BUGWRIGHT2 remote inspection techniques in medium and small-sized Scandinavian ports
Techniques d'inspection à distance dans les ports scandinaves de petite et moyenne taille

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During the last few years, the utilisation of remote inspection techniques (RIT), including unmanned aerial vehicles (UAVs) and remotely operated vehicles (ROVs), has gained significant momentum in the maritime sector. Today, RIT are rather extensively exploited for ship inspection and maintenance purposes, revolutionising conventional practices and setting a new benchmark in the industry. In this context, these technologies are clearly emerging as indispensable tools in the modernisation of port operations. By effectively leveraging the capabilities of these technologies, ports can achieve remarkable strides in security, safety, efficiency, and sustainability. This paper aims to examine the extent to which small and medium-sized ports in Scandinavia are using RIT for ground-based port operations and sea navigation. It is based on findings from a focus group discussion with seventeen different Port Facility Security Officers (PFSOs) in Scandinavia concerning the extent to which these technologies are used in ports. Recommendations for the use of RIT in ports are then made, namely considering the need for a review of the International Ship and Port Facility Security (ISPS) Code to address the application of UAVs in managing port security.

Keywords: remote inspection techniques, drones, remotely operated vehicles, port security, port technology

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Au cours des dernières années, l'utilisation des techniques d'inspection à distance (RIT), y compris les véhicules aériens sans pilote (UAV) et les véhicules télécommandés (ROV), a pris une ampleur considérable dans le secteur maritime. Aujourd'hui, les techniques d'inspection à distance sont largement exploitées à des fins d'inspection et de maintenance des navires, révolutionnant ainsi les pratiques conventionnelles et établissant une nouvelle référence dans l'industrie. Dans ce contexte, ces technologies apparaissent clairement comme des outils indispensables à la modernisation des opérations portuaires. En exploitant efficacement ces technologies, les ports peuvent réaliser des progrès remarquables en matière de sécurité, de sûreté, d'efficacité et de durabilité. Cet article vise à examiner dans quelle mesure les ports de petite et moyenne taille en Scandinavie utilisent les technologies de l'information et de la communication pour les opérations portuaires au sol et la navigation maritime. Pour ce faire, il s'appuie sur les conclusions d'un groupe de discussion avec dix-sept agents de sûreté des installations portuaires (PFSO) en Scandinavie qui font référence à l'étendue de l'utilisation de ces technologies dans les ports. Des recommandations pour l'utilisation des technologies de l'information et de la communication dans les ports sont ensuite présentées, compte tenu de la nécessité de réviser le Code international pour la sûreté des navires et des installations portuaires (ISPS) afin de prendre en compte l'application des drones dans la gestion de la sécurité portuaire.

Mots-clés : *techniques d'inspection à distance, drones, véhicules télécommandés, sûreté portuaire, technologie portuaire*

The Fourth Industrial Revolution represents a transformative era marked by a convergence of digital innovation and technological advancements. This period is characterised by the widespread adoption of digital technologies and the digital transformation of industries, integrating the industrial Internet of Things (IoT) and an array of personal connected devices (Mhlanga, 2022). It is further defined by the rapid development and application of artificial intelligence (AI) technologies, comprehensive automation across various sectors, and advanced data analytics capabilities. These elements collectively redefine how industries operate, emphasising efficiency, connectivity, and intelligent automation. In this era, new ocean technologies constitute a data revolution, offering an array of advanced sensors and a unique opportunity to address environmental issues and redesign how we manage our shared global environment (World Economic Forum, 2017). The maritime industry, frequently viewed as the cornerstone of global trade, has witnessed significant technological advancements over time and especially during the past few decades (World Maritime University, 2019). Among various advanced technology applications, it is the progression of autonomous technologies that stands to radically alter the landscape of maritime and port industries, promising an amalgamation of efficiency, safety, and economic viability.

