



HAL
open science

BUGWRIGHT2 Remote Inspection Techniques in Medium and Small-Sized Scandinavian Ports: Application, Advantage & Adversity

Aspasia Pastra, Tafsir Johansson, Herbert Francke, Dimitrios Dalaklis

► **To cite this version:**

Aspasia Pastra, Tafsir Johansson, Herbert Francke, Dimitrios Dalaklis. BUGWRIGHT2 Remote Inspection Techniques in Medium and Small-Sized Scandinavian Ports: Application, Advantage & Adversity. 2023. hal-04273142v1

HAL Id: hal-04273142

<https://hal.science/hal-04273142v1>

Preprint submitted on 7 Nov 2023 (v1), last revised 15 Mar 2024 (v2)

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

BUGWRIGHT2 Remote Inspection Techniques in Medium and Small-Sized Scandinavian Ports: Application, Advantage & Adversity

Aspasia Pastra¹, Tafsir Johansson², Herbert Francke³ and Dimitrios Dalaklis⁴

Abstract: During the last few years, the utilization of Remote Inspection Techniques (RIT), including Unmanned Aerial Vehicles (UAVs) and Remote Operated Vehicles (ROVs), has gained significant momentum within the maritime sector. Today, RIT are rather extensively being exploited for ship inspection and maintenance purposes, thereby revolutionizing 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. To this end, it is based on findings from a focus group discussion with seventeen (17) different Port Facility Security Officers (PFSOs) in Scandinavia that draw reference to the extent of use of these technologies in ports. Recommendations for the use of RIT in ports have been, thereupon, tabled 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.

¹ WMU-Sasakawa Global Ocean Institute (GOI), World Maritime University, Malmö, Sweden.

² WMU-Sasakawa Global Ocean Institute (GOI), World Maritime University, Malmö, Sweden.

³ Nordic Crisis Management AS.

⁴ World Maritime University, Malmö, Sweden.

1. Introduction

The maritime industry, quite frequently viewed as the cornerstone of global trade, has witnessed significant technological advancements over the course of time and especially during the past few decades (WMU, 2019). Among various other 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. In this era of the fourth industrial revolution, Robotic and Autonomous Systems (RAS) in the maritime sector emerged after a cascade of Artificial Intelligence (AI) technological 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 a survey that enables examination of any part of the structure without the need for direct physical access of the surveyor" (IACS, 1997/Rev 2023). Currently, the 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 utilized in vessel surveys to inspect areas that may be dangerous or inaccessible to humans, thereby minimizing 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 relieve tasks that are otherwise time-

consuming, strenuous or fatal due to lack of oxygen or exposure to polluted vapors in confined spaces (Poggi et al., 2020, p. 881-882).

In the context of RIT, the EU project Bugwright2 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 pre-determined algorithmic pathway for visual and acoustic inspection of a vessel 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 assumed the task of conducting an in-depth analysis of the legal framework and prepare recommendations for the reform and progressive development of relevant norms concerning autonomous robotics regulation and standards.

The extent of utilisation of RIT and the challenges accompanying their use from Recognised Organisations (ROs), which have traditionally been responsible for the statutory survey of a vessel on behalf of the Flag Administration, have been addressed by WMU. 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 the 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 and minimal risk of harm to users (Alexandropoulou et al., 2022; Johansson et al., 2021; Johansson et al., 2023; Pastra et al., 2022; Pastra et al., 2023).

However, 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. The aim of this

paper is to identify the extent of use of these technologies by small and medium-sized ports and provide some relevant initial recommendations to policymakers and port authorities.

2. 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) . 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 & 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: 191). This "smartness" is realised through emerging technologies that boost connectivity, achieving horizontal and vertical integration across the entire port's ecosystem (Leclerc and Ircha 2023: 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, 2020a; Ichimura et al., 2022).

Technologies shaping the future of smart ports include Artificial Intelligence (AI), the Internet of Things (IoT), Blockchain Technology, Big Data Analytics, 5G and Unmanned Aerial Vehicles (Ichimura et al., 2022) Artificial intelligence can optimize port operations through demand forecasting and decision-making automation and determine the best course/speed for each voyage (Dalaklis, 2020b). IoT devices that exchange information between people and equipment, and between equipment, such as sensors and cameras, enable for 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).

5G technology promises to elevate the competitiveness and efficiency of ports, 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 the 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 threat,

cyberattacks, stowaways, smuggling of drugs, weapons, terrorism, and cargo theft (de la Peña Zarzuelo 2021; Ibrahim 2022; Rébé 2021).

