management System for RIT, based on ISO 9001 as well as the general rules applicable for Class approved service suppliers.

In 2016, GDI applied with Bureau Veritas for the approval of RIT. The audit contained a paper audit (checking all the procedures) and a practical audit for confirming that the pilot operating a drone could deliver a similar output similar to that of surveyor conducting surveys through physical presence in the tank. GDI was the first company in the world that passed this audit. All other Classification Societies like American Bureau of Shipping (ABS), Lloyds Register, Registro Italiano Navale (RINA), Nippon Kaiji Kyokai (Class NK), and Korean Registry of Shipping (KRS) followed shortly.

Eventually, all Classification Societies developed standard rules for RIT. As soon as the new guidelines came into force, DNV approved GDI as an "RIT-approved service supplier". It is noteworthy that the RIT certification is valid for 3 years, whereafter the company has to go through a renewal audit, which means that:

- A Class surveyor verifies if the company still works according to its own and approved procedures;
- There are discussions about potential improvements to the management system; and
- Experiences are shared between Class and service supplier to get more insights on pros and cons of the technology.

As technology evolves with thickness measurement tools built into UAV and ROV, two certification schedules reach an overlap resulting in the following possibilities:

1. RIT companies prefer to transition to an approved Non-destructive Testing (NDT)-company;
2. NDT-companies want to become RIT-approved; and
3. Partnerships between two approved service suppliers.

The first two scenarios have the potential to increase investments in new personnel with equipment experience and approval audits, which might, in turn, pose a risk for companies due to the fact that although class embraces the new technology—the market response remains slow.

The author forecasts that scenarios 1 and 2 will become a steady situation, scenario 3 is one where all parties will join forces for a shared experience. This requires a change in mindset and perhaps a change in the rules promulgated by Classification Societies. In general, service suppliers could argue that the desired quality level of technical criteria should be met regardless of the organization/commercial relationship.

Moreover, the rules do note the manner in which measurement equipment is brought to the asset. It is up to the NDT-company to validate and approve the data based on their pre-determined criteria.

As of recent, two Classification Societies are approving the companies under certain conditions. Further investigation reveals that one Classification Society is not entirely certain, one Classification Society indicated that they are currently unsure since there are no clear rules, one Classification Society responded with a concrete "no", and three other Classification Societies are yet to respond to the questionnaire. In all cases, this is a topic that will be addressed by the International Association of Classification Societies (IACS) through the development and circulation of new rules/approvals.

3 Challenges: Actual Technology

3.1 Current Available RIT

The best available RIT in 2022 which are useful for the Maritime Industry include the following:

- *Data collection technology*
  1. UAV for close-up visual inspections (indoor and outdoor);
  2. UAV for Ultrasonic Thickness Measurement (UTM)-inspections (indoor and outdoor);
  3. Crawlers (visual and UTM-inspections); and
  4. ROV (visual and UTM-inspections).
- *Data processing and visualization software*
  1. 3D modeling through;
     a. Photogrammetry;
     b. LiDar (laser point clouds);
  2. Image recognition; and
  3. Data storage/reporting tools.

3.2 Challenges for Drones Operating Indoor and Outdoor

3.2.1 Regulations

Many countries have national regulations and require a local license to operate drones outdoors. Although European regulations are aligned, the licenses may not be accepted by other countries, such as the United States of America (US) or countries in Asia, and visa-versa. Also, local authorities and clients might issue local permits to fly above their premises with strict limitations. For an approved service supplier, it is impossible to obtain all local permits, but currently Class allows the subcontracting of a local pilot if the inspection and payload operator is RIT-approved. In tandem, there are internal discussions among classification socialites and at the IACS level to find a solution on how to deal with the certification if thickness measurements are carried out by drones.

3.2.2 Technology

The outdoor UAV technology has become mature, with staggering flight and camera performances. However, challenges remain, such as problems with flying underside of a large crane vessel, which requires an outdoor drone that could fly on vision only (no GPS signals under the vessel) and does not suffer from magnetic interferences.

Battery capacity of outdoor drones is restricted on airplanes, as airline companies do not allow batteries above 160-Watt hours on board a plane.

Indoor UAV technology has improved rapidly over the years and the use of UAVs in unconventional spaces such as indoor or GNSS denied environments has surged in the last decade (Nex et al., 2022). Manufacturers have solved the problem of receiving double signals and the cage of Faraday. Remaining challenges include relatively short flight times (maximum 8 minutes), manual navigation, location of defects, training of skilled pilots with knowledge of ships and thickness measurements.

There are drones which can conduct thickness measurements, even vertically. Challenges with those types of drones are that they cannot reach niche areas because they are too large in size, do not have the right protections, cannot carry all sensors and/or the surface, and cannot always be prepared properly.

3.2.3 Challenges: Crawlers

There are no specific rules for the usage of crawlers. From a regulatory standpoint—there are no restrictions.

From a technology perspective, crawlers have improved over the years. However, the application is limited to large flat vertical areas in the cargo holds (flat bulkheads). Their usage also becomes limited when the holds are dirty/rusty and debris starts to gather near the magnetic wheels, which leads to situations where they could fall off the surface. What is also noted is that crawlers cannot move across the web frames and through manholes in ballast tanks.

3.2.4 Challenges: ROV

In terms of regulation, it is usually the local port authorities that have to approve underwater-related work, especially when divers are involved. For ROV—the rules are unclear, and it is advised to check with local authorities in advance.

Challenges with ROV technology are mainly associated with visibility, navigation, and tools to execute specific tasks. Although ROV has reduced in size and there are tools like DVL (that measure and control the speed over the ground), sonar and tools for thickness measurements, the technology is relatively new per se and good performance is a criterion that needs to be proved over time.

3.2.5 Challenges: 3D Modeling

3D modeling through photogrammetry is a good option although a critical challenge is that the same object must be framed from different angles and the surface must have clearly independent markings (stitching pictures of one large similar surface is impossible). Therefore, in an indoor environment, specific flight patterns need to be followed to obtain a successful model. Flying outside and hovering around an asset is easier, as in many cases GPS-data can be easily paired to the model.

LiDAR (Light Detection and Ranging) technology utilizes laser for data collection of scanning areas, which can then be processed into 3D models. In enclosed spaces, such as tanks, where GPS reception is not available, drones with a LiDAR sensor can create a 3D map of the inspected space and geo-tag with position data for all the relevant images and videos.

For UAV, flying indoor is relatively easy as it brings a location between the video footage and the location, and is easy to navigate. It is also a stepping-stone for future autonomous flights.

The challenges with 3D Models are the value it creates. It can serve as:

- A centralized visual data storage environment, where documents for reference, evidence, or information are stored (a virtual archive). One single source of truth of all information reduces a hidden inefficiency within any organization if well maintained; and

- An environment where repeated inspection data can be collected and compared over time, and try to forecast the progression of the condition of the asset over time. A first attempt to predictive maintenance.

The value is only for the high-end market as they are carrying out asset management and stretch the life time to an asset if possible. The low-end market treats their assets like consumables and is likely not to invest in high-performance technologies, such as 3D models.

3.2.6 Challenges: Image Recognition

Image recognition is used to identify defects automatically. The technology is not new, but it needs to be made application-specific. For relatively reliable output, the software needs more than 10,000 pictures that require manual validation. The more data it receives, the smarter it becomes. Obtaining the data (there is not always an asset available) and validating the correct pictures (manually) is an onerous manual job.

In certain cases, creation of a digital twin to simulate errors and then feeding this information back into the image recognition software makes sense, but still remains a labor intensive and expensive process.

The value is only added when large data needs to be analyzed in a relatively small timeframe and the outcome must be secure. As an emerging technology, Image Recognition is rather expensive. That being said, it has the potential to become an important piece of the puzzle in the not-so-distant future.

3.2.7 Challenges: Data Storage

Transition to digitalization requires the capacity to hold tremendous amounts of data as well as having high data processing capacity. A 4 k movie of 6 minutes already has the size of 5 Gigabytes (Gb), and if an average tanker of 12 tanks is inspected, we are looking at approximately 250 Gb.

File-sizes already raise issues when it comes to handing over the data to the client:

- Many clients do not have enough space on their local laptops to store the data and bring it to the main office;

- Many clients have blocked their laptops for the usage of Universal Serial Bus (USB) sticks;
- We-Transfer files work out well, but only useful when high speed internet is available; and
- Sending data on local File Transfer Protocol (FTP)-storage is an option, but also in this scenario only useful when high speed internet is available

In general, data storage is no longer expensive. We are also in a transition phase as to where and how data is being stored. There are clients that prefer to have their data stored on local servers and heavily protected with fire walls, Virtual Private Network (VPN), and virus scanners. There are also clients which prefer to have their data in the cloud.

One of the challenges with data storage on the cloud is issues with internet connectivity, which is a big challenge in many areas of the world.

3.2.8 Challenges: Reporting Tools

Many suppliers of equipment have developed their own reporting tools to transfer the data in such a format so that that reporting is made easy. Usually, the output is in pdf and/or word documents format.

The challenge is that many of these manufacturers have made the mistake to assume that the reporting is done by the end-user, which is often not the case. In many cases, the equipment is bought by a service supplier that already has a specific approved reporting format.

Presently, many service suppliers use the draft-data and transfer it into their own reporting tool which has the required format and logo.

3.2.9 General Market Challenges

As technologies become complex, techno-specialists are required to keep pace and possess an advance those areas. It is observed that specialists are becoming hard to educate/train. Keeping specialists motivated to stay within the company is harder. So, all stakeholders are vulnerable in relation to the continuity of their product development, production, and service.

The amount of people that are able to build bridges between the technology and different industries are even more difficult to find, as knowledge of both is required by the same person.

4 Vision: Future Technology and Business Models

Fortunately, manufacturers, service suppliers, and regulatory institutions are working hard to overcome all challenges. As mentioned earlier, there are several joint industry projects, but the challenge with these projects is that it takes time, commercial interests are high, and in many cases the subsidized technology is available on a small scale. It is anticipated that the market will change for the best within the next 10–15 years.

4.1 Regulations

In the future, outdoor flight regulations have the potential of becoming stricter and hiring suppliers becoming too expensive to conduct inspections outdoor with the exception in the high-end market. It is also projected that more countries will reduce the requirements for indoor flights.

In the future, certification for NDT and RIT will remain, but both service suppliers will be allowed by Class to work together as well. The quality of the end-result will prevail. Eventually, this market will merge with service suppliers simultaneously approved for both services.

4.2 Technology

Technology will develop fast, although not many have a vision of the complete picture of the puzzle. In terms of the future, the following are projected:

- Battery technology improves to increase the flight/sailing time;
- LiDAR technology will facilitate easy navigation and eventually will be used to automate the flights and link the position and the defects;
- The flights can be automated and therefore repetitive in the future, which means that with the right software it might be possible to compare the overlays of the image recognition software and build up trends;
- Reporting tools will be modular and can be amended in each format;
- 3D modeling and creation of digital twins will be common tools for data storage and reference;

- Development of software to determine whether action is required or not (predictive maintenance) and create work orders in asset management systems to prepare repairs. Sections of 3D models can be used and shared to prepare the repairs in advance; and
- There will still be a combination between the drone carrying out thickness measurements and the traditional methodology, as there are areas which needs to be done which do not need a drone or cannot be reached by drone.

4.3 Business Models

The above implies that eventually the job of drone pilot becomes obsolete and service providers will transform into rental companies for equipment and/or data processing companies for those clients that do not wish to put this equipment in the hands of unexperienced employees.

Although many maintenance engineers will opt for automation and analysis of the data, there are many that will stay engaged with the core business which is asset management. Inspection and reporting are just one part of the job, as the reported proposals still need validation and proper follow-up, which of course will be the next phase of automation.

Many will not invest in only a few inspections a year and will leave it up to the specialists that take the financial and operational risks as well, but are capable to do so because of the larger volume of inspections and analyses.

5 Conclusions

We are living in an interesting time, with a sharp increase in development of technology and opportunities. There are many hurdles to overcome to connect the dots among financial, technical, regulatory, commercial, and human resources, and that is why developments are slower than expected. Every two steps forward require one step back as each step needs to be validated, effectiveness proven, and certified before being accepted by the market. Nevertheless, the pieces of the puzzle are available and at this juncture, simply need to be polished to get them connected. The biggest challenge is not the absence of technology anymore but the right partners with the right attitude to work together to develop the right “connection plugs”.

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CHAPTER 18

Human-Autonomy Teaming in Ship Inspection: Psychological Perspectives on the Collaboration Between Humans and Self-Governing Systems

Thomas Ellwart and Nathalie Schauffel

1 Introduction: Human-Autonomy Teaming in Maritime Contexts

The concept of human-autonomy teaming (HAT) is used to describe humans and intelligent, autonomous agents working interdependently toward a common goal (O'Neill et al., 2022). HAT as a new form of collaboration is the focus of research under multiple heterogeneous terminologies such as human-agent teams (Chen et al., 2011), human–robot

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collaboration and hybrid teams (Straube & Schwartz, 2016), human–robot teaming (Endsley, 2017), or socio-digital teams (Ellwart & Kluge, 2019). In this chapter, we use the term HAT consistently.

HAT has been described as at least one human working cooperatively with at least one autonomous agent (McNeese et al., 2018). An autonomous agent is understood as a computer entity or robot with a partial or high degree of autonomy in terms of decision-making, adaptation, and communication (O'Neill et al., 2022). HAT provides new qualitative challenges for teamwork compared to traditional human–human teams (HHT) (Ellwart & Schauffel, 2021). Autonomy is capable of decision-making independent of human control. Chen et al. (2018) distinguish between autonomy at rest (e.g., intelligent software systems) and autonomy in motion (e.g., robots). Because functional HAT complementary combines the strengths of humans and machines (i.e., human intelligence and artificial intelligence, human and agent skills), HAT can achieve complex goals that are unreachable by either humans or machines alone. For example, the inspection of ship hulls needs to be time- and cost-efficient, precise, safe, and highly reliable—when humans and machines interdependently combine their expertise and strengths these goals can be achieved simultaneously.

To work interdependently, synergistically, proactively, and purposefully to achieve a shared goal, human members and autonomous agents in HAT regulate actions based on coordinative processes (e.g., communication) as well as cognitive and motivational-affective states (e.g., situation awareness, system knowledge, or system trust). Psychological models and research on HHT offer thoroughly researched taxonomies between team variables to explain and predict both dysfunctional and functional cooperation and coordination (Ellwart, 2011; Mathieu et al., 2008). These models of HHT have been transferred to human–machine interactions (e.g., Ellwart & Kluge, 2019; You & Robert, 2017) pointing out several key variables that are of high relevance also in the maritime context. The models show that functional HAT must be considered from a task-specific perspective in the maritime sector, balancing key perspectives on the human (e.g., human team members' knowledge, skills, and personality), technical (e.g., features of the autonomous multi-robot system), and organizational sides (e.g., legal regulation or maritime culture, see Fig. 1)

In the maritime context, the inspection and maintenance of large vessels such as bulk carriers is an important pillar of maritime services.

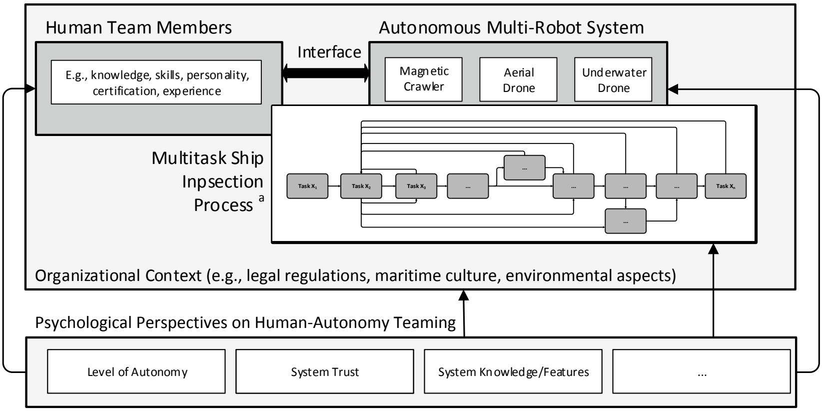

Fig. 1 Holistic perspective on human-autonomy teaming in ship inspection and maintenance
(*Note* [a]Exemplarily multitask ship inspection process scheme [Task X_1-X_n]. *Source* Authors)

Thousands of medium to large ships pass across world seas. To date, ship inspection and maintenance is a manual field of work but the introduction of autonomous systems (i.e., autonomous robotic systems, intelligent software agents, etc.) offers benefits for human safety (e.g., reduced work accidents), the economy (e.g., time and cost-efficient services), and the environment (e.g., reduced full consumption). The World Maritime University (2019) highlights the automation potential of inspection drones, repair robots, or condition-based maintenance systems, and emphasizes that advanced user interfaces will provide a whole new user experience.