Robotic and autonomous systems (RAS) in the maritime sector emerged after a cascade of AI technology breakthroughs (Ichimura *et al.*, 2022; Johansson, 2022). Within this tech-forward wave, remote inspection techniques (RIT), an offshoot of RAS, emerge as a vital trend, redefining inspection methods and ensuring vessel seaworthiness. RIT has been conceptualised as “a means of survey that enables examination of any part of the structure without the need for direct physical access of the surveyor” (IACS, 1997, p. 38). Currently, this mode of operation is termed “supervised autonomy”, denoting the ongoing necessity for human surveyor oversight (Pastra *et al.*, 2002). Common types of industry-deployed RIT include unmanned aerial vehicles (UAVs) and remotely operated vehicles (ROVs). UAVs can be utilised in vessel surveys to inspect areas that may be dangerous or inaccessible to humans, thereby minimising the relevant occupational hazards. Similarly, ROVs, which are submersible tethered robots employed in various underwater applications, can safely inspect parts of a ship that might be challenging, such as ship hulls, propellers, and submerged structures. RIT can facilitate more efficient and potentially safer survey and inspection methods. For instance, they can take over tasks that are otherwise time-consuming, strenuous, or potentially fatal due to lack of oxygen or exposure to polluted vapours in confined spaces (Poggi *et al.*, 2020, p. 881-882).

In the context of RIT, the EU project BugWright2[1] aims at paving the way towards more effective utilisation of robotics for infrastructure inspection and maintenance by introducing a multi-robot survey team programmed to follow a predetermined algorithmic pathway for visual and acoustic inspection of a vessel’s structure to detect corrosion patches, cracking, and deteriorated coatings. The World Maritime University (WMU), a BugWright2 consortium member and a United Nations academic institution founded by the International Maritime Organisation (IMO), has been given the task of conducting an in-depth analysis of the legal framework and preparing recommendations for the reform and progressive development of relevant norms concerning autonomous robotics regulation and standards.

The WMU has addressed the extent to which RIT are used and the challenges concerning their use from recognised organisations (ROs), which have traditionally been responsible for the statutory survey of a vessel on behalf of the flag administration. Key challenges to consider for their widespread utilisation include: (a) developing guidelines that will provide a uniform approach to conducting statutory remote surveys, (b) categorising different “degrees of autonomy”, (c) forming a secure data governance framework to establish provisions and processes that could offer adequate protection to data assets, and (d) delineating product safety and liability parameters to ensure high levels of safety

1 |BugWright2—*Autonomous Robotic Inspection and Maintenance on SHip Hulls*, online: https://www.bugwright2.eu/

and minimal risk of harm to users (Alexandropoulou *et al.*, 2022; Johansson *et al.*, 2023; Pastra *et al.*, 2022; Pastra *et al.*, 2023).

The extent of the adoption of these technologies in small and medium-sized ports, along with the barriers to overcome for mass utilisation, remains unexamined, however. The aim of this paper is to identify the extent to which these technologies are used by small and medium-sized ports and provide some relevant initial recommendations to policymakers and port authorities.

Ports and ocean technologies

Ports, essential hubs for global trade and transportation, have historically been at the forefront of adapting various technological innovations (Christodoulou *et al.*, 2021a; Doelle *et al.*, 2023). For instance, the implementation of automated container handling systems has revolutionised the way ports manage cargo operations. These systems use robotic cranes and autonomous vehicles to move containers between ships and storage areas, significantly reducing loading and unloading times while improving safety by minimising human error.

The escalating demands on ports—spurred by burgeoning international trade and heightened environmental concerns—have necessitated the adoption of advanced ocean technologies, fundamentally transforming the landscape of port operations. The surge in automation is reshaping the port sector, influencing its finances, human capital, and operational cadence, thereby affecting productivity in terms of total traffic handled and maximum output obtainable using a given level of resources (Baskin and Swoboda, 2023; Karnoji and Dwarakish, 2018; Talley, 2009).