UAVs can monitor illegal and accidental discharges, strengthening port state jurisdiction to prevent ship source pollution, reduce human labor requirements and eliminate human error (Argüello, 2023; Paddock & 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).

3. Methodology

This study seeks to glean insights from subject matter experts in the port industry, utilizing focus group discussions as the 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 discussions were orchestrated during a two-day Annual Seminar for 17 Scandinavian Port Facility Security Officers (PFSOs), co-organized by the Nordic Crisis Management and the World Maritime University (WMU) on 18-19 April, 2023.

The session was facilitated by an academic faculty member of WMU who presented to the participants the Bugwright2 project and then guided the discussions using a pre-determined set of closed and open-ended questions. 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 size, managing an annual volume between 10 and 50 million tonnes.

4. Findings

4.1 Drones and ROVs: Utilisation, Benefits and Challenges

The PFSOs were asked to specify if they had set up a formal risk assessment for drones based on a systematic approach from safety hazard identification to risk management and 47% responded affirmatively (Diagram 1).

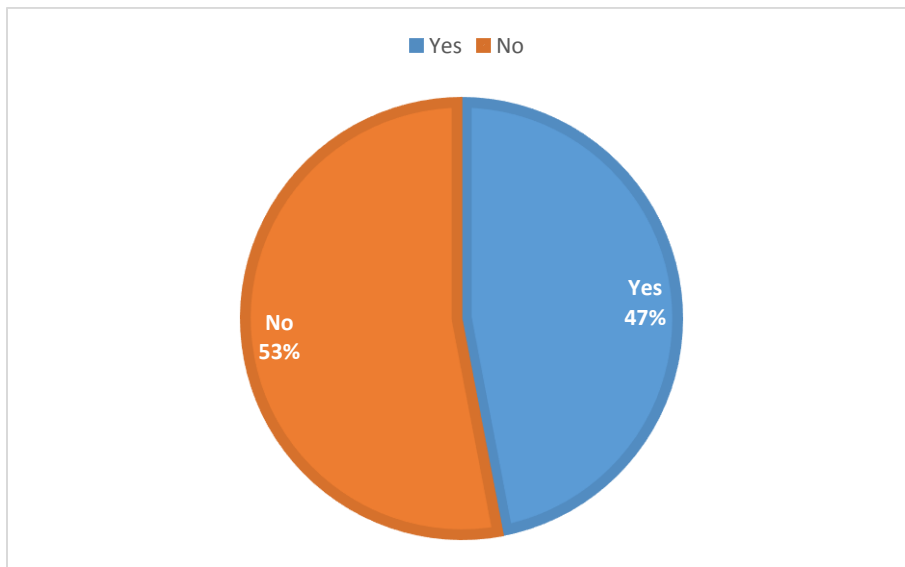


Diagram 1: Formal Risk Assessment for Drone Use

Despite that drones having a multitude of potential applications, small and medium-sized port authorities primarily utilise 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 utilize them; we are only scratching the surface".

During the workshop, the principal benefits and challenges were thoroughly discussed. A pivotal benefit identified was the drone's capacity to reduce time lags from inspection to emergency response, facilitating swifter responses in scenarios necessitating immediate action, such as security breaches or infrastructure malfunctions. Furthermore, drones offer a comprehensive

monitoring solution for extensive port areas, capable of navigating and inspecting locations that are either inaccessible or challenging for human inspectors, including towering cranes, cargo tops, or narrow waterways.

Regarding their 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 characterized 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 of 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 can 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 unauthorized 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.

Financial considerations are not to be overlooked as high-quality drones for port operations often entail significant expenditures for port authorities, encompassing hardware, software, routine maintenance, and training investments.

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

The primary benefits identified associated with ROV use include time-saving in inspecting ship hulls and underwater infrastructure due to the immediate feedback and reduced human intervention (Diagram 2). This technological transformative shift in port operations emphasizes not only the time-saving attributes of ROVs but also their critical contributions to enhancing security and safety within the port environment. On the one hand, remote techniques bolster the safety of the inspection process, mitigating accidents and potential loss of life during diving operations. On the other hand, ROVs can identify underwater threats or obstructions, explosive devices, 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 (Diagram 2). Ports, often situated in locations with constant ship traffic, frequently experience heightened turbidity, resulting from stirred-up sediment, creating murky conditions that hinder ROVs from 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.