In multiple interdisciplinary research projects (EU projects with focus on maritime autonomy concerning ships and ports, e.g., BUGWRIGHT2, 2020; RAPID, 2020; ROBINS, 2020) researchers and practitioners collaborate to unleash the full potential of such novel technologies. Among these, the EU project BUGWRIGHT2 *Autonomous Robotic Inspection and Maintenance on Ship Hulls* aims at developing an autonomous multi-robotic system for inspection and maintenance on ship hulls combining diverse autonomous technologies including aerial drones, magnetic-wheeled crawlers, and underwater drones as well as virtual reality and augmented reality in the user interfaces (see Fig. 1).

The present chapter has two central aims. First, we underline the benefits of combining psychological models, system engineering, and end-user perspectives to develop and introduce functional HAT in the maritime sector. Therefore, Sect. 2 elaborates on three psychological perspectives that are crucial for evaluating functional HAT and mirror the perspectives of system developers and end-users concerning these concepts in the specific application task of BUGWRIGHT2 (maritime voices). Second, we aim to reflect on future developments of HAT in maritime services. Therefore, Sect. 3 elaborates on the adaptability of HAT configurations and poses questions for designing the next generation of autonomous maritime technology.

2 Psychological Perspectives on Human-Autonomy Teaming in Ship Inspections

The implementation of HAT including multi-robot systems in ship inspection and maintenance will transform HHT into HAT. Research in work psychology and human factors outlines numerous interdependent factors that are relevant for functional cooperation in HAT (Ellwart & Schauffel, 2021; O'Neill et al., 2022; You & Robert, 2017). The chapter can only address a narrow selection of critical factors (see also Schauffel et al., 2022). We focus on three psychological perspectives that received profound scientific attention (e.g., meta-analyses, reviews) and were reflected as critical for HAT in the special context of ship inspection and maintenance across stakeholders: (1) the level of autonomy (LOA), (2) system trust, and (3) system knowledge and features.

The critical factors are reflected in the light of the specific maritime application within the project BUGWRIGHT2. The often-abstract theoretical concepts of research in work psychology take on a special significance against the background of voices from the perspective of concrete application and feasibility in the maritime sector. This not only highlights the ecological validity of the theoretical concepts, but also the need to involve end-users and developers in close exchange during the development of systems. Therefore, an extensive interview series was conducted to reflect on the potential needs, opportunities, and challenges of HAT in ship inspection and their consequences for end-user acceptance. Relevant maritime stakeholders (Johansson et al., 2021; Pastra et al., 2022) participated in the interview series (e.g., shipyards, service suppliers, shipowners, and ship inspectors). In line with theoretical models of technology acceptance (Venkatesh et al., 2016) that have been successfully applied to the context of HAT (e.g., Bröhl et al., 2019) and models of human-centered system design (Karltun et al., 2017), the results from 23 expert interviews point to multiple critical factors of HAT that holistically touch the human element, technological systems involved, and organizational context of maritime inspection and maintenance (see Fig. 1, thin arrows). Participation in the interview study was voluntary. Withdrawal was possible at any given time of the interview without consequences. The interviews were conducted video-supported and lasted in total 1 h each. Interview statements were documented and clustered qualitatively. The present chapter documents excerpts from the interview results. For further details on the interview methods and results see the official project homepage (BUGWRIGHT2, 2020).

Table 1 summarizes the psychological perspectives, supportive interview statements from maritime stakeholders (maritime voices), and empirical evidence from the field of work psychology and human factors that we focused on in this chapter. In detail, each perspective is discussed in the following paragraphs. Quotes included in the paragraphs refer to interviewees' comments, which are compiled in Table 1 for an overview.

2.1 Level of Autonomy

Conceptualization. The level of autonomy (LOA) refers to the degree of system autonomy in HAT ranging from no autonomy (i.e., manual human control), and semi-autonomy (i.e., no system independence in task realization, the human can veto) to full autonomy (i.e., high system independence, the human is at most informed). The LOA is differentiated by four specific task types to refrain from abstraction (Parasuraman, 2000; Parasuraman et al., 2000): information acquisition, information analysis, decision selection, and action implementation. Each task type can be realized on each LOA. In addition to a task-specific evaluation of LOA, Schiaretti et al. (2017) highlight that concerning maritime autonomy each technological subsystem must be evaluated separately regarding the LOA. Exemplarily for a multi-robot system in ship inspection and maintenance, magnetic-wheeled crawlers, aerial drones, and underwater drones have different LOAs that might vary depending on the specific subtask (e.g., monitoring the steel plate thickness, generating options for the

Table 1 Psychological perspectives for human-autonomy teaming including exemplarily interview statements from maritime experts and references to related research evidence

Psychological perspective and exemplarily maritime voices	*Research evidence*
1. Level of autonomy (LOA)	
• **Task-specificity:** "We need different LOAs for different tasks." • **Technology-specificity:** "The LOA is higher for the magnetic-wheeled crawlers and lower for the aerial platforms, the LOA underwater is not clear at the moment." • **Human decision-making:** "Responsibility needs to remain on side of the human, no decision-making by robots." • **Perception of control:** "Humans need a feeling of control over the swarm teams." • **The benefit of process optimization:** "We need LOAs that allow people to do separate tasks at the same time as robots are inspecting the ship."	e.g., Endsley, 2017; Kaber & Endsley, 1997, 2004; O'Neill et al., 2022; Onnasch et al., 2014; Parasuraman et al., 2000; Parasuraman, 2000; Schiaretti et al., 2017; Sheridan, 2016; Zhou et al., 2019
2. System trust	
• **Mental models:** "We need realistic expectations about robot features."; "A clear understanding of what the system can do and cannot do, with precise examples in terms of autonomous navigation and positioning." • **Maritime culture:** "In the marine sector trust might be a problem because, in general, surveyors do not have much trust in autonomy."; "Surveyors, in general, are impressed by the possibility and abilities of technology. But it is a traditional field of work, with high rigidity, low technology trust, and high skepticism." • **Transparency:** "Trust in autonomy is a big topic that has a strong connection to transparency: knowing and anticipating the robot behavior." • **Timing:** "There is the risk of testing too early or too late."	e.g., Hancock et al., 2011; McKnight et al., 2011; Parasuraman & Manzey, 2010; Pastra et al., 2022; Schaefer et al., 2016

(continued)

Table 1 (continued)

Psychological perspective and exemplarily maritime voices	*Research evidence*
• **Competence comparisons:** "Comparison on side of the surveyors is sometimes wrong, then they compare the best human performance with the worst robot performance."	
3. System knowledge and features	
• **Reliability:** "Retest stability is more important than exact localization."; "Robots need to be sensitive to the ship structure with the reliability of 100 out of 100."	e.g., Pastra et al., 2022; Rieth & Hagemann, 2021a, 2021b; Schauffel et al., 2022
• **Functionality:** "Inspection on longer distance is unrealistic due to battery capacity."; "Robots need a function to stop and be put into a safe mode where robots can't move or automatically move into uncritical areas."; "We need to avoid those errors in mission planning by technology, for example with proximity sensors."	
• **Task, roles, and competences:** "People need training in moving the robots and using the joysticks."; "A new role needs to be the role of maintaining robots."; "End-users need to know what their role is in the future automated process (e.g., giving information to the system)."	
• **Two-way communication:** "How the human will control and interact with the robots is an open question and there is no solution to this question."; "The human end-user has to be able to interfere if he decides to do so, based on his long-year experiences or intuition."; "The robot should be able to give a warning sign to the human user, e.g., if the navigation goes under a threshold."	

Note Exemplarily maritime voices refer to selected statements by different stakeholders, collected within a qualitative interview series of the BUGWRIGHT2 project. *Source* Authors mission paths, or executing additional thickness measurements or visual inspections of critical hull areas based on former inspection reports).

Different LOAs have unique consequences for human operators and HAT performance. Multiple strategies exist to allocate a task to a human or an autonomous agent in HAT (Rauterberg et al., 1993). Their functionality or dysfunctionality for HAT can be evaluated based on well-established criteria of functional teamwork and human-centered work design (e.g., DIN EN ISO 9241–2, Klonek & Parker, 2021; Wäfler et al., 2003). Thereby, one needs to consider that high LOA does not necessarily result in human benefits (e.g., reduced cognitive load, monotony, or stress) but may also correspond to dysfunctional outcomes, highlighting the two-sidedness of high LOA concerning situational awareness and human control. The dilemma is that high LOA combined with high system reliability and robustness results in decreased situational awareness and the limited ability of the human operator to resume control in critical situations (i.e., automation conundrum, Endsley, 2017).

Maritime Voices and Concluding Proposition. Reflecting on the LOA (see Table 1), in line with theory and research, maritime experts highlighted the task-specificity of LOA ("We need different LOAs for different tasks") when anticipating HAT in ship inspections. The process of ship inspection is a highly complex multi-phase process including preparation, operation, and reporting phases (Pastra et al., 2022). Referring to the task types by Parasuraman et al. (2000), maritime experts formulated the clear need for human decision-making for example when deciding on the to-be-inspected areas of the ships and the final evaluation of the results (i.e., seaworthiness certificate), challenging the allocation of responsibilities and decision rights within HAT. Also, the technology-specific focus on LOA was mentioned by maritime experts including clear anticipations of a rather high LOA for the magnetic-wheeled crawlers and lower levels for the aerial drones. In addition, it becomes clear that LOA is not static but a dynamic element of HAT, as constant technological development and team habituation might lead to flexible adaptation of a specific LOA. For example, "the LOA underwater is not clear at the moment," considering current technological challenges regarding video streaming and localization underwater. Furthermore, maritime experts say that "humans need a feeling of control over the swarm teams," thereby referring to humans' basic needs. Humans have an inherent and fundamental need for control and autonomy (Deci & Ryan, 1985, 2000). However, the concept of LOA adopts a strong focus on system autonomy. The higher the system

LOA the lower the control and autonomy of the human interacting with the technical systems. Large amounts of research from work psychology elaborated on the crucial role of human autonomy (i.e., control) in performance, individual well-being, and motivation (Deci & Ryan, 1985; Hackman & Oldham, 1976; Olafsen et al., 2018). It has to be the goal of HAT design to balance technical LOA and human control. Humans' basic need for autonomy must not conflict with system autonomy. In addition, stakeholder statements indicate that the LOA serves functional HAT if LOA is high enough to enable parallel work and the optimization of existing work processes ("We need LOAs that allow people to do separate tasks at the same time as robots are inspecting the ship").

Taken together, empirical evidence and stakeholder comments illustrate that LOA can serve functional HAT in ship inspection when agent autonomy and human control are constantly balanced on a task- and technology-specific level. There is no simple all-or-nothing principle, but LOA must be balanced and adaptable, evaluated, and designed against the background of the task at hand.

2.2 System Trust

Conceptualization. System trust describes the willingness to depend on technology due to its characteristics (McKnight et al., 2011). In the context of maritime HAT, the object of interdependence is multifaceted including heterogeneous robotic technologies (e.g., magnetic-wheeled crawlers, underwater drones). System trust depends on multiple factors that are rooted in the technology, human, task, and organizational context (see Hancock et al., 2011). For maritime applications, following Pastra et al. (2022), technical robustness and safety, data governance and regulation, and policies are the most vital elements of system trust. However, the authors emphasize that depending on the human element (e.g., skills), the specific vessel (e.g., age or type), and situational environmental conditions (e.g., in-water visibility) system trust might differ. Thus, system trust is not static but dynamic and develops over time. First- and second-hand experiences impact trust dynamics, and also dispositional aspects (i.e., ability to trust) are powerful for system trust in HAT, especially within the early stages of technology adoption (Hoff & Bashir, 2015). Subjective competence comparisons between a human and an autonomous agent impact system trust (Ellwart et al., 2022), given that humans have a basic drive to compare themselves with others in a group or a team (Festinger, 1954). Regarding the optimal level of system trust, not the highest but a well-calibrated level of system trust is requested, as both mistrust and overtrust are associated with performance reduction (Parasuraman & Manzey, 2010).

Maritime Voices and Concluding Proposition. Reflecting on system trust (see Table 1), maritime experts highlight that the maritime context might be a special challenge for HAT, stating that ship inspection and maintenance "is a traditional field of work, with high rigidity, low technology trust, and high skepticism." Maritime HAT thus requests a paradigm shift and cultural change. High end-user participation might enhance such cultural change and establish system trust in maritime autonomy but the timing of end-user participation is focal. Especially early robot failures lower trust (Desai et al., 2013). Therefore "there is the risk of testing too early or too late." Referring to the aspect of trust calibration (i.e., not too high nor too low system trust), end-users "need realistic expectations about robot features" including "a clear understanding of what the system can do and cannot do, with precise examples in terms of autonomous navigation and positioning." Such mental models of HAT help humans to calibrate trust appropriately in routine and especially non-routine tasks. Of note, the consideration of system trust only falls short when discussing HAT in ship inspection, as multiple human stakeholders will remain active in the inspection process. Thus, interpersonal trust will remain focal alongside system trust. In addition, high LOA of single technologies requests a discussion on inter-robot trust which further complicates the topic of trust in maritime HAT.

Taken together, well-calibrated system trust that considers human uniqueness, as well as autonomy's strengths and limitations, serves functional HAT whereas both over-and mistrust reduce HAT functionality. Thereby system trust is subjective and dynamic, developing over time with different trust levels for routine or non-routine situations.

2.3 System Knowledge and Features

Conceptualization. System knowledge is a key aspect of functional HAT and describes "the human's understanding of the general system logic, its processes, capabilities, and limitations" (Rieth & Hagemann, 2021a, p. 5). In the context of maritime autonomy, two domains of system knowledge should be distinguished. First, short-term system knowledge refers to transparent communication and situation awareness in HAT. Here, interface design can help to achieve a constant level of high situational awareness and foster agent transparency (see Schauffel et al., 2022). Numerous research in human factors and work psychology highlights the importance of agent transparency or situational awareness as a crucial knowledge domain for system trust, adaptation, and coordination (Chen et al., 2018). Second, a long-term perspective on system knowledge refers to knowledge about system features, (team) goals, roles, and tasks. Different than situational awareness, long-term knowledge integrates the operators' understanding of tasks, roles, goals, and work processes from administrative guidelines with learned experiences from operations. Here, for example, high reliability during operation is vital, referring to the accurate functioning of autonomy over time and the reproducibility of the tests performed (Pastra et al., 2022). Moreover, accurate mental models of HAT tasks, roles, and responsibilities help to establish well-calibrated system trust and guarantee appropriate human competences (e.g., by training or certification), as human competence demands will increase in HAT (Rieth & Hagemann, 2021b). Crucial for the development of situative knowledge and long-term mental models is communication between the system and the human operator. Communication helps to understand the current decisions of the system and integrate the experience into long-term mental models.

Maritime Voices and Concluding Proposition. Reflections from maritime experts support that high reliability ("Robots need to be sensitive to the ship structure with the reliability of 100 out of 100") in combination with precise examples of robot strengths and limitations is strongly needed for functional HAT. It becomes evident that end-user participation reveals concrete technological elements that need to be considered in robot design (e.g., safe mode, proximity sensor, see Table 1). Maritime experts note that aspects of communication between human and autonomous entities in HAT are so far open questions. Communication needs to be two-sided meaning that humans can intervene in robot missions ("The human end-user has to be able to interfere if he decides to do so, based on his long-year experiences or intuition") and autonomous technologies can contact humans actively in case of critical situations ("The robot should be able to give a warning sign to the human user"). System knowledge also refers to new roles and tasks that go along with the implementation of a multi-robot system (e.g., drone driving, robot calibration, see Table 1).

Taken together, functional HAT requires accurate knowledge about ongoing team processes plus knowledge about robot features as well as subsequent consequences for human competences, roles, and responsibilities.