In recent years, the term “smart ports” has gained significant prominence. Smart ports represent a natural evolution in the maritime industry, propelled by the convergence of technological innovation and the escalating demands of global trade. A smart port is an “intelligent digital port that can operate autonomously via the self-configured, self-protective, more adaptive, more secure, more responsive, and highly connected port system” (Min, 2022, p. 191). This “smartness” is achieved through emerging technologies that boost connectivity, making horizontal and vertical integration across the entire port’s ecosystem possible (Leclerc and Ircha, 2023, p. 175). The ongoing advancement of information and communication technology (ICT) facilitates an integrative environment between crew members, onshore officials, port officers, and electronic equipment that engage synergistically in maritime operations (Dalaklis, 2020; Ichimura *et al.*, 2022).

Technologies shaping the future of smart ports include AI, the Internet of Things (IoT), blockchain technology, Big Data analytics, 5G, and unmanned aerial vehicles (Ichimura *et al.*, 2022) Artificial intelligence can optimise port operations through demand forecasting and decision-making automation to determine the best course/speed for each voyage (Dalaklis, 2020). IoT devices that exchange information between people and equipment, and between equipment such as sensors and cameras enable real-time cargo tracking, monitoring of ships, and enhanced port security (Leclerc and Ircha, 2023).

In addition, port authorities worldwide have increasingly embraced blockchain technology to boost service effectiveness, enhance cargo status updates, streamline the customs clearance process, and facilitate the decision-making at every level in the supply chain (Wang, 2021; Yang, 2019). The domain of "Big Data Analytics" entails the scrupulous analysis of large data sets to elucidate concealed patterns, associations, and additional insights, such as market tendencies and consumer predilections, thereby facilitating business decision-making (Dalaklis *et al.*, 2022). Meanwhile, 5G technology promises to elevate the competitiveness and efficiency of ports, as well as the bandwidth and speed required for large-scale implementation of automation. Automated cranes, self-driving container vehicles, and other robotic equipment can be seamlessly integrated and operated without lag. Major ports such as Rotterdam, Singapore, and Hamburg are progressively transforming into network developers (Johansson *et al.*, 2023). Accordingly, 5G communication networks will enable their users to benefit from ocean technologies and RIT, contributing to sustainable development in various port areas (Cavalli *et al.*, 2021). Beyond streamlining daily operations and global supply chains, 5G and smart ocean technologies can save valuable time and mitigate threats and vulnerabilities in port facilities, including armed robbery, bomb threats, cyberattacks, stowaways, drug smuggling, weapons, terrorism, and cargo theft (de la Peña Zarzuelo, 2021; Ibrahim, 2022; Rébé, 2021).

RITs, UAVs, or drones (Image 1) are designed to perform tasks that are either too risky or dull for humans and range in size from small handheld devices to large aircraft depending on their purpose. Equipped with state-of-the-art technology, including high-resolution cameras, advanced navigation systems, and sometimes even AI, UAVs can execute a wide array of missions precisely and efficiently. They can monitor illegal and accidental discharges, strengthening port state jurisdiction to prevent ship source pollution, reduce human labour requirements, and eliminate human error (Argüello, 2023; Paddock and Crowell, 2021). In addition, the deployment of UAV systems in the port sector can counter maritime security threats and drug trafficking by sea, offering insights into potential criminal activities below the waterline (Ávila-Zúñiga-Nordfjeld *et al.*, 2023).

Image 1: Unmanned Aerial Vehicle in a port area
Source: Photo by the authors.

ROVs (Image 2) are vehicles designed to function at the port's depths, which are equipped with high-resolution cameras, advanced sensors, and robotic arms. They are guided remotely by operators aboard a ship or from shore and can perform detailed inspections of ship hulls, port infrastructure, and even the seabed precisely and efficiently, revolutionising the way ports conduct underwater inspection, maintenance, and repair tasks.