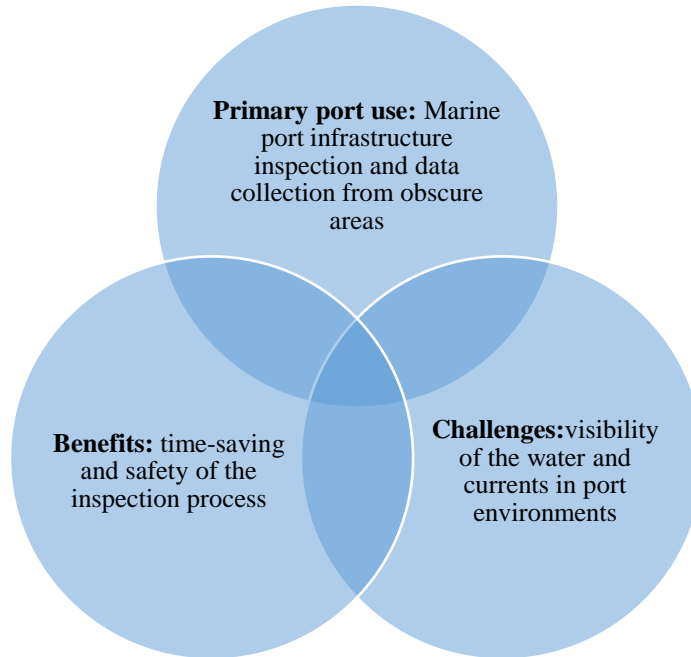


Diagram 2: Benefits and Challenges of ROVs

4.2 Paving the Future: Integrating RIT in Modern Port Operations

The discussion identified the level of trust of the PFSO in drones and ROVs by asking them if they consider these technologies trustworthy. Forty-one percent (41%) of the participants were neutral and thirty-five (35%) replied *rather yes* (Diagram 3).

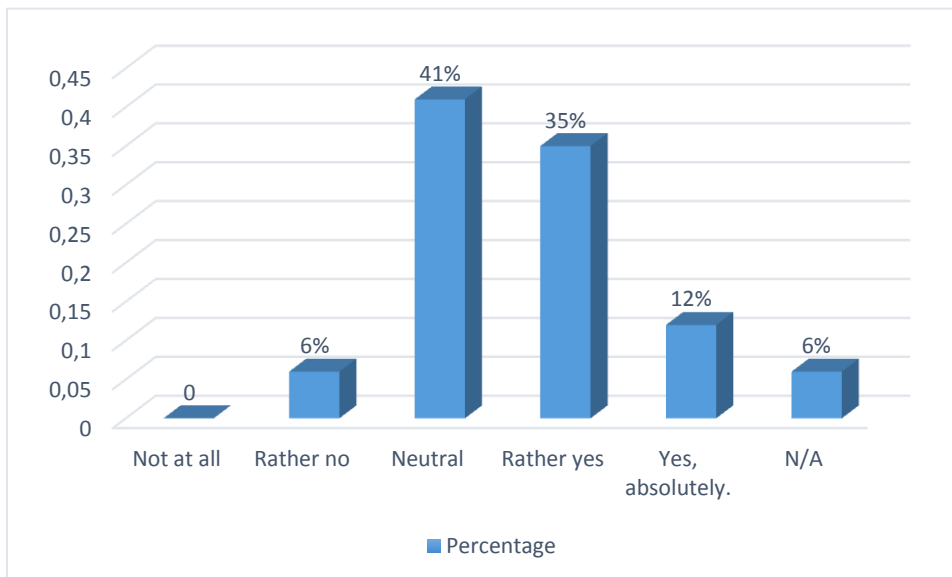


Diagram 3: Level of Trust in RIT

To increase their utilisation and trustworthiness even more, addressing several barriers to facilitate the mass utilization of RIT in port environments is imperative. These barriers encompass the following elements.

Firstly, all the participants agreed on the need for implementing 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 standardized 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 International Ship and Port Facility Security (ISPS) of IMO as this is the ultimate tool for setting the measures aimed at enhancing the security of ships and port facilities, primarily targeting threats of terrorism. The participants pointed out that although the Code forms the basis for implementing remote airborne - and underwater technology, no substantial revisions have taken place in the past 20 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. 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 MARSEC, EMSA, ENISA have also implemented supporting recommendations and guidelines. Although the provisions in sections B 15.3.5,

15.4.1, 15.7.31, and 15.16.5 acknowledge the need to address networks and computer systems, it is questionable whether these provisions adequately account for future development. 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 multi-faceted perspective on possible integrations and enhancements, facilitating a comprehensive overhaul of the existing Code that is cognizant of potential future trajectories.

5. Conclusion

In light of the escalating digitization 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 as they can be utilised not only within shipyards and ports, but also at sea or inland waterways, to serve very "niche" transport service needs (Dalaklis et al., 2022; Johansson et al., 2021).