3 Envisioning the Next Generation of Maritime Human-Autonomy Teaming

Looking at current developments of maritime robotic systems, as described above in the BUGWRIGHT2 example, it is noticeable that although the technical solutions include a certain degree of autonomy, it cannot yet be assumed that the systems are fully self-governed while operating in complex tasks. Visions of highly autonomous systems are being researched and developed. Here, autonomous robots take over complex activities and work interdependently with humans. The factors described above (i.e., system trust, LOA, and system knowledge) remain relevant for functional HAT in the next generation of maritime autonomy that includes fully autonomous systems but these factors are supplemented by a factor that is critical for self-governed systems: team adaptability. Adaptability means that systems can detect changes in the environment and select alternative courses of action that fit new situations. Adaptability in complex environments such as maritime inspections must be described and designed on different levels: (1) reactive adaptability, (2) reflective adaptability, and (3) long-term applicability and strategic adaptability.

Reactive Adaptability. A reactive level of adaptability means that a system comprising of humans and robots recognizes changing requirements and situations during task operation and can adjust behavior. In work psychology, Rico et al. (2019) speak of adaptation through implicit coordination during task action when team members anticipate the information or behavior needed in a given situation and react "automatically." The prerequisite for this is that the autonomous technical system and human operator both have valid situational awareness to detect changes and possess appropriate knowledge of how to react in the given situation. As a result, there is no explicit command necessary, because the team of humans and autonomous agents "knows" about alternative action plans in certain situations or anticipates human needs. For example, in a maritime context, robots should recognize and avoid obstacles or be programed to communicate new undefinable sensory inputs to the operator without being asked. From a research perspective, there are a few empirical papers on this type of adaptability, mostly in the context of aviation and pilot teams with human and software agents. For example, Johnson et al. (2021) showed that coordination training between software agents and human pilots led to better adaptation in critical situations through higher communication anticipation. Brand and Schulte (2021) developed a workload-adaptive and task-specific cognitive agent for helicopter crews that adjusted support by identifying task situations and the workload of the crew. Liu et al. (2016) showed in a human–robot interaction that participants were highly sensitive to the anticipative adaptation of a robot while interacting with a human. Robots that adapted to human actions over time were preferred to work with over non-adaptive ones.

Reflective Adaptability. A reflective level of adaptability means that humans and robots can reflect on task performance after an action period, evaluate performance feedback, and (re-)plan subsequent action phase behavior. In work psychology, Rico et al. (2019) speak of adaptation through explicit coordination during a transition phase (i.e., between two action phases). Successful adaptation during transitions relies on a valid and shared situation awareness that feeds back functional and dysfunctional performance from the action phase. Moreover, successful adaptation in transition relies on explicit communication to reflect on prior achievements and plan future tactics (Ellwart et al., 2015). This level of adaptation places high interaction-related demands on HAT. On one side, sensors and user interfaces have to support human-autonomy reflection and on the other side, the systems software must be able to handle such tactical adjustments. For the maritime context, for example, humans would evaluate robot inspection performance, feedback about missing information, or mistrust of the robot which leads to adjustments in subsequent inspection phases. Probably because of the technical challenges, there is little research about reflective adaptation in HAT. Kox et al. (2021) investigated trust repair strategies between robots and humans during transition phases. When the robot failed its job the system feeds back expressions of regret and explanations, which resulted in high trust repair.

One type of reactive or reflective adaptation is the concept of adaptive LOA. This means that formerly autonomous actions of the robot become manually controlled (or vice versa) depending on the task or team characteristics. HAT may adapt the LOA of the robot or software agents depending on system errors (Chavaillaz et al., 2016) or the workload of the human (Calhoun et al., 2011). Adaptive LOA may be implemented automatically during action (i.e., reactive) or after task reflection on demand by the human team member. In this vein, the concept of socio-digital self-comparisons may be relevant for future research. When humans compare their task-related competences with robots, Ellwart et al. (2022) found that perceived advantages of robot competences (compared to own individual competences) were related to task allocation toward the robot. Thus, adaptive LOA may also impact the evaluation of own and robot competences in a given situation.

Long-term Applicability and Strategic Adaptability. While reactive and reflective adaptation focus on short-term adjustments of HAT during a given sequence of action and transition phases, there is a long-term perspective on the applicability and adaptability of HAT. Field interviews in the maritime sector of ship inspections within the BUGWRIGHT2 project pointed toward long-term issues that are closely related to user acceptance and knowledge needs before implementation. For example, inspectors of ship hulls asked if the autonomous system can be used sustainably for a long time without any loss in quality and performance. This relates to technical reliability after years of application but also to the question if the system will fit the demands of the future. Thus, systems need to strategically adapt to new changing conditions, such as new ship types, inspection or software regulations as well as new workflows. To successfully implement these adaptations, close cooperation between members of HAT and system developers is required not only in the phase of technology introduction but also in the long term over the life cycle of the HAT.

4 Conclusion

From a psychological perspective, the collaboration between humans and self-governing systems can be described as a complex interaction of numerous factors at the level of human, technology, and organization. The robot must no longer be just a tool, but an autonomous team member in HAT. The resulting requirements for the design of maritime HAT can be developed in an interdisciplinary collaboration between work psychologists, system developers, and end-users in a participatory manner. Yet, there is no optimal design solution. In this context, well-researched interaction processes, as well as cognitive and emotional states of psychological models, can provide a frame of reference to design functional and adaptive systems. Thereby, the specific task must be at the center of system design. It makes a difference if robots gather data for ship hull inspections autonomously and give this information to a human inspector for decision or if robots gather data and decide about the seaworthiness of the ship and the hull's safety autonomously. The optimal design solution is always bound to the specific task and thus opens up a wide range of application perspectives for HAT in the maritime sector.

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CHAPTER 19

Lessons Learned from Maritime Nations Leading Autonomous Operations and Remote Inspection Techniques

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1 Introduction

Digitalization and the emergence of artificial intelligence (AI)-based technologies are increasingly pervading all areas of our lives, and in parallel, posing multiple challenges for nations. It is observed that the AI agenda remains a strategic priority for governments. Combinedly, respective

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priorities have led to a form of global competition with regard to the development of AI applications and policies (Smuha, 2021). In 2017, Canada became the first country to establish a national plan for AI. The "Pan-Canadian Artificial Intelligence Strategy" fosters a collaborative AI ecosystem by establishing interconnected nodes of scientific excellence in three major centers for AI: Edmonton, Montreal, and Toronto. The EU AI strategy of 2018 specifies the region's goal to "lead the way in developing and using AI for good and for all, building on its values and its strengths". In the following year, the US, through Executive Order 13,859, promised to sustain and enhance the scientific, technological, and economic leadership position in AI research and deployment through a coordinated Federal Government strategy (Federal Register, 2019). During the same year, Singapore launched the "National AI Strategy" that spelled out plans to deepen the usage of AI technologies and rethink business models by 2030. From an Asian context, with its ambitious "Next Generation Artificial Intelligence Development Plan", China has

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set out a top-level design blueprint charting its approach to developing AI technology by 2030.

In short, governments from across the globe are catering to the needs of end-users through the adoption of policies that could stimulate beneficial innovation while protecting their citizens from risks involving the usage of AI. Safety, responsibility, and product liability aspects of AI, including negligence, design defects, and manufacturing defects, usually fall into a legal and regulatory vacuum. At the same time, participants of regulatory debates hold divergent views on the so-called term "autonomy". A unified and well-synchronized "safety" and "liability" approach is vital to the mitigation of potential damages caused by AI. According to the participants, the above is what makes AI trustworthy, i.e., legal, ethical, and robust.

AI national plans also set specific targets for niche ocean and maritime sectors. In this context, semi-autonomous RIT platforms for unmanned aerial vehicles (UAVs) or drones, remotely operated vehicles (ROV), and magnetic crawlers, *inter alia*, do not explicitly reside on the national agenda despite having gained attention from relevant stakeholders and end users. Today, RIT platforms are being tested and used by service providers, classification societies, and ship owners. However, many intrinsic matters, similar to ones that emanate from the usage of AI, remain undiscussed and therefore, ambiguous. Problems have been projected: standard definitions, third-party liability, data management, and insurance are to name a few thorny issues. The absence of unified guidelines (covering the above) leads to the hypothesis that a single RIT platform may be governed by dissimilar rules and requirements. Today, this is evident from the content found in RIT procedural documents issued by leading classification societies. The current state-of-fragmentation and lack of a standardized approach have the potential to stall innovation in the long run. The authors assert that, before any attempt is made to standardize RIT approaches, it is important to assess the lessons learned and best practices from countries that are taking the lead in AI and RIT-based operations.

2 National Comparative Study

2.1 The Case of the US

The US is a maritime nation comprised of 25,000 miles of coastal and inland waters and rivers home to 361 ports (USCG, 2018). It is axiomatic that the US marine transportation system is expansive. The US maritime domain involves a complex regulatory framework in a variety of locations, from inland ports and waterways to the high seas, often with overlapping legal authorities and agency responsibilities. Several jurisdictional zones exist in the maritime domain that may implicate international and domestic law. The location and use of the autonomous systems' operations may call into play multiple overlapping jurisdictional concerns, including domestic and international legal obligations (Pribyl, 2018). The US Coast Guard (USCG) has 11 statutory missions and maintains broad authority over navigation safety in the navigable waters of the United States, including the inspection of vessels registered in the US or sailing in US waters. In terms of autonomous vehicles, the USCG is the lead agency for marine vehicles and exercises its oversight in this regard under its port state control, vessel inspection, environmental compliance, and navigational safety authorities. The US Flag fleet includes 18,967 vessels subject to inspection with Coast Guard marine inspectors conducting 19,474 inspections (United States Coast Guard, 2021). The majority of the US fleet is comprised of barges, passenger, and towing vessels.

The Coast Guard delegates this responsibility to the Officer in Charge, Marine Inspection (OCMI), whose primary responsibility is to inspect vessels to ensure compliance with applicable laws and regulations related to safe construction, operation, and manning. The Coast Guard Office of Commercial Vessel Compliance (CG-CVC) is the designated body for the development and maintenance of marine safety and security policies and standards.

There are currently no US regulations that expressly govern the use of RIT or remote inspection technologies. However, as a response to the Covid-19 pandemic crisis, including considerations of the lessons learned from the pandemic, the Coast Guard is taking steps to encourage its inspectors to use remote methods as a means to verify vessel compliance (Marine Safety Information Bulletin, 2020). Many statutory surveys are also performed by Recognized Organizations (ROs) that act on behalf of the Coast Guard. The American Bureau of Shipping (ABS) is the largest RO in the US. For remote inspections, the Coast Guard generally approves the usage of remote techniques on a case-by-case assessment. ROs that use remote survey in lieu of attendance on vessels that are both classed and certificated should contact the relevant Coast Guard office, such as the Flag State Control Division (CG-CVC-4) or the Towing Vessel National Center of Expertise (TVNCOE), to propose the methods and administrative procedures that will be used (Marine Safety Information Bulletin, 2020).

Given the current stage of technological development, remote techniques have not yet achieved an optimum level since they continue to develop equivalent functions on par with human senses used in inspections (i.e., sight). More peer review studies are needed to compare the existing regime of inspections with remote techniques to provide evidence as to which option is better suited and feasible.

The ABS Guidance Notes on the Use of Remote Inspection Technologies (ABS, 2022) offer best practices for class surveys and non-class inspections carried out using unmanned aerial vehicles (UAVs), ROVs, and Robotic Crawlers. The document offers a holistic approach to govern RITs and adequate emphasis is given to "data security policies and procedures" in Sect. 4.11.1. Nonetheless, according to the document, it should be noted that those policies and procedures should be developed by the concerned end-users, including service providers. The Guidance Note includes reference to the following relevant international documents:

- IACS Recommendations No. 42, Guidelines for Use of Remote Inspection Techniques for Surveys;
- IACS UR Z7, Hull Classification Surveys 1.6 Remote Inspection Techniques; and
- IACS UR Z17, Procedural Requirements for Service Suppliers.

According to the ABS Guidelines, during the planning stage, the ship owner/operator should liaise with ABS and decide jointly on whether to proceed with the survey using RIT (Fig. 2 below). The owner is responsible for selecting an ABS Recognized service provider. Approved service providers should possess all applicable certificates of authorization from recognized national/local authorities and have an internal Quality Management System, Safety Management System, Safety Risk Management, Safety Assurance, and competent personnel to oversee all the above aspects. It is also noted that the owner should provide all documents and drawings related to the work scope to the selected provider, approve the remote inspection plan, and set the Survey Planning (Fig. 1 below). The service provider, during this stage, develops an inspection plan that includes different types of RIT to be used based on risk assessment. The Class reviews the survey planning document to verify whether the survey plan satisfies the applicable ABS Rules. During the operation, which is the second stage of the inspection process, the owner coordinates the survey with the surveyor and the provider (Fig. 1 below). The provider conducts the inspection according to the survey planning document, RIT operation plan, and ABS requirements. The attending class surveyor ensures that the RIV operations team conducts the survey according to the relevant requirements. During the reporting phase of the survey, the provider shares the report and data with the asset owner and Class. Finally, based on the reports, the Class surveyor shall confirm if an additional inspection is required (Fig. 1).

2.2 *The Case of the Netherlands*

The Netherlands has a longstanding maritime tradition dating back over five centuries and holds a strategically significant geographical position with connections to rivers and seas. According to the Maritieme Monitor (2020), the Dutch maritime cluster incorporates eleven sectors: shipping, shipbuilding, offshore (energy), inland shipping, dredging, ports, navy, fishing, maritime services, yacht building/watersport industry, and marine equipment supply. The cluster generates 3.1% of the total GDP of the country and employs approximately 284,917 individuals, which equates to 3.0% of the national workforce (Maritieme Monitor, 2020). The Ministry of Infrastructure and Water Management is currently working to facilitate new initiatives and innovations in the inland maritime sector. Moreover, the Port of Rotterdam has positioned itself as an EU frontrunner in autonomous shipping technology and services through partnerships with tech-start-ups, leading institutions, and national authorities.

According to the Ministry of Infrastructure and Water Management, there is no single legislation for all types of transport modalities to facilitate autonomous drones or any other types of service robots. Maritime autonomous robotic systems are not permitted to operate within Dutch inland waterways; however, experiments are ongoing with (semi-) autonomous inspection vessels. Parties that wish to experiment

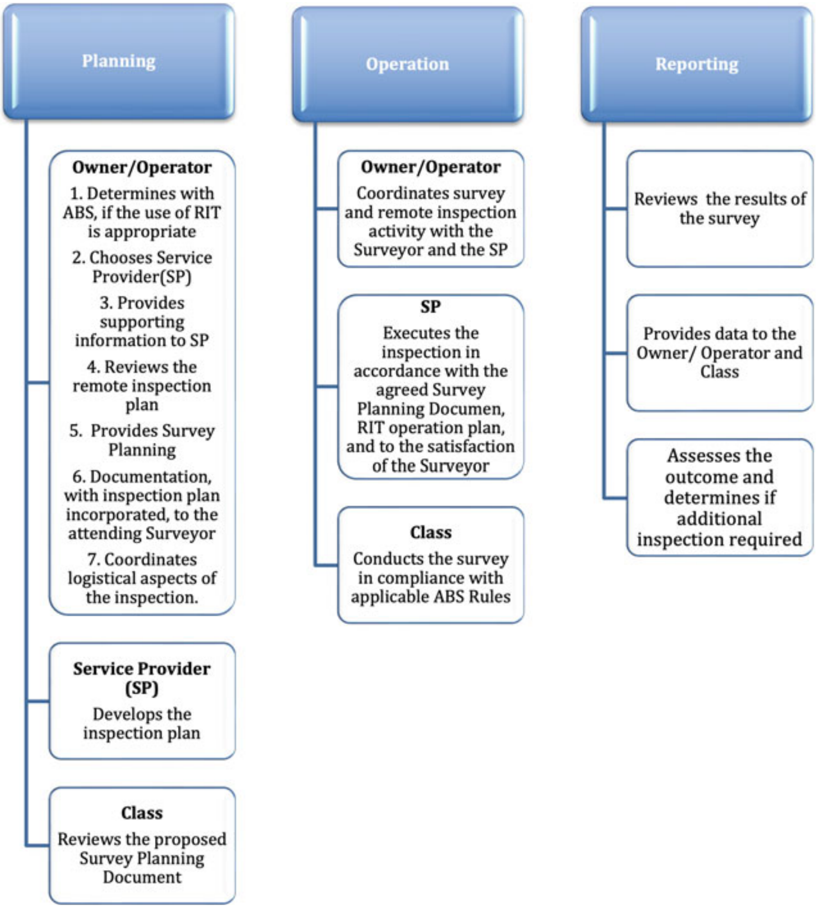

Fig. 1 Roles and responsibilities of the key stakeholders during the 3 phases of the inspection process (*Source* Adapted from ABS [2022])

with any categories of smart shipping, including maritime drones and robotic systems, are invited to contact *Rijkswaterstaat* (RWS) to evaluate the possibilities.