Image 2: ROV in a port area
Source: Photo by the authors.

Methodology

This study seeks to glean insights from subject matter experts in the port industry, utilising focus group discussions as its primary qualitative research method. This approach fosters an environment where participants can interact and brainstorm about the potential use of RIT within their respective ports. The two-hour discussions were orchestrated during a two-day annual seminar for seventeen Scandinavian PFSOs from Denmark, Sweden, and Norway. The event was co-organised by the Nordic Crisis Management and the World Maritime University (WMU) on 18-19 April, 2023, and was part of the annual training that Nordic Crisis Management offers to PFSOs for the implementation and maintenance of International Ship and Port Facility Security (ISPS) and related EU and national security regulations. The session was facilitated by an academic faculty member of WMU who presented the BugWright2 project to the participants and then guided the discussions using a predetermined set of closed- and open-ended questions (Annex 1). Data was collected from participants using the software Slido, an efficient tool for gathering insights during events that allows for real-time polling. A set of sixteen questions was given to the participants, of which twelve focused on the utilisation of RIT in their respective ports, two addressed the trustworthiness of these technologies, one pertained to their governance framework, and one was an open-ended question. After the participants completed the questionnaire, the findings were presented to the group, setting the basis for additional comments and brainstorming.

Fifteen out of the seventeen participants (88%) indicated that their port falls under the small EU taxonomy and manages an annual volume of goods below 10 million tonnes, whereas two of the participants (12%) confirmed that their port is medium sized, managing an annual volume between 10 and 50 million tonnes.

Findings

Drones and ROVs: utilisation, benefits, and challenges

The PFSOs were asked to specify if they had set up a risk assessment format for drones based on a systematic approach from safety hazard identification to risk management, and 47% responded affirmatively. Even though drones have a multitude of potential applications, small and medium-sized port authorities primarily use them for (a) routine and on-demand equipment/infrastructure inspections, (b) port construction projects, and (c) vessel inspections. As noted by the participants, “there are so many ways to utilise them; we are only scratching the surface”.

During the workshop, the principal benefits and challenges were thoroughly discussed. A pivotal benefit identified was drones' capacity to reduce lag times from inspection to emergency response, facilitating swifter responses in scenarios requiring immediate action such as security breaches or infrastructure malfunctions. Furthermore, drones offer a comprehensive monitoring solution for extensive port areas since they are capable of navigating and inspecting locations that are either inaccessible to or challenging for human inspectors, including towering cranes, cargo tops, or narrow waterways.

When it came to drone-related challenges, the participants pinpointed technical, regulatory, security, and financial hurdles. From a technical standpoint, the potential malfunctioning of drones raises concerns, especially in the harsh environments of ports, which are characterised by saltwater exposure, high humidity, and strong winds. Addressing concerns surrounding navigation, communication interference, and weather resilience is critical in promoting the successful integration of drones into port operations. Technical damage to a drone and potential collision necessitates stringent safety protocols to safeguard both the human element and infrastructure.

Participants also highlighted the current lack of a regulatory framework and universally accepted standards governing drone operations in ports. Ports could leverage the full potential of drone technology, fostering safer, more efficient, and innovative operations with uniform standards for their operation, including safety protocols, privacy safeguards, and security measures.

Another considerable security challenge is distinguishing between friendly and potentially hostile drone activities. Drones could be misused for unauthorised surveillance, leading to possible industrial espionage and threats to port security. Therefore, a central challenge is the differentiation between drones used for legitimate operations and those piloted by malicious actors or inexperienced individuals. Moreover, stringent guidelines need to be set for flight paths and no-fly zones to ensure physical security. It is also vital to obtain consent from vessels and nearby industries, particularly when surveillance or inspection activities could infringe on their privacy or sensitive operations.

Finally, financial considerations are not to be overlooked, as acquiring high-quality drones for port operations often entails significant expenditures on the part of port authorities, encompassing hardware, software, routine maintenance, and training investments.