It goes without saying that the Dutch maritime sector is subject to national, as well as international and European regulations. The *Schepenwet* (Ships Act) is the central instrument that applies to all seagoing vessels flying the Dutch flag (Government of the Netherlands, 1909). The Act aims at preventing shipping disasters at sea and addresses issues such as ship safety and shipping disaster investigations. There are no provisions in the Act related to the use of remote technologies. In the inland maritime sector, the national legal framework on inland waters, excluding waterways governed by the standards and regulations of the Central Commission for the Navigation on the Rhine (CCNR), can be found in the Inland Navigation Act-*Binnenvaartwet* (Government of the Netherlands, 2007).

The Dutch Flag Registry is known as the Netherlands Shipping Inspectorate/NSI (Inspectie Leefomgeving en Transport), which is a part of the Human Environment and Transport Inspectorate (ILT) of the Ministry of Infrastructure and Water Management. The Registry has delegated all statutory certification services to eight pre-assigned EU RO: ABS, Indian Register of Shipping, Lloyd's Register, Nippon Kaiji Kyokai (Class NK), DNV, RINA Services S.p.A., BV (Buraeu Veritas), and Register Holland. It is noted that the Register Holland is a Classification Society that conducts only non-Conventional and/or non-European legislation-based surveys. The Administration supports the use of remote inspection in minor statutory deficiencies and minor damages. However, if an inspection is performed remotely, a physical inspection still needs to be performed afterward.

In cases where the ship owner/manager, in agreement with the captain and personnel on board, requests a remote survey, written justifications should be provided. If the RO accepts this request, then IACS 42 Rev.2 should be followed. Remote inspections are evaluated on a case-by-case basis and as such, no uniform guidelines apply.

It is noted that the request for remote inspection imposes an additional burden on the ship owner/manager and the RO, and that is why it is important to justify why a remote survey is more appropriate than a physical inspection.

Respondents noted that the Covid-19 pandemic could have been the catalyst and the paradigm for remote inspections, but unfortunately, the flag registry did not explore this option further. Instead of remote inspections, extensions were mainly granted for the statutory ship certificates by the Human Environment and Transport Inspectorate. Moreover, the Dutch fleet is in decline, and vessels are usually too small to obtain financial benefits from the usage of UAVs and ROVs. What is observed is that ship owners are yet to be convinced about the advantages of deploying remote technologies for the conduct of surveys and inspections. The following set of challenges were revealed during discussions with Dutch key experts in addition to the aforementioned:

- Visibility in the Dutch water imposes a burden for underwater inspections with autonomous underwater vehicles (AUVs);
- Problems have been noted with live-streaming technology. The sector needs companies that can provide effective live-streaming video-audio tools for a thorough examination of the structural defects;
- Drones, during the livestream operation, should always show their exact location during the inspection (which is currently not the case). This facilitates the work of the surveyors;
- Permission for hull cleaning from the Port Authority remains a challenging task. It should be kept in mind that hull cleaning is not a part of the Statutory certification and remains at the ship-owner's discretion;
- Flag Registries like Liberia are keener than their European counterparts to promote the use of remote technologies; and
- Specific Regulations are needed for trials and inspections. The findings of these trials should be crosschecked with findings from physical inspection to address gaps and overcome barriers.

2.3 The Case of Canada

With the world's longest coastline and connection to three oceans, the maritime sector in Canada contributes around CAN$31.7 billion annually in gross domestic product and accounts for close to 300,000 jobs (Government of Canada, 2021). Similar to other major maritime nations, Canada aims to be a global leader in the blue economy by integrating growth with ocean conservation and climate action. Activities dependent on the ocean, such as fish processing, shipbuilding, and marine transportation, create stable jobs and prosperity for coastal regions. Currently, there are no regulations/provisions for remote inspection techniques. However, the current four-level regime that entered into force in June 2021 is said to facilitate the eventual adoption of new inspection techniques in the future. The four documents relevant to the Canadian vessel inspection are described in Table 1 (below).

Table 1 Documents relevant to the hierarchical system of vessel inspection

Regulations and standards (Sources)	*Description*
1. Canada Shipping Act, 2001	Overarching legislation for marine safety and pollution prevention. The Act set the legal framework, and inspection authority, details of inspection are found either in regulations or supporting instruments
2. Regulations, such as the Vessel Safety Certificate Regulations (VSCR) as of 10 of June, 2021	The regulations specify which vessel needs a safety certification, and therefore need to be inspected. The regulations do not specify the inspection details; these are included in the TP 15456 document titled Canadian Vessel Plan Approval and Inspection Standard (Government of Canada, 2022)
3. Standards, such as the new Canadian Plan Approval and Inspection Standard, TP 15,456	The objective of this standard entered into force on 23 June 2021 is to provide instructions and guidance for inspections of vessels subject to the Vessel Safety Certificates Regulations under the authority of the Canada Shipping Act, 2001 (CSA, 2001). This document contains crucial details, for example, when a vessel needs to be inspected and what elements need to be inspected. If modern remote inspection techniques will be included in the Canadian regime, it will be done at this level or at the next one (fourth level). This would be an administrative exercise (done by Transport Canada Marine Safety and Security), rather than a legal one (e.g., Act or regulatory amendment, with Canadian Justice Department and others)
4. Supporting material such as Guidelines and works instructions	These may be developed on a needed basis to address certain specific elements

Source Transport Canada (Sources indicated in the first column)

In the context of the Covid-19 pandemic, like many other administrations, Transport Canada adapted its inspection processes on a case-by-case basis and accepted remote inspections to a certain extent. Transport Canada is looking forward to developing a framework that would support the use of new emerging technology. To this effect, there is a multimodal (air, surface, rail, marine) departmental modernization initiative, and the usage of RIT is one of the end objectives of this initiative. The discussions with Deep Trekker, one of the largest providers in the country for remotely operated vehicles and robots, confirmed the limited use of remote techniques on Canadian vessels. The advantages and disadvantages of underwater inspection methods are summarized in Table 2 (below):

Table 2 Advantages and disadvantages of underwater inspection methods

Inspection method	*Certainty*	*Pros*	*Cons*
Drydock	High certainty	Clear visibility above water	Extremely high cost and time-consuming
Divers	Moderate certainty	1. Proven to perform adequately well, regulated and guided worldwide 2. Moderately high cost	1. Difficult to clarify if divers have inspected the entire vessel and difficult to know their exact position when finding defects 2. It can be time-consuming to wait and schedule a dive team 3. It is dangerous to send divers underwater
Remotely Operated Vehicles (ROVs)	Lower certainty but technology is evolving rapidly	Quick to deploy, most cost-effective and safest alternative	Inability to know its position. The ROV can run in transects along the hull in straight lines to maintain an understanding of position

Source Deep Trekker

Respondents underlined that three main obstacles are present when it comes to using ROVs:

1. Understanding what you have inspected (vs. not inspected);
2. Visualizing the data in a meaningful way; and
3. Sending the data to stakeholders in a meaningful way.

The first obstacle is related to the location of the inspection. GPS positioning systems do not work underwater as they can travel only a couple of inches through the water. One potential solution is the utilization of technology such as the underwater positioning system (USBL), which provides a position of the ROV using acoustic positioning. USBL consists of a transceiver mounted on the vessel and a transponder mounted on the ROV which jointly cooperate to communicate the ROV's position relative to the vessel. However, there are cases that USBL on its own does not work well because the vessel is an obstacle for acoustics to communicate from the dunking transducer to the ROV's transponder. USBL is also inherently inaccurate by 20 cm of error and with seconds of delay between pings, making autonomous motions difficult and unreliable using just

USBL. Deep Trekker is currently working on other methods for getting positioning and allowing for autopilot functionality.

The second obstacle is the visualization of the data in a meaningful way. Like a diver's eyes, video has a limited field of view to give positional context to the images the surveyor is seeing. A 3D rendering or model allows the surveyor to analyze the aggregate of the data points collected during an inspection. Currently, underwater 3D models are too time-consuming and require expert-level expertise whereby the technology remains prohibitively expensive.

The third obstacle is the proper interpretation of the data. The surveyors usually rely on divers' expertise to confirm the vessel's condition. In contrast, an ROV allows video streaming or video recording through which stakeholders could monitor the inspection process. However, there are many hours of footage to comb through to get the answers needed for the surveyor. The operator of the ROV should still be certified and experienced in hull inspections to identify issues. If the surveyor can monitor the inspection process next to the pilot, the quality of the report could be increased. A hull survey report engine must enter the inspected data and then produce a PDF report with photos of points-of-interest and easy access to key milestones during the video with text added for additional details.

Despite the obstacles that have been identified, it should be underlined that 3D RIT and reporting technologies are paving the way for significant developments in ship inspections. Interpreting changes over time with the use of a 3D model is helpful for maintenance purposes, evaluating corrosion, fouling changes, and damage. Providing classification societies with historical information on the vessel could prove valuable in their determination if the vessel is seaworthy and safe. There are three main methods for building underwater 3D models: Sonar, Laser, and Photogrammetry. There are other interesting combinations of other sensor technology such as hyperspectral imaging and LiDAR that could provide good data as well, but these are still unproven underwater.

Sonar is very useful for larger areas and general target identification with its longer range and capabilities even in murky water, but it should be noted that 3D sonar technology is limited in its capability for identifying small defects or changes over time in structures such as the propeller. The most used technology for propeller and small structure evaluations is the laser. Nonetheless, laser scanning has a very short-range capability (1–5 m) and is severely impacted by water clarity, making it more difficult for it to effectively provide full hull 3D models in a reasonable and cost-effective manner. Photogrammetry faces similar range and clarity issues, but there are encouraging developments that have found ways to utilize stereo cameras to stitch together 3D models faster and with less manual effort. As these technologies come down in size, price, and complication, they will play a critical role in making effective hull inspections easier.

2.4 The Case of Norway

Norway is a leading ocean economy with well-developed business clusters and local communities living along the coastline. The Norwegian shipping industry is at the forefront of exploiting new technologies like autonomous ships and onboard systems. The Norwegian Maritime Authority (NMA) is an agency of the Ministry of Trade, Industry, and Fisheries and the Ministry of Climate and Environment. NMA is the administrative and supervisory authority for environmental, safety, and legal issues of vessels flying the Norwegian flag and foreign ships in Norwegian waters.

The Register of NMA consists of the Norwegian ordinary ship register (NOR), the Norwegian International Ship Register (NIS), and the Shipbuilding Register (a sub-unit of NOR). For the NOR, there is a mandatory registration for all Norwegian ships of 15 meters and above and voluntary registration of Norwegian fishing and commercial vessels less than 15 meters. The regulatory framework for registration to NOR is based on the Norwegian Maritime Code of 24 June 1994 no. 39 (NMA, 1994). The NOR is open to EU or Norwegian owners and is the responsible authority for surveys and statutory certificates of vessels registered in NOR. International ship certificates for cargo ships above 500 gross tonnages (GT) are usually delegated to RO—upon request from the owner in accordance with the Class Agreement (NMA, 2013).

NIS was formed as a competitive alternative for Norwegian shipping companies operating in international waters and mainly competes with flags of convenience registers such as Panama and Liberia. NIS, which aims to maintain Norwegian vessels under the Norwegian flag, is open to owners of all nationalities. Ships are registered according to the law of 12 June 1987 No. 48 related to the Norwegian International Ship Register (NMA, 1987). Vessels above 500 GT classed by a RO are delegated to class according to the Class Agreement. The NMA inspects ships less than 500 GT as well as NIS ships of 500 GT and more which are not classed by one of the ROs. The number of vessels by the end of 2020 for NOR and NIS are presented in Table 3 (below).

Six classification societies are authorized to carry out surveys on behalf of the Norwegian administration namely, ABS, Bureau Veritas (BV), DNV, Lloyds Register of Shipping, RINA, and Class NK. Classification societies are used for the inspection of NIS vessels. For surveys of the NOR, the inspectors of NMA are usually appointed. The 130 in-house surveyors of the Norwegian Maritime Authority perform all vessel-related surveys and thickness measurements as seen fit. NMA Surveyors do not conduct thickness measurements themselves. These are performed by RO-approved suppliers on the "IACS List of Thickness measurement Firms", and according to IACS UR-Z7.

Currently, there are no specific regulations and policies for remote surveys, especially when it comes to surveys conducted for the Norwegian Ordinary Ship Register. The NMA may utilize remote technologies when achieving equivalency with a traditional survey. As a consequence of Covid-19 pandemic, the NMA allowed RO to extend the validity of statutory certificates for three months (NMA, 2020). DNV works in close cooperation with the NMA and completed the world's first in-water remote ship surveys using ROVs in 2020. When a classification society decides to perform a remote survey, especially for NIS-registered vessels, no further approval is required from the NMA.

It is important to note that respondents displayed a high level of trust in remote technologies, especially in drones given that mitigating technical challenges through drone testing has been successful in other sectors (i.e., aerospace and oil industries). Discussions also revealed that in the near future, more emphasis should be given to the development of guidelines for data-relevant issues, such as minimal requirements for

Table 3 Norwegian registered vessels 2020

Norwegian Registered Vessels 2020	*Registry*	*Norwegian owned 2020*	*Foreign owned*
Ships in the Merchant fleet	NOR	892	24
	NIS	485	170
Ships not in the Merchant fleet	NOR	20,417	73
	NIS	29	11

Source Statistics Norway

data quality, data ownership, and data flow. Guidelines will be required to govern the work of service robots once they reach the stage of full autonomy. Drone swarms are expected to be the next generation of robotics in the maritime sector. Aerial drone swarms deployed from an unmanned marine robotic station will autonomously inspect the vessel removing the need for a manual human inspection system.

2.5 The Case of China

With an array of ambitious AI plans and policies, China is said to be leading the way for AI technological developments and market applications. These policies aim to motivate different stakeholders on the ground that AI is a field that is being backed by the government and is worth investing in (Li et al., 2021).

The Maritime Safety Administration of the People's Republic of China (CMSA) is the governmental agency for maritime safety, vessel inspection, and pollution from ships. The Agency is responsible for regulations, technical codes, and standards in safety supervision, marine pollution prevention, and navigational aid. The Agency supervises the statutory survey and certification for ships. For international ships trading internationally, the statutory survey processes have been delegated to the China Classification Society (CCS). According to respondents, no specific regulations or guidelines have been released by the Agency that enables the use of remote inspections.

CCS provides classification services to ships, including statutory surveys, verification, certification and accreditation, and other services in accordance with the International Maritime Organization (IMO) rules and requirements and relevant regulations of the authorizing flag States or regions. Class services are provided to more than 32,000 international and domestic shipping ships and 2,600 ocean fishing vessels. Surveys utilizing RITs are mainly operational and not statutory. These techniques are applied on oil tankers, but not for hull survey, inspection, and cleaning. In 2018, the CCS released the "Guidelines for Use of Unmanned Aerial Vehicles for Surveys" (CCS, 2018) for ships and offshore installations following the relevant requirements of IACS Recommendation 42 titled "Guidelines for Use of Remote Inspection Techniques for surveys". Remote inspections by way of UAVs are to be carried out by professional organizations. The specified technical standards are relevant to safety, operational performance, endurance capacity, data transmission and communication, storage, airborne lighting, and airborne cameras. Provisions also exist for the collection and processing of visual data and data security.

Steel ships are built and surveyed following the Rules for Classification of Sea-going Steel Ships published by CSS (CCS, 2022). The updated version of the rules includes provisions for RIT utilized in (a) thickness measurements and close-up surveys—hull structures and (b) In-Water Survey (Table 1). For surveys conducted using RIT, one or more of the following means for access, acceptable to the Surveyor, is to be provided: (1) unmanned robot arm; (2) ROV (3) UAV/Drones; and (4) Other means acceptable to the Society.

2.6 The Case of Singapore

Singapore's maritime network is an amalgam of entrepreneurs, research and development institutions, classification societies, technology companies, and international partners. Over the last two decades, the MPA has developed the Maritime Innovation and Technology (MINT) Fund to expand its maritime innovation ecosystem. The Singapore Registry of Ships (SRS), with more than 4,400 vessels, aggregating over 96 million gross tons (GT), ranks fifth among the list of global fleets (MPA, n.d.b). The Merchant Shipping (Safety Convention) Regulations is the instrument for traditional surveys and certificates (Singapore Statutes Online, 2021). MPA has delegated the survey and certification of ships under the Singapore Registry of Ships (SRS) to eight (8) Recognized Organizations that are full members of the International Association of Classification Societies (IACS): ABS, BV, CCS, DNV, KR, LR, NK, and Rina.

Singapore advocates the usage of emerging technologies to improve the safety and efficiency of the maritime industry. Since 2018, Singapore has accepted the conduct of surveys on board Singapore Registered Ships via the use of RIT. Where permitted, RIT may be used to facilitate the required external and internal examinations. Before any inspection, the Flag State should proceed toward approval on a case-by-case basis. Shipping Circular No.13 of 2018 dated 23 Oct 2018 was promulgated to inform all stakeholders regarding approval aspects concerning RIT (Table 4, below). The RIT, to this end, may comprise the following:

- Unmanned Robotic Arm;
- ROV;

Table 4 MPA Circular No. 13 of 2018: Acceptance for the use of RIT for surveys

UAS	For periodical surveys using UAS, if the UAS is not operated by the RO itself, the company engaged to operate the UAS for the inspection is to be approved by the RO for carrying out such services in accordance to the RO's criteria for approving service providers. Inspections should be carried out in the presence of the Surveyor
Inspection Plan	An inspection plan for the use of remote inspection technique(s), including any confirmatory survey/close-up survey/thickness measurements, is to be submitted to the RO for review and acceptance in advance of the survey. The proposal for usage of UAS in periodical surveys is to be submitted by the RO to the Administration for acceptance
Acceptance	The results of the surveys by remote inspection techniques when being used towards the crediting of surveys are to be acceptable to the attending Surveyor. Confirmatory surveys/close-up surveys may be carried out by the Surveyor at selected locations to verify the results of the remote inspection technique, if required
Thickness Gauging	The acceptance of remote inspection techniques does not waive the requirement for thickness gauging where applicable. Thickness gauging by remote inspection techniques can be accepted subject to the same criteria of approval as applied to other Non-Destructive Test (NDT) techniques by the RO. Confirmatory thickness measurements on-site may be requested by the attending Surveyor, if required
Close-up Survey	Reference is made to the ESP Code Annex A (Bulk Carrier) and Annex B (Oil Tankers); "Close-up survey is a survey where the details of structural components are within the close visual inspection range of the surveyor, i.e., normally within reach of hand." In addition to requirements in paragraph 1 to 7 above, the usage of remote inspection techniques such as UAS can be accepted for close-up survey on ships subjected to the ESP Code, if the attending surveyor is satisfied that the information provided by the remote inspection technique, such as video footage from the UAS, is equivalent to a survey where the details of structural components are within the close visual inspection range of the surveyor

(continued)

Table 4 (continued)

Annex 1	Unless agreed by the Administration, the usage of remote inspection technique is not accepted or not to be continued for the specific location on the ship, at the following conditions: • Where there is existing record or indication of abnormal deterioration or damage to structure or to items to be inspected; • Where there are existing recommendations for repairs or conditions affecting the class of the vessel; • Where during the course of the inspection survey, defects were found such as damage or deterioration that requires attention. In such cases, the normal closeup survey/thickness measurement without the use of remote inspection technique is to be carried out to determine the scope of repairs required; and • Where the coating condition of the tank/hold is rated as less than "Good" by the Surveyor. This does not app apply to sections of cargo oil tanks that are not coated and stainless-steel cargo tanks

Source MPA (2018)

- Unmanned Aircraft System (UAS); and
- Other means acceptable to the Administration.

Remote surveys have been embraced by the sector for quite some time, but albeit still lack a standardized approach. Singapore seeks to address the lack of industry standardization and for this reason a Joint Industry Project (JIP) has been launched for the development of a Singapore standard in remote surveys, inspections, and audits.

In 2020 BV Singapore cooperated with PSA Marine to conduct the first remote survey for a harbor tug registered under the Singapore Registry of Ships. The tug underwent a fully accredited annual survey of the hull, machinery, load lines, safety, and telecommunications equipment using smart mobile devices and optimized live-streaming without the physical presence of a surveyor. During the Covid-19 pandemic outbreak, another joint remote inspection was conducted by BV, Nokia, and Sembcorp Marine. The inspection set the basis for establishing a new class procedure for the remote survey of vessels under construction that could optimally assess the integrity of the hull components efficiently.

The service providers that conduct hull inspection and surveys using RIT are authorized service providers under the respective RO. Relevantly, RO follows UR Z17 Rev14 CLN issued by IACS for the procedural requirements for approval and certification of service providers. RO, after being authorized by MPA to carry out statutory survey and certification, are required to ensure that the service providers meet the service standards. Respondents informed that disputes concerning liability between service provider and client should be settled through appropriate legal clauses in the service contract governing the unsatisfactory quality of service rendered on board.

Participants from the MPA informed that they anticipate the development of detailed guidelines from IACS on RIT, in particular, with reference to IACS Recommendation—REC 42 REV 2 CLN. Currently, they have noted a plethora of guidance and notes prepared by different classification societies, such as ABS, DNV, LR, and RINA. A comprehensive guidance from IACS, detailing the principles of usage, limitations, and procedures, according to the respondents, would be helpful for the flag administration and its stakeholders, such as ship owners/managers to assess the suitability of RIT deployment subject to specific conditions experienced by the ship. Subsequently, a global framework promulgated under the auspices of the IMO, as noted by the participants, would help achieve governance uniformity in the likelihood of RIT mass deployment by IMO member States.

3 Conclusions

The current study highlights that there are robust AI national plans in place by some of the major maritime nations. Those plans set specific targets for the ocean and maritime sectors. However, autonomous and semi-autonomous RIT platforms (e.g., drones, ROVs, and magnetic crawlers) have been used in the past by flag States only on a case-by-case basis.

As work continues to expand the usage of RIT, participants note the value of a "lawful system" that could serve as a tool to boost trustworthiness in RIT given that reliance on law is important to certain stakeholders involved in the RIT business model, such as policymakers and flag state officials that are not familiar with the system technicalities (Pastra et al., 2022). In parallel, IACS and IMO techno-regulatory instruments could be updated as well. Altogether, based on the responses provided by respondents, the following elements could be taken into account with a view to making the system "lawful":

- *Regulation*: IMO harmonized System aligned with IACS Unified Requirements;
- A separate *Codes of Conduct*: IACS rules and procedures;
- *Standardization*: ISO Standards or the IEEE P7000 standards series for maritime remote technology;
- *Certification*: Certificate standards for service providers and RITs operators;
- *National legislation for UAVs*: (a) for their operation in Visual Line of Sight (VLOS), Extended Visual Line of Sight (EVLOS), and Beyond Visual Line of Sight (BVLOS) and (b) the certification of operators;
- *Energy Efficiency*: While AI and new technologies, including RIT, introduce efficiency gains and offer many advantages in undertaking tasks that were previously done partly or fully manually, then it will introduce new energy demands which in turn could result in a negative impact on greenhouse gas emissions and the environment. Therefore, it is important that in parallel with the introduction of RIT that renewable and green energy forms are integrated into this process to best ensure a sustainable way forward. For example, underwater hull cleaning can result in a true win–win situation if using hull cleaning crawlers that are fueled by electricity that has been produced using solar or wind power, sustainable biofuels, or any other renewable energy forms. The same can be said for drones used for close-up inspections and thickness measurements.

In summary, flag States are, slowly but steadily, supporting and developing requirements for the use of RIT and are currently going through an experience-building phase. It could, therefore, be beneficial if the noteworthy developments and best practices could be consolidated and applied in the development of harmonized guidelines in order to establish a global level playing field that fosters investments in the technology. As RIT, generic emerging technologies, and technologies with emerging applications are becoming increasingly robust, the human element is still an important part that cannot be overlooked. This will have to be duly understood and reflected in all future work with regards to RIT (progressive autonomy) regulatory frameworks. The authors assert that further developments leading to the adoption of an international regulatory framework could certainly lead to an increased uptake in the use of RIT.

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CHAPTER 20

Towards an International Guideline for RIT End-Users: Spearing Through Vessel Inspection and Hull Cleaning Techno-Regulatory Elements

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1 Introduction: Setting the Scene

Over the last few years, discussions have taken place at various international fora in regards to RIT in performing inspections of steel structures on ships and floating offshore. Primarily, RIT represents systems based on machine learning that offer time-efficient and conceivably cost-effective

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alternatives to existing manual-driven survey and maintenance operations (Johansson, 2022). What is certain is that manual inspections could be replaced through the usage of UAVs, ROVs, magnetic crawlers, and any other technological apparatus approved by classification societies.

From a specific-functionality standpoint, UAVs are capable of performing general visual inspection (GVI), ultrasonic thickness measurement (UTM), and close-up surveys on ships requiring statutory and or classification surveys. On steel plates, magnetic crawlers could conduct UTM for scanning plates should there be restrictions to access a vessel's

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interior. Crawlers are also designed to perform hull cleaning. Finally, ROVs are tethered, maneuverable underwater robots that could perform tasks below water without the need for divers.

Noticeably, RIT have been approved by several flag State administrations on a case-by-case basis. National flag State authorities, classification societies, and ship owners are slowly but steadily adapting to RIT-based alternatives, especially during the COVID-19 pandemic that engendered special challenges and limitations of human-presence on board ships.

Currently, RIT mass deployment, should it continue to remain an international objective, calls for a holistic governance framework that could optimally dissipate fragmented methods and dissimilar procedural matters. In other words, the smooth integration of RIT alternatives for the conduct of dull, dirty, and risky tasks requires for the development and implementation of uniform international standards (Johansson, 2022). Targeting uniformity, generally speaking, means developing standards, policies, and guidelines that could stimulate innovation and safeguard people from risks emanating from automated technologies (Smuha, 2021). Given that the RIT governance framework is at nascent stages of development, the authors (of this chapter) assert that a blueprint covering all essential elements could help overcome regulatory barriers that may hinder RIT deployment resulting in a substantial and well-founded impact on the field.

Evidence-based research also indicates that efforts to maintain good environmental stewardship, principally at the EU level, will not only require seamless technical integration of RIT but also a guarantee that all techno-regulatory elements vital to semi-autonomous platforms are built into an international stand-alone *guideline for end-users* through international multi-stakeholder consultation. Ideally, all efforts should be aligned with the EU “Next Generation Digital Commission” of 2022, which aims at optimizing processes and automating workflows through the usage of digital technologies, products, and services with the view to increase productivity and digital sovereignty.

Against the foregoing, this chapter presents critical findings derived from project BUGWRIGHT2 which aspires to change the EU landscape of robotics for vessel structure-inspection and maintenance. The research-findings provide important insights into key elements that constitute a harmonized regulatory blueprint that could serve as a foundation for the anticipated international stand-alone *guideline for end-users*—bridging all potential gaps through cooperation-based strategic techno-regulatory governance founded on critical safety, security, quality, performance, and efficiency standards with regards to maritime semi-autonomous platforms.

2 Main Elements of a Regulatory Blueprint

At the outset, it is important to note that the threads of individual elements discussed below are tied to International Maritime Organization's (IMO) Strategic Directions (SDs):

- (SD 1) aiming at the efficient and consistent implementation and enforcement of the provisions of the IMO instruments;
- (SD 2) aiming at integrating and advancing technologies in the regulatory framework;
- (SD 3) intending to respond to climate change by reducing greenhouse emissions;
- (SD6) addressing human-element-related issues including consideration of new technologies and human-centered design; and
- (SD7) ensuring regulatory effectiveness in the development of advancing technologies (IMO, 2022, Resolution A.1149 (32)).

All elements have been carefully extracted based on the exposition of legal texts, international instruments, relevant scholarly literature, academic and professional journals containing legal opinions and expert commentaries, industry standards, procedures, requirements, and the likes. Expository research, i.e., an essential component of the doctrinal methodology, serves as the primary methodology employed in the research leading to this chapter. It is used to analyze the extant law (*de lege lata*) pointing out its drawbacks and deficiencies that has been thoroughly understood to determine what the law should be in the future (*de lege ferenda*). Needless to say, this approach highlights the continuum of past, present, and future in terms of the progress of the law.

2.1 Element 1: Compelling Evidence Redux

Effective and efficient environmental performance is the main principle that drives the world fleet's operation (Johansson, 2022). Observing increased fuel consumption and higher emissions emanating from the accumulation of harmful micro-organisms, the adverse effects of biofouling on ship performance and energy efficiency have been well documented (Adland et al., 2018; Coraddu et al., 2019; Deligiannis, 2017; McClay, 2015; Moser et al., 2016). The United Nations (UN) Climate Change Conference of the Parties (COP26) in Glasgow (2021) also stressed the need to mitigate biofouling build-up, which explicitly contributes to increased greenhouse gas emissions, together with technical and operational measures to reduce them. Therefore, niche sources and technological tools for environmental excellence and hull cleaning cannot be overlooked. It should be noted that IMO conventions are subject to continuous amendments. The introduction of risk assessment techniques, such as formal risk assessment or goal-based standards, paves the way for a new regime that might even embark on a decision to carry out surveys depending on risk profiles (Núñez, 2016). Secondary sources confirm that novel data detection methods, machine learning modeling techniques, and new technologies to diagnose hull and propeller fouling enable better asset management—giving the owners the means to predict hull condition and suggest the best time for hull maintenance work (Coraddu et al., 2019).

For vessel survey and inspection, including maintenance, stakeholders are currently focused on two technology-related aspects: RIT and remote survey. Inspection using RIT, for example, by default, requires physical verification through interaction with associated components. It goes without saying that the majority of vessel's class and statutory surveys require the physical attendance of class representatives. Remote verification, on the other hand, is an option that is exercised when physical attendance is not feasible or the extent of survey is deemed limited.

Published documents and online articles are a confirmation of the noteworthy shift towards technology-based alternatives due to their manifold advantages. For instance, it is noted in the document titled "Remote Technology Points to Cost Efficiency and Quality Gains" by Det Norske Veritas (DNV), AI-based alternatives are projected to save ship's operation time that makes up a significant portion of running costs (DNV, 2018). This is further validated by Bureau Veritas (BV) in an online article published in 2021 titled "Proving the Value of Remote Inspection Techniques" (BV, 2021). Patently, the outbreak of COVID-19 pandemic provided an impetus to test RIT. Nonetheless, the integration of RIT raises concern for the viability of common minimum standards developed by international organizations, especially when it comes to guaranteeing the same standard of safety and environmental protection, which is also related to liability.

Noteworthy are the "capex and opex" benefits that include: "reduced travel/accommodation costs; shorter response times; potentially quicker inspection and survey activities; greater scheduling flexibility; instant access to deep technical expertise; and less operational downtime" (Haukerud, 2020). In terms of the economical aspect—a cost–benefit analysis for an RIT-assisted survey was conducted by the members of the EU project titled ROBotics technology for INspection of Ships (ROBINS) (ROBINS, D 9.2, 2021). RIT-in-focus included UAV for close-up Inspection, magnetic crawler for thickness measurement, and ROV for close-up inspection/thickness measurement for hull inspection. The following costs were calculated in the analysis:

- Direct costs for the means of accessibility such as cherry pickers and temporary staging or portable ladders; and
- Indirect costs include (a) the improvements in the safety of the personnel in monetary terms (Probability of Fatal Accident, Probability of Non-Fatal accident, Compensation for Fatal Accident, and Compensation for Non-Fatal accident) and (b) the opportunity cost which is the time the ship stays idle (ROBINS, 2021).

According to the analysis developed solely for the market of large Bulk Carriers, a staggering €190 million could be saved by shifting to RIT-based alternatives (ROBINS, 2021). In sharp contrast, remote verification, dubbed as "remote survey", is contingent on information and communication technology (ICT) and has no direct correlation with costs.

Further research reveals that "remote survey" is, for the moment, associated with consideration of the following factors:

1. Instant accessibility and examination of the initial condition and assessment if physical attendance is required (or not);
2. Data record tracking and condition comparison with past maintenance records;
3. Sharing of data with multiple recipients and affected entities in real time;

4. Development of archives that maintain the data and can be used for research purposes (by shipyards, classification societies' technical teams, etc.), and
5. "Flag state acceptance" in case of statutory Surveys and that before any classification society can take a decision.

It is recalled that in shipping, the term "inspection" entails a plethora of dimensions. Some inspections are conducted for simple operational reasons, i.e., to improve the efficiency, while others bear a more commercial connotation, especially when it comes to chartering, insuring, or purchasing a ship.