Comparatively, the utilisation of ROVs is less prevalent, with only 24% of ports adopting them, mainly for (a) subsurface port inspections to verify the integrity of moorings and other marine infrastructures—including quay wall structures, jetties, and breakwaters—and (b) data collection from areas that are difficult to reach, supporting managers in decision-making and accident prevention.

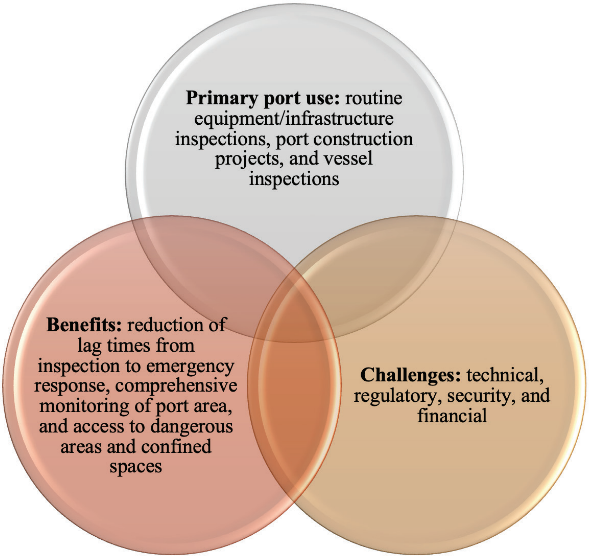

Figure 1: Benefits and challenges of UAV

The primary benefits identified with ROV use include saving time in inspecting ship hulls and underwater infrastructure due to the immediate feedback and reduced human intervention (Figure 1). This transformative technological shift in port operations emphasises not only the timesaving attributes of ROVs but also their critical contributions to enhancing security and safety within the port environment. Remote techniques bolster the safety of the inspection process, mitigating accidents and potential loss of life during diving operations. Meanwhile, ROVs can also identify underwater threats or obstructions, explosive devices, and hidden contraband or illicit goods, ensuring smoother port operations and rapid response to potential disruptions.

The primary challenges encountered with ROVs revolve around visibility constraints and the effects of currents and wind in port environments (Figure 2). Ports, often situated in locations with constant ship traffic, frequently experience heightened turbidity, resulting in stirred-up sediment that creates murky conditions, hindering ROVs when it comes to capturing clear visual data. Additionally, strong water currents can impede ROV navigation, making it difficult to maintain a steady position, particularly during detailed inspections or delicate operations.

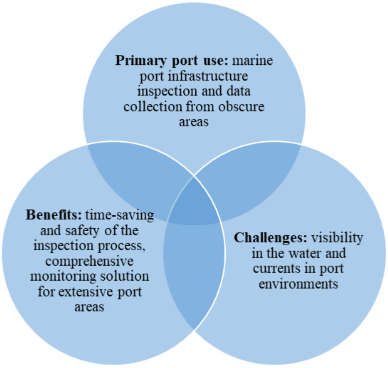

Figure 2: Benefits and challenges of ROV

Paving the way to the future: integrating RIT in modern port operations

The focus group identified the PFSOs' level of trust in drones and ROVs by asking them if they consider these technologies trustworthy. Forty-one percent of the participants were neutral and 35% replied "rather yes" (Figure 3).