Another important aspect concerns the understanding of "ship classification". In general terms, it is considered as being the development and worldwide implementation of a set of standard published rules and regulations that set and maintain quality and reliability. It is compliance with specific *class rules* that determine the class notation assigned to a ship and recorded in the register book. With that in mind, *classification* is a partnership between the flag state, class society, owner, and operator that collectively ensure the correct application of rules to endorse the:

- Structural strength of all essential parts of the hull and its appendages;
- Safety and reliability of the propulsion and steering systems; and
- Effectiveness of all features and auxiliary systems that have been built into the ship in order to establish and maintain basic conditions onboard, so that personnel and cargoes can be safely carried at all times.

To this end, class ensures that surveyors maintain the above through periodical visits to the ship with a view to carrying out corresponding periodical surveys to determine compliance with mandatory rules and regulations.

Relevantly, Enhanced Survey Programme (ESP) requires a close-up survey of defined structures in addition to an overall survey (see Fig. 1 below). It also requires an enhanced number of scantling thickness measurements. In order for these to be conducted properly, prior planning is in order so that tanks and holds are sufficiently clean with well-ventilated and suitable access arrangements provided. Considering the risk of entrance in confined spaces and the time required for those

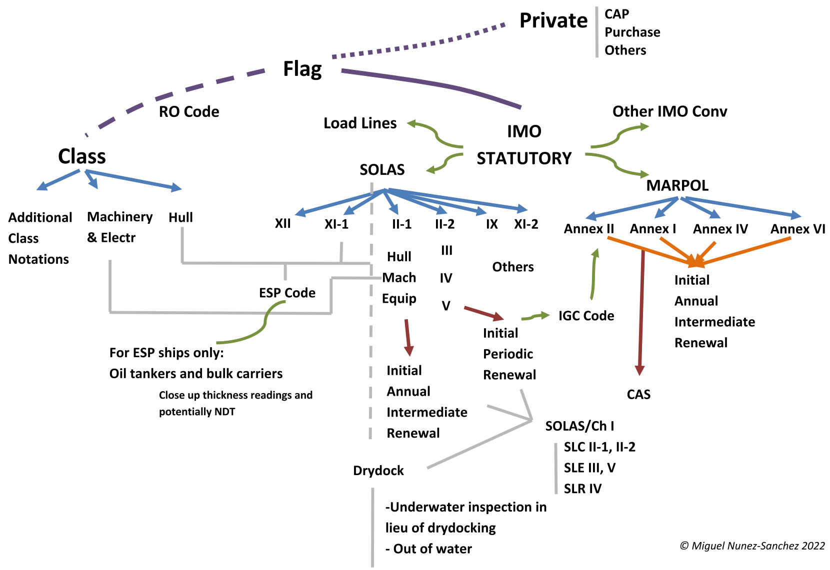

Fig. 1 Diagram synthesizing IMO's Statutory Survey Regime (*Source* Authors) *Note* **Remote Inspection Techniques** for underwater inspection, thickness readings, close-up and non-destructive testing with a need for planning, approval of service providers, validation, and certification; **Remote Surveys** with extreme due care or non-acceptance for structures with coating with a poor condition; and **Remote Survey Techniques** for all statutory and class inspections; and Remote Audit Techniques for verification audits

spaces to be effectively ventilated, as well as the associated costs, alternative methods of remote inspections are taken into account. Taking advantage of the digital tools and processes that are the byproducts of the fourth industrial revolution, DNV and other classification societies have incorporated drone surveys into class services. It should be underlined that drones used for these inspections are intrinsically safe for gas hazardous areas, and operated by trained surveyors. Drones are equipped with high-definition cameras and are able to provide high-resolution video and images even in the absence of light.

The biggest advantage of remote inspection using drones is the opportunity to carry inspection in real-time. The results are reviewed and recorded by the surveyors and vessel's representatives in a safe environment. Obviously, if the inspection reveals issues of concern, then there is a provision that enables surveyors to revert back to traditional physical inspection.

The statutory survey, if carried out by a class surveyor, is being conducted on behalf of the Flag Administration for the country with which the ship is registered. The class survey is carried out on behalf of the classification society itself.

The requirements of the statutory survey are governed by the flag administration and not classification society promulgated rules and requirements. As with statutory surveys, all associated services such as approval of intact and damage stability and approval of safety equipment arrangements offered by the classification society are conducted on behalf of the flag administration.

In most cases, the statutory instruments used for the survey of ships are based on the internationally adopted codes and conventions covering subjects such as safety construction, safety equipment, safety of navigation, pollution prevention, load line, and safety management. It is worth noting that even countries that have adopted international convention codes may, in addition, develop and implement respective national requirements that are commonly known as "flag requirements" (Fig. 1).

The practice of taking thickness readings in conjunction with close-up and hull inspection is delegated to companies authorized either by the Flag administration or the classification society in compliance with the International Association of Classification Societies' (IACS) unified requirement (UR) Z17. The surveyor progresses rapidly during the inspection and with results of the thickness readings reviewed only after a few hours—most likely on a daily basis. With regards to the underwater survey, the divers are normally on the spot and there is visual and audio communication with the surveyor that is on board, or in case of broadcasting in front of his computer, to certify the inspection of the underwater body in case the ship has not been drydocked.

2.2 Element 2: Uniform Definitions

The minimum standard definition of RIT has been specified in s. 1.1 of IACS Recommendation 42. Taking into consideration the evolving nature of innovation, the current types of RIT endorsed by IACS will inevitably branch out into other expeditious complex systems, making the development of unified definitions necessary for each and every type of technique that maneuver in different environments (Johansson, 2022). Table 1 (below) provides a summary of the definitions that currently exist and ones that could set the pragmatic basis for umbrella/uniform definitions for all future varieties.

Table 1 Summary of existing definitions relevant to RIT

Autonomy	*Ability to perform intended tasks based on current state and sensing, without human intervention (ISO 8373:2021)*
Robot	Programmed actuated mechanism with a degree of autonomy to perform locomotion, manipulation or positioning (ISO 8373:2021)
Operator	Person designated to start, monitor and stop the intended operation (ISO 8373:2021)
Validation	Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use have been fulfilled (ISO 8373:2021)
Verification	Confirmation by examination and provision of objective evidence that the requirements have been fulfilled (ISO 8373:2021)
Unmanned Aerial Vehicle (UAV)	An aircraft with no pilot on board that is controlled remotely or can fly autonomously based on a predefined flight route and/or using dynamic automation systems. The industry may refer to Unmanned Aerial Vehicles as "drones", Remotely Operated Aerial Vehicles (ROAVs), or Unmanned Aircraft Systems (UASs) (ABS, 2022)
Remotely Operated Underwater Vehicles (ROVs)	An ROV is an unmanned unit designed for underwater observation, survey, inspection, construction, intervention, or other tasks. Like UAVs, an ROV can be remotely controlled or programmed to travel a predetermined route using the information on a specific asset's condition to target known areas of concern. It can collect visual data, perform Nondestructive Testing (NDT), and measure plate thickness in difficult to-reach areas. (ABS, 2022)
Robotic crawler	A robotic crawler, commonly referred to as a "crawler", is a tethered or wireless vehicle designed to "crawl" along a structure using wheels or tracks. Crawlers are often equipped with magnets to operate on a vertical or inclined surface or hull structures in air or underwater (ABS, 2022)

Source ISO 8373:2021; ABS, 2022

2.3 Element 3: Remote Survey vs RIT

The main IMO Conventions such as International Convention for the Safety of Life at Sea, 1974, International Convention for the Prevention of Pollution from Ships (1973/1978) (MARPOL) and the International Convention on Load Lines, 1966 (CLL) do not deal with "remote survey" because, by default, surveyors should be physically present on board to carry out inspections. While this does not hinder resorting to "remote survey", however, there are legal aspects for consideration due to the fact the ship is certified by flag administration.

The role of recognized organization (RO) surveyors acting on behalf of flag administrations was befittingly reflected in the Protocol of 1988 relating to the International Convention for the Safety of Life at Sea, 1974, the Recognized Organization (RO). It is also stressed that the administration bears all responsibilities even when the work is delegated to a RO. Therefore, the concept of remote surveys could be extended to statutory surveys but it should, nevertheless, remain grounded within the IMO Conventions. Firstly, the use of low-level voluntary instruments, such as circulars with interim guidance might be extended to voluntary resolutions, and, at the latter stage, into mandatory ones once the system is in place and safeguards safety and environmental protection level remain the same. The above serves as important information in the context of "remote survey".

To ensure that all classification societies have uniform guidance on the concept of remote surveys, IACS developed UR Z29 titled "Remote Classification Surveys" (that will enter into force on 1 January 2023), which conceptualizes remote survey as a "process of verifying that a ship and its equipment are in compliance with the rules of the Classification Society where the verification is undertaken, or partially undertaken, without attendance on board by a surveyor" (IACS UR Z29, 2022). In short, and as briefly mentioned before, a "remote survey" denotes the survey conducted via the use of ICT, such as email and zoom, without the requirement of the physical presence of the surveyor. In the process, a remote survey should provide the same level of assurance as a survey with physical attendance on-board of a surveyor.

It is also important to bear in mind that certain audit activities, known as verifications, are carried out by the flag administrations or the RO acting on their behalf. These are mainly connected to safety aspects in relation to the ship and the company (document of compliance) under

SOLAS IX and the International Safety Management Code, and *security* aspects under SOLAS XI-2 and the International Ship and Port Facility Security Code, 2004 (ISPS Code). Since there exist several standards for remote audits—they could be also carried out for ships and companies, provided that risk assessments permit them. According to the authors, the same approach towards their introduction in SOLAS and MARPOL should prevail.

When the focus is on RIT, one could turn to s 1.1 of IACS Recommendation 42 that provides: "Remote inspection techniques may include the use of: Divers; Unmanned robot arm; Remote Operated Vehicles (ROV); Climbers; Drones; Other means acceptable to the Society". Section 1.2 further stipulates that external and internal examinations require the presence of a surveyor. In short, RIT could be identified as technologies that allow external and internal examinations through close-up surveys and thickness measurements (where applicable) without the need for direct physical access of the surveyor. Authors observe that currently, both RIT and "remote survey" are used interchangeably, although the former refers to robotic platforms, and the latter being survey via ICT, and as such does not entail mobile robotic platforms. Moving forward, researchers assert that the following points should be taken into account in all future discussions:

- The inherent differences between RIT and "remote survey" must be preserved so as to refrain from using the two terms synonymously. A way forward could be to develop separate all-embracing definitions on RIT, remote survey and remote audit (see Table 2 below);
- S. 1.2 of IACS Recommendation 42 should be revised and/or complemented with other IACS instruments so as to allow remote surveys using RIT to be conducted without the physical presence of the surveyor being mandatory, for classification purposes. The word "attending" should be omitted, and the word "may" be replaced with "should" so as to provide sufficient flexibility. Given that remote surveys could be surveys conducted using RIT, it is advised that RIT procedures concerning the engagement of surveyor be left open-ended; and
- Remote surveys and audits for IMO statutory certification, either total or partial also need to be agreed upon at the level of the IMO after careful consideration following a step approach (Table 2).

Table 2 Conceptualization of RIT, remote survey and remote audit

Remote Inspection Techniques (RIT) may include:	(i) The use of unmanned robot arm, remotely operated vehicles (ROVs), climbers, drones, or any other techniques acceptable to the Society (ref: IACS Recommendation 42, s. 1.1); (ii) The use of: Divers, Unmanned robot arm, Remote Operated Vehicles (ROV), climbers, drones, other ther means accepted. (ref: ABS, 2022); and (iii) Inspections performed using (a robust system governing the deployment of) techniques mentioned in (i) may be carried out in the presence of the Surveyor (ref: IACS Recommendation 42, s. 1.2)
Remote survey	A "Remote Survey" is a process of verifying that a ship and its equipment are in compliance with the rules of the Classification Society where the verification is undertaken, or partially undertaken, without attendance on board by a surveyor (ref: IACS UR Z29, s. 1.2.1)
Remote audit	"Remote Audit" means a process of systematic and independent verification without being physically present at the site of the audited party, and through the collection of objective evidence through available online tools, to determine whether the Safety Management System (SMS) complies with the requirements of the ISM Code and whether the SMS is implemented effectively to achieve the Code's objectives (modified with ref. to: s. 1.1.1 IACS, Procedural requirements for ISM Code Certification)

Source Adapted from ABS, 2022; IACS recommendation 42; IACS UR Z29 and IACS, Procedural requirements for ISM Code certification

2.4 Element 4: Operational and Technical Considerations Based on Variety

The operational and technical differences that stem from the different types of RIT should be considered when developing standards for these technologies. The objective here is twofold: (i) to set a framework for determining operational limitations; and (ii) as a minimum to get the same level of results that a physical inspection would provide. It is important to note that the American Bureau of Shipping (ABS) has identified different operational challenges for UAV, ROV, and robotic crawlers, which might serve as a model framework should discussions, at any time, lead towards the development of an international stand-alone *guideline for end-users*:

- **Pre-operations**: Items to be discussed during the short briefing session, such as, reviewing weather forecast (AUV), confirmation of enclosed space free of sediments (for ROVs), reviewing RIV maintenance records, reviewing emergency escape/evacuation plan, reviewing identified risks and associated mitigation, verifying the responsibilities of all personnel, assessing field conditions and amending operation plans as deemed fit, and confirming the work-scope of intended RIT operation, and as a part of job safety analysis on the date of the field operations, but prior to the; commencement of the RIV operations, inter alia (ref: ABS, 2022);
- **In-operation**: Items to be included by the service Supplier in the Standard Operation Procedure (SOP) for each RIV, e.g., checklist clearance, RIT Launch, and Recovery Zones, Communication, Documentation, Visual Line of Sight for UAVs, Deconfliction for UAVs, in the Standard operation Procedure by the Service Provider (ref: ABS, 2022); and
- **Post-operation** considerations including logging and maintenance (including launch time, operation duration, recovery time, and the type of work completed) (ref: ABS, 2022).

What is noteworthy is that there are various hazards associated with UAVs, magnetic crawlers, and ROVs that should be considered while expanding operational standards. ABS (2022) has categorized the risk areas as follows: explosion risks in hazardous areas, dropped object risks, Collision risks, Lost link risks, other risks consisting of high-risk working areas, risk associated with other parallel operations, and emergency situations. China Classification Society (CCS) has also specified technical standards for UAVs that touch upon safety performance, operation performance, enduring capacity, data transmission and communication, and data storage (CCS, 2018). The Risk Assessment Report, according to CCS, should be compliant with the ship's hazardous area plan and agreed upon by the shipowner/operator class society and service supplier prior to the commencement of inspection. A noteworthy technical issue (related to operation performance) that needs to be addressed is one that concerns "connectivity". RIT-based remote surveys require high-speed internet connection, which to date, remains a challenge on board vessels, especially in certain trading areas.

2.5 Element 5: Degree of Autonomy

The degree of autonomy is relevant to systems under progressive autonomy. The current technical system governing RIT, as of 2022, is not fully autonomous and requires intervention from the human element. The current stage of RIT is subject to "supervised autonomy" or "semi-autonomy" given that an operator is involved in operating the technology in question remotely. In order to keep track of progress (towards full autonomy) and in order to harmonize standards based on categories and types of RIT (followed by future amendments, if required)—the "degree of autonomy" or the "level of autonomy" for the current system should be conceptualized.

It is noted that RIT could be fully autonomous in the not-so-distant-future, and be able to function without human involvement. The "degree of autonomy" is a stress on carving out the level of the autonomous systems in a fashion similar to what has been done for maritime autonomous surface ships (MASS) (IMO Doc. MSC 100/20/Add. 1, Annex 2). Such categorization (Table 3 below) or assigning RIT to a certain "degree" could help keep track of the advancements towards full autonomy, thereby, assisting classification societies with future potential revisions (Johansson, 2022).

2.6 Element 6: Data Governance and Cyber Security

High-definition cameras, artificial lighting, high-precision sensors, and 3D scene reconstruction models are paramount to data quality. High-quality data plays an important role in detecting vessel's structural defects (Pastra et al., 2022). In digital data such as photos, live-stream, and recorded video, data are the predominant outcomes of conducting inspection using RIT. In this process, "metadata" could also be generated which includes time/date stamps, GPS location, camera orientation, focal length, shutter speed, aperture setting, ISO level, camera type, and lens type (ABS, 2022, 9).

Based on the different types of data generated, authors assert that a data governance framework could be developed to establish provisions and processes that could offer adequate and appropriate protection to data-assets as they are relayed between and among the different stakeholders (Al-Badi et al., 2018; Sarsfield, 2009).

Table 3 Categorization of RIT based on MASS degree of autonomy (hypothetical comparison)

Degree/Level of autonomy	*MASS*	*RIT*
First Degree	Ship with automated processes and decision support with seafarers on board to operate and control the systems. Systems are partially automated, unsupervised with seafarers on board ready to assume control	RIT-survey conducted in the presence of the attending surveyor. This degree aligns explicitly with IACS Recommendation 42 and IACS UR Z17
Second Degree	Remotely controlled ship with seafarers on board	Remote class survey with the possibility of surveyor to intervene, if necessary
Third Degree	Remotely controlled ships without seafarers on board	Remote class survey without attending surveyor
Fourth Degree	Fully autonomous ship	RIT with automated processes and Artificial Intelligence-based machine learning operating systems to support decision-making

Source Authors (with reference to IMO Doc. MSC 100/20/Add. 1, Annex 2)

Data governance has been conceptualized by the Data Management Association (DAMA) as "the allocation of authority and control and shared decision making over the management of data assets" (Earley et al., 2017). By way of explanation, data governance is related to decisions in regards to the allocation of responsibilities, access, control, and use of data, as opposed to data management, which is primarily linked to data collection and protection, as well as the implementation of governance-related decisions (Johansson et al., 2021).

Johansson et al. (2021) underscore that data quality, data ownership, preservation entity, security measures, sharing, data lifecycle, copyright, and data liability are the terms that should be included in the contract-form that is executed by ship owners, classification societies and service suppliers (Fig. 2 below). The roles and responsibilities concerning data ownership, quality, storage, security, and sharing of information currently remain uncatered for and requires an in-depth review of all private contracts developed by service suppliers. What is currently absent is a

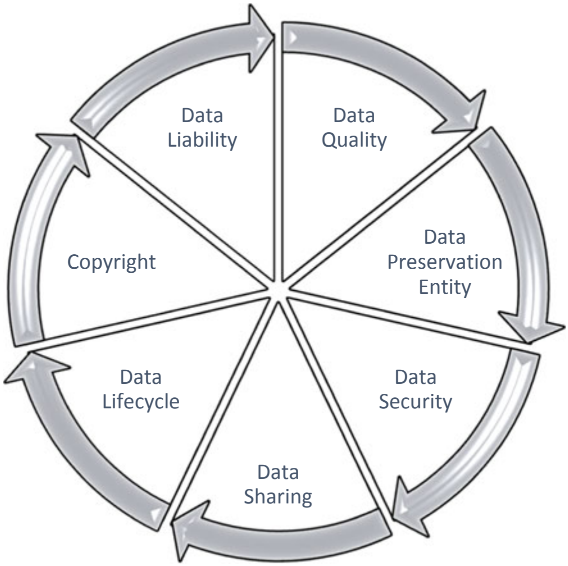

Fig. 2 Data elements to be included in the Contract between service suppliers, classification societies, and asset owners/operators (*Source* Johansson et al., 2021)

reliable instrument that ensures the long-term usability of data and metadata and protection from being misused by third parties (Johansson et al., 2021). Furthermore, the key parties in RIT inspection planning, operation, and reporting stages are advised to utilize a trusted data platform to safeguard the data generated through the systems. Data security and the effectiveness of data collection, data processing, and distribution of analysis outputs need to be demonstrated through further tastings and checks in order for RIT platforms to achieve trustworthiness among the stakeholders of the business model (Johansson et al., 2021; Pastra et al., 2022).

Additionally, data-sharing of confidential audio and visual information by remote means requires sufficient protection against cybersecurity threats. To avoid unforeseen challenges pertaining to non-personal asset-data, it is important to consider the above with reference to the following five concurrent functional elements that bolster support to effective cyber risk management:

- **Identify:** Define personnel roles and responsibilities for cyber risk management and identify the systems, assets, data, and capabilities that, when disrupted, pose risks to ship operations;
- **Protect:** Implement risk control processes and measures and contingency planning to protect against a cyber-event and ensure continuity of shipping operations;
- **Detect:** Develop and implement activities necessary to detect a cyber-event in a timely manner;
- **Respond**: Develop and implement activities and plans to provide resilience and to restore systems necessary for shipping operations or services impaired due to a cyber-event; and
- **Recover:** Identify measures to backup and restore cyber systems necessary for shipping operations impacted by a cyber event (IMO, 2017).

The same would also apply for the protection of the integrity of the data when surveys and audits are carried out via remote means with audio and video end-products. For instance, when SOLAS XI-2/ISPS security verifications are executed, there are documents, such as the ship or port security plan, which are confidential in nature. If those are discussed via video conference, the integrity of the ship or the port facility being audited or inspected may be compromised in the absence of stringent measures against cybersecurity threats. It should also be mentioned that IMO Resolution MSC.428(98) requires actions to ensure that safety management systems take into account cyber risk management in accordance with the objectives and functional requirements of the International Safety Management (ISM) Code, no later than the first annual verification of the company's "document of compliance" after 1 January 2021.

2.7 Element 7: Liability and Safety

There is also a crucial narrower focus: policymakers ought to shape the regulatory conditions having the best interest of end-users in mind so as to ensure accountability for software and product development. Product safety and product liability are two complementary mechanisms that ensure high levels of safety and minimal risk of harm to users. Robotics and Autonomous Systems (RAS), such as autonomous vessels, autonomous vehicles, or RIT, are merely "products". Defective products, incur liability, and ergo, the functional approach could be to apply a legal framework to govern the usage of products (Alexandropoulou et al., 2021).

Risks ranging from dropped objects, collision or lost link, and defective products, inter alia, make it more urgent to solve RIT-induced liability issues through existing regional or national policies, for example, the EU Product Liability Directive 85/374/EEC (EU Product Liability Directive, 1985; Johansson, 2022). RIT is operated using (battery-produced) "electricity"—that is viewed as a product pursuant to Article 2 of Directive 85/374/EEC (Johansson, 2022). Although this needs to be further substantiated, the preliminary connection is clear. According to Article 1 of the Directive, the producer shall be liable for damage caused by a defect in his product. Article 7 of the Directive gives resorts to the defense mechanism of manufacturers, stating that the producer shall not be liable as a result of this Directive if he is able to prove:

a) that he did not put the product into circulation; or
b) that, having regard to the circumstances, it is probable that the defect which caused the damage did not exist at the time when the product was put into circulation by him or that this defect came into being afterward; or
c) that the product was neither manufactured by him for sale or any form of distribution for economic purpose nor manufactured or distributed by him in the course of his business; or
d) that the defect is due to compliance of the product with mandatory regulations issued by the public authorities; or
e) that the state of scientific and technical knowledge at the time when he put the product into circulation was not such as to enable the existence of the defect to be discovered; or
f) in the case of a manufacturer of a component, that the defect is attributable to the design of the product in which the component has been fitted or to the instructions given by the manufacturer of the product (Directive 85/374/EEC).

The original equipment manufacturers (OEMs) of RIT could follow internationally agreed and accepted requirements for safe commercial operations, such as standards developed by the International Organization for Standardization (ISO). Whether a manufacturer is liable will depend on the circumstances and whether relevant international or industry product specification standards have been violated. During the design phase, manufacturers of RIT should exercise due diligence to ensure that connectivity will, under no circumstances, compromise safety (of the product) or data accuracy. In tandem, manufacturers should ensure transparency, accountability, and responsibility for all intelligent information systems that are developed. Certified products following international standards should be provided by manufacturers and subsequently, deployed by end-users. From an RIT perspective, service providers/suppliers should ensure prescribed equipment safety standards for hardware and software. All systems should be rated against the intended operational environment (intrinsically safe in hazardous areas, operational wind speed, etc.).

At this juncture, it is important to note that any progress in terms of "degree of autonomy" inevitably raises the question of who is responsible if RIT should violate a contractual obligation; therefore, clarity on responsibility in connection with the use of remote systems is a requisite. Clearly, embedded provisions in the contract should specify the liable party (manufactures, developer of the AI system, or pilot of the drone) in different scenarios when an RIT operated by a pilot, or fully autonomous RIT drops, crashes, and causes damage. The different scenarios include but are not limited to collisions with asset structures, collisions due to malfunction of the equipment, or unexpected or unforeseen incidents occurring in cases where visual line of sight (VLOS) is not maintained.

Regardless of how provisions on liability take shape in the long run, service suppliers should secure third-party public liability insurance and professional indemnity insurance for protection against legal liability for third-party property damage or injury while using RIT.

2.8 Element 8: Determine "Proof of Concept"

Improving technical reliability and confirming/determining the "proof of concept" of functionalities of the remote survey could be achieved after conducting more live experiments in a controlled environment. Classification societies, once RIT witnesses mass deployment, should ensure that these technologies are robust, and are able to accomplish quicker, safer, and more efficient ship inspections. In short, the validity of these systems will be concretely substantiated if technical robustness and data quality are demonstrated (Pastra et al., 2022). For the former, i.e., technical robustness, systems should function properly and be able to reproduce the verbatim results if the operation is repeated should that fall under the scope of "confirmatory survey" in the future, timeliness, completeness, and credibility (Johansson et al., 2021; Khatri & Brown, 2010). The final step could be to initiate validation of the final output through a series of tests on different types of vessels during close-up inspections and statutory surveys. The results should be compared and contrasted with data gathered through results gathered from physical surveys.

2.9 Element 9: Risk Assessment Framework for Determining the Feasibility of Remote Survey

A strategic risk assessment process could be adopted whereby a common risk assessment framework for the eligibility of remote survey should consider the following elements: the age of the vessel, port state control history, class history, hull condition, and severity of corrosion on hull structure, type of survey, areas to be inspected, ship location, environmental conditions in the area, approved service supplier and well-trained surveyors on remote technologies (Fig. 3 below).

The feasibility of carrying out statutory inspections with RIT should not only depend on ship parameters, e.g., age, historic records, and sister ships, but also on company aspects, e.g., records of deficiencies and trust between the company and administration. Considerations ought to go beyond legal risk parameters. In the case of statutory surveys, for example, there is a need to ensure that all is in good order conditions for carrying out a remote survey satisfactorily. In terms of complexity, stakeholders should be cognizant of whether any special planning is required bearing in mind the "special planning" prerequisites for special surveys with regard to oil tankers and bulk. The survey planning for the above takes into consideration how and where close-up inspections, together with thickness measurements will be carried out. The document is signed or accepted by the company so as to allow for the survey to start. When it comes to remote surveys, planning becomes even more critical because of the need to ensure that the results would be equivalent to the results obtained from manual/physical inspection. Failure to provide the desired quality would increase risks that will have a negative implication on costs.

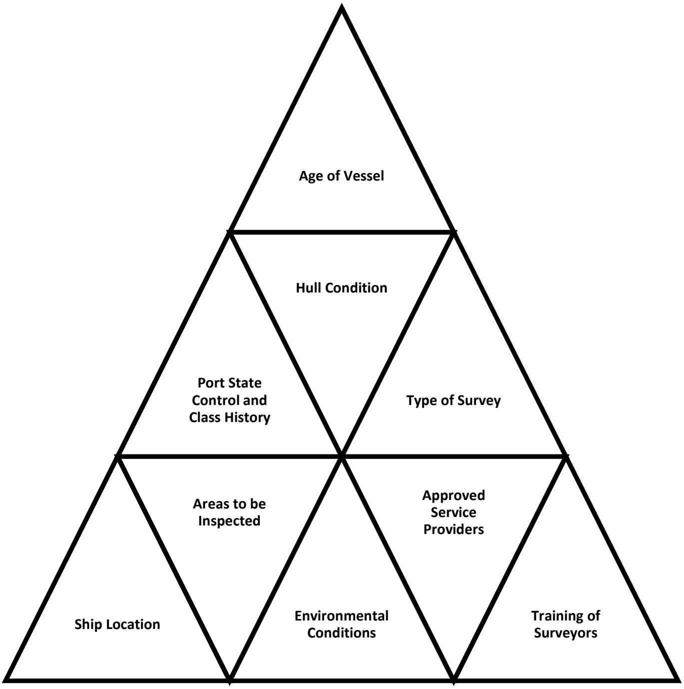

Fig. 3 Considerations when assessing the feasibility of the remote survey (*Source* Authors)

2.10 Element 10: Allocation of Responsibilities

Each party during the different stages of the remote inspection process (planning, operation, reporting) should have clear roles and responsibilities. For example, during the planning pre-inspection phase, the ship owner/operator must determine, in consultation with the class, if the use of RIT is appropriate, and if this is the case, then a recognized service supplier should be appointed (ABS, 2022). The supplier ought to develop the inspection plan that includes the different types of RIT to be used coupled with the results of the risk assessment, whereas the class should review the "survey planning document" provided by the ship operator and verify that the survey plan satisfies the applicable rules (ABS, 2022).

During the second stage of the inspection process, the service provider should conduct the inspection according to the "survey planning document", and the attending class surveyor must ensure that the RIT operation team conducts the survey according to the relevant requirements (ABS, 2022). In the reporting phase, the service provider shall send the report and data to the asset owner and class to assess if a physical or additional inspection is required (ABS, 2022).

3 Conclusions

RIT includes the possibility of effective examination of vessel structure without the need for direct physical access by the surveyor. Remote surveys may be applied to satisfy both statutory and classification requirements during normal situations and force majeure. Markedly, currently, other than procedural requirements stipulated by IACS, no specific international guidance covers the fundamentals of remote surveys/inspections, remote audits, and verifications.

IMO has recently embarked on the development of guidance for assessments and applications of remote surveys, ISM Code audits, and ISPS Code verifications, with 2024 as the target completion year. This may likely result in amendments to current instruments such as Survey Guidelines under the Harmonized System of Survey and Certification (HSSC), 2019 (Resolution A.1140(3)), or guidelines to other security-related instruments, where appropriate, with reference to IACS rules and requirements (ref: IACS Recommendation 42 and IACS UR Z29) to streamline the usage of remote inspection techniques. This would serve the purpose of establishing a strong foundation for moving forward with the conduct of remote surveys since RIT remain at the crux of all surveys conducted off-site.

It should also be noted that IACS UR Z29 on remote survey, which was issued in March 2022 and will be uniformly applied by IACS Societies for remote surveys commenced on or after January 1, 2023, could set the foundation for suitable procedures and instructions for RIT under the purview of its regulations. It is essential to proceed with a different mindset that could assist stakeholders to comprehend the topic, explore different ways to approach it, set a strategic basis for RIT, and finally, move forward towards class certification.

In parallel to the above, policymakers could consider developing and harmonizing existing flag state-initiated practices, given that all IMO rules and requirements concerning survey/inspection are aimed at flag States that can then delegate responsibilities to classification societies. Fragmentation in methodologies for remote surveys must be avoided at all costs. Uniformity contributes to certainty that in turn, is an acknowledgment that technology-policy interface developments are keeping pace with innovation.

The authors stress the need to assess the feasibility of remote surveys adopting a case-by-case approach. In that very process, it would be important to develop training and certification requirements for personnel involved in the conduct of remote surveys. The current IACS rules and requirements for RIT take into account the role of the attending surveyor, which is quite different from remote surveys given that the physical presence of the surveyor is not obligatory.

In conclusion, service robots pave the way for a service revolution that will dramatically improve customer experience, service quality, and productivity (Wirtz & Zeithaml, 2018). Within this context, responsible innovation practices and measures, call for strategic stakeholder engagement (Leenes et al., 2017). Through the process of testing, learning, and reflection, different stakeholder groups should join forces to fill the current vacuum (identified in this chapter) by drafting an international stand-alone *guideline for end-users*. Innovation cannot be contained. As it progresses, a guideline would certainly assist in governing niche incidental areas that could otherwise detract from unleashing the full potential of the byproducts generously bestowed by the fourth industrial revolution. The maritime and ocean community could certainly benefit from autonomy-renaissance. Much work lies ahead.

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PART V

Tying the Threads

CHAPTER 21

Smart Ports and Robotic Systems: Where Is It All Going from Here?

Paul Topping

1 Introduction

While fully autonomous or crewless vessels are some time off in the future, smart ports and robotics are growing in use every year. Broadly, both approaches represent a growing use of automation in the maritime industry. Activities that once required people to carry out tedious and repetitive tasks or to be put in harm's way are now being replaced by automated systems. These systems can be either automated sensors or networks that collect data and carry out analysis for reporting, oversight, and management, or robotic systems that perform tasks in hazardous environments or tasks that pose higher risks for crew injury or fatigue. With global labor shortages for the marine industry, the use of automated systems often supports the work of humans rather than replace them (Ng et al., 2014). As with any new technology, these systems can both help

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with current regulatory compliance in some fields or see the emergence of new regulatory conflicts in others.