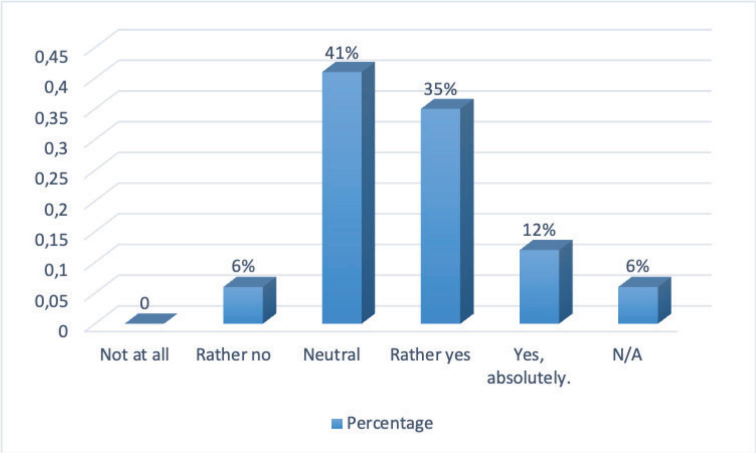

Figure 3: Level of trust in RIT

To increase their utilisation and trustworthiness even more, addressing barriers to the mass utilisation of RIT in port environments is imperative. Firstly, all the participants agreed on the need to implement a comprehensive global framework set by the IMO, which will play a pivotal role in orchestrating the use of RIT. The IMO should engage port authorities, shipping companies, drone manufacturers, and technology providers to understand challenges and collaboratively devise solutions that will lead to a set of standardised guidelines. A unified port training program could also be designed for port drone pilots specific to maritime operations that will encompass safety protocols, emergency responses, and security considerations.

Secondly, PFSOs underlined the need for an update of the ISPS Code, as this is the ultimate tool for setting the measures aimed at enhancing the security of ships and port facilities. The code is a 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. Adopted by the IMO in December 2002, the ISPS Code is part of the Safety of Life at Sea (SOLAS) Convention and came into force in July 2004. It mandates a wide range of security measures, including the establishment of security levels, development of security plans, and adherence to strict procedures designed to detect and deter security incidents affecting ships or port facilities used in international trade. The ISPS Code applies to passenger ships, cargo ships of 500 gross tonnage and upwards, and mobile offshore drilling units, as well as to port facilities serving such ships engaged in international voyages.

The participants pointed out that although the ISPS Code forms the basis for implementing remote airborne and underwater technology, no substantial revisions have taken place in the past twenty years. While the ISPS Code was forward thinking at its inception, it did not anticipate the exponential growth in drone technology and other digital innovations. The fact that the code is quite broad in its requirements and descriptions implies that it is open to adaptations through IMO and national regulations. Indeed, the code offers the possibility of accommodating different interpretations and tailoring implementation to fit specific national circumstances. For instance, the 2005/65 EU Directive for Enhanced Port Security is a good example of an attempt by the EU to extend the ISPS Code. Other regulatory bodies such as the North American three-tiered Maritime Security System (MARSEC) or the European Maritime Safety Agency (EMSA) have also implemented supporting recommendations and guidelines. Although provisions in the ISPS Code (sections B 15.3.5, 15.4.1, 15.7.31, and 15.16.5) acknowledge the need to address networks and computer systems, whether these provisions adequately account for future development is questionable. The participants underlined that the possibility of updating the code in the future requires stakeholder consultation and careful consideration of potential implications. Involving port authorities, shipping companies, technology providers, and security agencies could foster a multifaceted perspective on possible integrations and enhancements, facilitating a comprehensive overhaul of the existing code that is cognizant of potential future trajectories.

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In light of the escalating digitisation pervading global supply networks, it is imperative for ports to safeguard their pivotal positions as “nodes” within these chains by metamorphosing into digitally enhanced operational hubs or “digital nodes” (Dalaklis *et al.*, 2022). In this context, robotics, such as drones and ROVs, signal a promising trajectory since they can be utilised not only within shipyards and ports, but also at sea or on inland waterways to serve very “niche” transport service needs (Dalaklis *et al.*, 2022; Johansson, 2023).