2 Smart Ports

Ports are the interface between ships and land-based transport modes and are essential links in global supply chains. From a global trade view, their primary goal is to ensure maximum throughput efficiency both to move imported cargo in land and exported cargo to international ships. From a domestic trade view, ports also provide the same modal interfaces as waypoints for domestic ships to move cargo within a country's borders. Other key goals of ports are to maintain their assets (cargo equipment, vehicles, infrastructure, etc.), manage asset upgrades and replacements, ensure the port complies with environmental standards and local regulations (run off, wastes, GHGs, land use, labor, development), and manage concerns with neighboring communities (noise, light pollution, dust, traffic congestion).

Smart ports use electronic communication technologies throughout their operations to gain insights to improve performance to meet these goals. Many ports have examined advanced warehouses to learn lessons but how to best use technology. Key technologies revolve around communications and the Internet of Things where cargos are no longer static objects sitting in the port of waiting final destinations, but with Radio Frequency Identification chips (RFIDs) can become "live" objects broadcasting their precise location in the port, their contents, if hazards are present, their status of their journey, their current condition (e.g., temperature) and destination. All this information can aid a port to prioritize movements of cargo and coordinate between modes. It also allows ports and ship owners to offer cargo owners options to see progress of their shipment, which influences related business transactions, and can provide added value to various actors in the supply chain. Such information also can benefit cargo facilitation procedures, namely, to aid efficient timing of required customs inspections and other regulatory tasks.

Ideally, smart ports are managing a ballet of ships and cargoes to ensure as cargoes clear the port, new cargoes go from ships to trains or trucks, and in turn trains and trucks can also enter and move smoothly to their destinations. In smart ports, the exchange of data begins well before a ship, truck, or train arrives. When cargoes leave their origin to journey the port, communications begin to share data on each other's status. Are berths available? When will there be openings? Is the ship late or early? Is the train delayed? Are ship inspections or cargo inspections required? These factors as they arise can then be relayed to port managers and to other ships, trains, and trucks that would receive the cargo and move it onto its final destination. This open communication between all actors in moving the cargo allows them to prioritize when to deploy their assets. If a ship is delayed, advanced notice can allow a trucking firm to prioritize other clients.

The technology just discussed helps make ports more efficient, what makes these ports "smart" is data collection and analysis. As sensors and RFIDs continuously broadcast data (at whatever rate—hourly or more frequently), the vast quantities of data they generate are captured into port databases and analyzed by artificial intelligence systems (AI). The vast quantities of data can yield trends that AI systems can identify and provide a basis for predicting future conditions. This means port managers are not only provided when births are currently available, but rather have predictions of when births will be available when cargos arrive between a week and up to a month later. This allows better scheduling of assets plans, such as coordinating when to take a crane offline for maintenance with expected low periods of activity.

Each port is different there is no one standard model to develop these systems (Ravetz, 2013). A smaller port may serve a single factory, larger ports may host a broad range of terminals with different trades and client requirements. The concept of smart ports is enabling ports to gain a better understanding of their cargo ebbs and flows over time and manage to attune operations accordingly.

An AI-driven data system that predicts both ship traffic and partnering truck and train traffic can minimize the need for these anchorage arrangements by enabling a berth reservation system. Many ports around the world now advise ships weeks in advance when a birth is available and offer specific time reservations. Once accepted, the captain now knows when they need to arrive and can plan their voyage accordingly for a just in time arrival. A "just in time" arrival allows ships to optimize speed, maximize fuel efficiency, and eliminates the need to waste time waiting for a berth at an anchorage.

The efficient movement of goods through the port enables efficient transport reduces greenhouse gases, and allows ports to work better with neighboring communities. Smart ports can be better equipped to manage concerns of their neighboring communities, such as ship traffic congestion that conflicts with shoreside residents. This congestion can impact nearby residents when ships at anchorages run engines for power or when, at night, they need to illuminate their deck spaces.

Of course, all of this is an idealized potential goal. This is what AI and big data analysis aim to achieve. Reality can still be different. Surprises happen and delays at anchorages can still occur. However, a smart port can be better equipped to manage these challenges.

2.1 Challenges for Smart Ports

Much like ship owners, ports face multiple cost challenges. Many ports can be severely restricted in terms of how much they can finance, when they can do construction, environmental review processes for new projects, and environmental mitigation measures. Ports can be subject to multiple orders of government and multiple agencies often with competing agendas. Ports that do not pay attention to their neighboring communities often find themselves facing more challenges when seeking approvals to upgrade or undertake new construction (European Parliament, 2009).

Adopting these technologies to bring about a smart port carries the same risks as adopting any new technology. What is the maintenance cycle? Are upgrades always needed? How secure are the transmissions? Do they interfere with other networks? How secure are the AI databases? How many people have access to these databases? What are the threats, systemic, natural, and human?

Large ports also face pressure to reduce their greenhouse gas emissions and many are working to switch to electric-powered vehicles and cargo-handling machinery. Electric vehicles and equipment are more amenable to automation, are quieter, and generally have zero emissions (Cargo dust aside). This brings other questions: Can the port's electrical utility providers meet demand? Can the port's electrical management systems meet the energy flows for the new electric equipment along with all the AI systems being implemented? Does the port need new generator units? Should it adopt wind, solar, or tidal energy systems to provide electricity? All of these questions can bring significant costs to any smart port project.

2.2 *Port Authorities and Partners*

Many port authorities around the world operate as landlords who also facilitate ship, rail, and vehicle movements within their boundaries. Such port authorities themselves do not directly carry out cargo operations between ships and other modes of transport. Hence, a key question to bring about smart port is what is the relationship between the organization advancing a smart port initiative and other organizations operating within the port.

A private terminal seeking to improve cargo flows through a smart port system may not get support from a Port Authority if they believe that the terminal's proposal impacts other clients within its boundaries. Similarly, a Port Authority seeking to promote such a system for wider efficiencies may face resistance from tenant terminal owners who may see the measure as a cost exceeding what is in the lease contract.

Smart port systems are being developed around the world so while these issues are serious, complex, and can be very difficult to manage, they are not insurmountable (Ravetz, 2013). Like any good partnership, setting out clear agreements and expectations between the partners play a key role in the success we have seen so far. Importantly, smart ports are in early stages of their evolution, no port can implement these technologies overnight, so they will see automated and digitized elements interacting with traditional elements that lack these technologies.

3 Robotic Systems

Many industries are seeing the advent of robotic systems; with some embracing them and others being more cautious. Images of many factories decades ago would show hundreds or thousands of workers toiling on assembly lines. Today in many factories we still see people, but working with robots, with their robotic arms endlessly undertaking a ballet of repetitive tasks, welding the same welds, attaching the same bolts, 24/7, with seemingly endless precision. Of course, that did not happen overnight, and things are much more complicated than that.

Most of us can understand what a robot is; a machine performing a task on its own, it may have some kinds of limbs to manipulate things, or it may not. Robotic systems can involve multiple robots—such as robots an assembly line—or a single robot that works over a wide area—such as an automated warehouse—where goods are stored and moved by autonomous machines controlled by a centralized system.

The marine industry is definitely one of the more cautious industries, but robotic systems on board ships and in ports are emerging. Robotic systems are taking on repetitive or dangerous tasks and saving time for human crews (Ng et al., 2014). Like all new technologies, its early adoption phases face challenges. Some are technical teething pains others are legal, since regulations often do not keep up with technology—an observation across most industries over the centuries.

3.1 Remote Inspections

An emerging class of robots in the marine sector enabling remote inspections. Companies have adopted drones and remote underwater vehicles fitted with cameras to carry out hull inspections above and below water. Most of these systems are not autonomous but are subject to control by a person operating in a relatively safe control area instead of being lowered over the side of the ship or having to dive underneath the keel in shallow depths, with low visibility, typical of many ports.

These systems can provide a thorough overall picture of a ship's hull. Some can also be fitted with additional sensors, such as X-rays or visual magnifiers, to detect cracks or micro-fractures in a ship's hull that the naked eye would not find. Some drones can fly into ship spaces and observe conditions from the inside, with cameras and other sensors (temperature, oxygen, air quality) to examine conditions. These drones, and the systems they carry, need to be engineered to be electrically intrinsically safe on board many vessels. Some of these specialized drones are also engineered for extreme high-hazard conditions such as having to fly and operate in high temperatures, or in vapors that are corrosive, toxic, flammable, or explosive.

These systems allow humans to remain outside of high-risk areas (Ng et al., 2014). They also can provide a greater level of visual and other types of information to surveyors or inspectors. Flaws and other issues can be detected earlier, and preventive action is taken often for less cost.

However, it is one thing when the surveyors or inspectors are working for the company as part of the ship's maintenance, but it is another when they represent government in an enforcement and compliance role.

3.2 Enforcement Role

The pandemic has given rise to the use of remote technologies in port state control inspections and classification surveys to avoid risks for inspectors, surveyors, and ships' crews.

A key legal question can be who is carrying out the inspection? As many maritime rules require a human to carry out either an inspection or a class survey (Ng et al., 2014). This also gives rise to the accuracy of the cameras or other sensors being deployed. Most times these questions can be surmounted since it is the inspector or surveyor that is either operating these systems or examining their visual records and that high-definition imagery is often the result.

In an enforcement role, the imagery from such an inspection maybe critical for evidence and give rise to questions about data integrity and chain of custody sequence. Evidence from such an inspection, like any evidence, would need to move from the analyst to the inspector to enforcement officials, to lawyers, and ultimately to the court where the case would be heard. Chain of custody rules may need to be updated to account for these new technologies and consideration given to selecting the appropriate security capabilities for remote inspection systems that may be used in legal matters.

Another legal element would be the education of the courts themselves. An early aerial surveillance case against a ship illegally discharging dunnage off the coast of Canada was dismissed on the basis that the judge believed the imagery to be too perfect. Over time, as jurists and lawyers became familiar with the capacity and limits of the new surveillance technologies, this evidence became more accepted (European Parliament, 2009). Similarly, it is likely that there will be some growing pains as new technologies come to bear with compliance inspections.

3.2.1 Cargo Management

Another potential use of robotic systems is cargo management systems, which include an array of technology and uses. Robotic systems can be used to assist the loading and unloading of liquid and solid bulk cargoes, technologies can include automatic hatch cover lifting, auto distributing load or ballast to ensure the ship's trim and stability during cargo operations, as well as monitoring of safety critical cargo properties such as temperature or pressure in liquid storage and handling systems. Monitoring systems can also be used during a voyage to ensure cargo remains within parameters to protect the ship's safety or the cargo's product specifications.

Other systems for container handling, network container load out and storage plans between the ship and the port—namely for people operating cranes and shuttle trucks. Some ports are experimenting with more autonomous systems—mainly shuttle trucks move containers within the port.

Another cargo management function that is being explored automation is for security or customs inspections of containers. Vehicles with mounted X-ray systems or other sensors allow for rapid screening inspections without having to open containers. These systems provide benefits to improve security while reducing the impact on the rate of the port's throughput.

3.2.2 Modal Management

In large ports, modal management plays a critical role to ensure efficient throughput. Drones or close circuit cameras can play a role to observe traffic patterns of ships expected to arrive, ships at anchorages, ships within the port, waiting road trucks, drayage trucks and trains within the port, and rail traffic that can automatically relay data to automated AI-based signal controllers to control traffic flow within a port.

These systems can also monitor flows of cargo within the holding areas of the port, which can include solid bulk cargoes, liquid bulk tankage, oversize cargoes, and container holding areas. Automated rules can be developed for traffic prioritization for ensuring safety and product specifications of key cargos. These systems can also reach beyond the port to communicate with both ships at sea and trains and trucks on land to minimize wait times. Given the safety considerations, most such systems rely on humans within a control room to oversee operations and intervene, if necessary, as even with AI systems, not all circumstances can be anticipated by machines (Ng et al., 2014).

In addition to solely managing traffic flow, some systems are being introduced to protect the environment, notably marine mammals. New systems of small slow moving fully autonomous surface craft and underwater craft have been used to survey waterways that are shared between ship traffic and large marine mammals. These advanced systems are now using what are now simple proven components in an innovative way: solar collectors, batteries, electric motors, and hydrophones.

4 Security and Interoperability for Smart Ports and Robotic Systems

As noted in the previous volume, security will need to be integral to the development of these systems (Ravetz, 2013). We must collectively recognize as an industry that is no longer acceptable to develop any system with an assumption that only benign actors will interact with it, or that the system would work flawlessly 24/7 (Ravetz, 2013).

Security measures need to be integrated into these systems to protect vital data and ensure smooth running of operations. As recently seen, bad actors can paralyze operations, or hold important economic organizations hostage, with ransomware and other malware—software (viruses) intended to do harm to a system. Good security practice at the start of development of these systems integrates solutions into the system itself, working with it, as opposed to adding a security solution on top of an existing system that may lead to inefficiencies, delays, and costs (Ravetz, 2013).

Interoperability will become a key element in the design of many future systems. Many industrial systems in the past often operated in isolation, suppliers of these systems often preferred it that way requiring their customers to work with them on upgrades or new features. Today the development of smart ports and autonomous vessels needs more and more systems to communicate and work together (Ravetz, 2013).

Data needs to be in a common open format that various systems can read and understand to respond correctly. It is not just the data format but also the information; as one example, a load out onto a truck by a machine measuring metric tons of material may end up exceeding a regulated load limit if that is set-in short tons. The machine may assume the units are simply tons and deliver 40 metric tons to a truck limited to 40 short tons; the results would not be pretty. As a development of automation progresses in ports, there will be myriads of transactions and decisions that require a common understanding by different systems to interact properly (Ravetz, 2013). Interoperability is one of the most important considerations governing how systems are developed and operate. It will likely keep standards-issuing organizations, such as ISO, busy for a long time (Ravetz, 2013).

5 Conclusions

The use of automation for smart ports and robotic systems is generally limited by the level of development of the technology. Aside from issues related to enforcement measures, these automation activities in the marine sector are comparatively simpler from a regulatory issues viewpoint. Most systems in place at this time are not fully autonomous; they are subject to human monitoring and control (Ng et al., 2014).

As the use of these systems expand and their tasks evolve, how these systems interact with humans will become more complicated (Ng et al., 2014). One example could be a port that adopts fully autonomous trucks to carry containers within the port, which can raise a few questions. How do these systems work with humans that need to work in the same space? If there is an accident between an autonomous vehicle and a vehicle somebody is driving how is the liability determined?

While answers to these questions are still being developed by legal experts, they are not insurmountable. These automated systems operate under the control of legal entities: shipowners or port authorities. Globally, most maritime law standards place responsibility on these legal entities and that they elect to use automated systems to carry out their work does not change their overall responsibility. As such, new technologies and systems that are developed will need to account for this fact either through human control, manual overrides, or systems programming (Ng et al., 2014).

Another element that has not been mentioned in this chapter is cost. This is likely one of the major reasons we have not seen as much advancement as many would like on smart ports and automation by robotics. While ship owners face tremendous costs with pending regulatory changes, ports also face significant costs for capital to maintain and expand facilities, manage labor issues, and manage legacy pollution and infrastructure issues. Many ports around the world are also constrained by how they can raise money, with different rules stemming from the different jurisdictions they may be subject to (which could be national, state, provincial, county, municipal, or combinations).

Jurisdictions may allow their ports to access private capital markets, such as issuing bonds or stocks, entering cost sharing with partners or tenants, or prohibit access to private capital or partnerships. Some ports may be able to access public funds or pursue other means to generate revenue, such as leasing land or facilities to various users (including non-marine). Others are limited only to their revenues in the port fees they charge ships. Ports seeking to develop smart port capabilities will inherently need access to the capital that would likely be beyond what they could reasonably charge through their port fees on ships alone.

Broadly, we see that jurisdictions with the most efficient port systems tend also to have more developed economies and higher standards of living. Past differences in port efficiencies between jurisdictions of different overall development levels may, in the future, give rise to differences in port efficiencies between jurisdictions with different interoperability standards. Ultimately, this could mean jurisdictions with high technology and economic development, but entrenched legacy marine infrastructure and poor interoperability standards, could find themselves less competitive than jurisdictions with lower overall technology and economic development, but with newer marine infrastructure and high interoperability standards. Something to think about.

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