This progressive step towards incorporating RIT into port operations heralds a new era of efficiency and safety in maritime operations. Small and medium-sized ports in Scandinavia have started utilising RIT, promising to blend efficiency, safety, and sustainability. However, to unlock their full potential and facilitate seamless incorporation into existing systems, a cohesive and universal regulatory framework is indispensable. A well-structured framework from the IMO will not only address the immediate challenges but will also pave the way for future innovations in the domain of remote inspections. A regulatory framework in the form of a code of conduct could certainly be a stepping stone to removing grey areas and thereby increasing the level of trust of port authorities in service robotics (Pastra *et al.*, 2022).

Considering the escalating prevalence of organised criminal activities, it has also become imperative to enhance port resilience (Bueger and Edmunds, 2017). This necessitates advancing beyond the established guidelines delineated in the ISPS Code to foster a more robust framework through incorporating technological advancements and adequately addressing contemporary security challenges (Ibrahim, 2022). Integrating drones and other emerging technologies will bolster port security and ensure that the maritime industry remains resilient and efficient in the face of global challenges. However, consulting stakeholders and careful consideration of potential implications are essential steps before any amendment is made.

The exploration of RIT through the lens of port security officers in Scandinavian countries offers a fertile ground for deriving valuable lessons for other small and medium-sized ports and understanding the broader implications of adopting such technologies. Despite varying stages of technological adoption and regulatory frameworks across the globe, ports worldwide face similar challenges and opportunities when it comes to the adoption of RIT. The universal nature of these challenges and opportunities underlines the potential for collective learning and adaptation in the maritime sector.

The shift to RIT necessitates a corresponding investment in training for port officers and involves not just understanding the technology but also being adept at interpreting data and making decisions remotely. Adoption of RIT also requires significant upfront investment in technology and infrastructure. This includes the purchase of drones and underwater vehicles as well as the development of secure digital communication channels. The long-term benefits, such as increased efficiency and safety, need to be weighed against these initial costs. At the same time, existing regulations may need to be revised to accommodate the use of RIT. This process can be complex, requiring a balance between innovation and safety/security concerns

While the maritime and shipping sectors are frequently perceived as conservative and somewhat intransigent to transformative shifts, a plethora of forward-thinking ports globally have begun to incorporate highly innovative technologies, yielding distinct economic, operational, and environmental advantages (Dalaklis *et al.*, 2022). The ports of the future will be smart, moving beyond obligatory regulatory mandates towards a comprehensive goal-oriented cooperation framework among the diverse port stakeholders, considering distinctive institutional circumstances and ownership structures along with the national, socio-economic-political system (Christodoulou *et al.*, 2021b; Doelle *et al.*, 2023). This transition signifies a paradigm shift, fostering a more resilient, efficient, and sustainable maritime industry that is ready to meet the diverse demands of the modern socioeconomic landscape, guided by informed and collaborative strategies.

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Annex 1: Questionnaire

1. Does your port fall under the small, medium, or large port EU taxonomy?
2. Do you have any formal risk assessment or port policy in place concerning drone use? (yes/no)
3. For which tasks do you use drones?
4. Which do you consider as the main benefit(s) for the adoption of drones in your ports?
5. Which do you consider as the main challenge(s) for the adoption of drones in your ports (e.g. regulation, security, safety, technical issues)?
6. Please offer any other views relevant to the utilisation of drones in the port sector
7. For which tasks do you use Remotely Operated Vehicles (ROVs)?
8. Which do you consider as the main benefit(s) for the adoption of underwater drones at the port?
9. Which do you consider as the main challenges for the adoption of underwater drones at the port?
10. Based on your current knowledge would you say that Remote Inspection Techniques (drones and ROVs) are trustworthy? (1) No, not at all. (2) Rather no. (3) Neutral (4) Rather yes. (5) Yes, absolutely.
11. In your opinion, what aspects (could) make Remote Inspection Techniques (RIT) trustworthy?
12. Do you think that ports should have their own policy for RIT or there should be a worldwide governance framework developed by the IMO?
13. Is there anything else that you would like to address in relation to the utilisation of Remote Inspection Techniques (RIT) at ports?