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 Scandinavian have started utilising RIT, promising a blend of 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 in unveiling the grey areas, increasing the level of trust of port authorities in service robotics (Pastra et al., 2022).

In light of the escalating prevalence of organized criminal activities, it has become imperative to enhance port resilience (Bueger & Edmunds 2017). This necessitates advancing beyond the established guidelines delineated in the International Ship and Port Security (ISPS) Code, fostering a more robust framework through incorporating technological advancements and adequately addressing contemporary security challenges (Ibrahim, 2022). Integrating drones and other emergent technologies will bolster port security and ensure that the maritime industry remains resilient and efficient in the face of global challenges. Stakeholder consultation and careful consideration of potential implications are paramount before any amendment.

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, taking into account 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, ready to meet the diverse demands of the modern socio-economic landscape, guided by informed and collaborative strategies.

Referencing list

Argüello, G. (2023) Smart Port State Enforcement Through UAVs: New Horizons for the Prevention of Ship Source Marine Pollution. In: Johansson, T.M., Dalaklis, D., Fernández, J.E., Pastra, A., Lennan, M. (eds) *Smart Ports and Robotic Systems*. Studies in National Governance and Emerging Technologies. Palgrave Macmillan, Cham. https://o-doi-org.pugwash.lib.warwick.ac.uk/10.1007/978-3-031-25296-9_11

Alexandropoulou, V., Johansson, T., Kontaxaki, K., Pastra A., and Dalkalis D. (2021) "Maritime Remote Inspection Technology in Hull Survey & Inspection: A Synopsis of liability issues from a European Union context", *Journal of International Maritime Safety, Environmental Affairs, and Shipping*, 5(4), pp. 184–195.
doi:10.1080/25725084.2021.2006463.

Ávila-Zúñiga-Nordfjeld, A., Liwång, H., Dalaklis, D. (2023) 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. In: Johansson, T.M., Dalaklis, D., Fernández, J.E., Pastra, A., Lennan, M. (eds) *Smart Ports and Robotic Systems*. Studies in National Governance and Emerging Technologies. Palgrave Macmillan, Cham. https://o-doi-org.pugwash.lib.warwick.ac.uk/10.1007/978-3-031-25296-9_7

Baskin, A., Swoboda, M. (2023). Automated Port Operations: The Future of Port Governance. In: Johansson, T.M., Dalaklis, D., Fernández, J.E., Pastra, A., Lennan, M. (eds) *Smart Ports & Robotic Systems*. Palgrave Macmillan, Cham. https://o-doi-org.pugwash.lib.warwick.ac.uk/10.1007/978-3-031-25296-9_8

Bueger C, Edmunds T (2017) Beyond seablindness: a new agenda for maritime security studies. *Int Af* 93:1293–1311

Cavalli, L., Lizzi, G., Guerrieri, L., Querci, A., De Bari, F., Barbieri, G., Ferrini, S., Di Meglio, R., Cardone, R., Tardo, A., Pagano, P., Tesei, A. & Lattuca, D. (2021) "Addressing Efficiency and Sustainability in the Port of the Future with 5G: The Experience of the Livorno Port. A Methodological Insight to Measure Innovation Technologies' Benefits on Port Operations", *Sustainability* (Basel, Switzerland), vol. 13, no. 21, pp. 12146.

BugWright2 – *Autonomous Robotic Inspection and Maintenance on SHip Hulls*. [online] Available at: <https://www.bugwright2.eu/>.

Christodoulou, A., Dalaklis, D., Ölçer, A. I., & Ballini, F. (2021a) "Linking digitalization to sustainable development: The case of the port of Gothenburg". In *Proceedings of the International Maritime Transport and Logistics Conference*, Arab Academy for Science, Technology and Maritime Transport.
<https://doi.org/10.13140/RG.2.2.12419.22564>

Christodoulou, A., Pastra, A., Doelle, M., Johansson, T. (2021b) "Four Spheres of Influence: The Critical Role of Ports in Global Decarbonization Efforts", *Ocean Yearbook*, Vol. 35. https://brill.com/view/journals/ocyo/35/1/article-p148_6.xml

Dalaklis, D. (2020a) Unleashing the power of data to optimize vessel performance. In Proceedings of the Vessel Optimization Webinar Week. London, UK. <https://doi.org/10.13140/RG.2.2.16851.40489>

Dalaklis, D. (2020b) Vessel optimization webinar week: Unleashing the power of data to optimise vessel performance [PowerPoint slides]. ResearchGate.

Dalaklis, D., Christodoulou, A., Ölcer, A., Ballini, F., Dalaklis, A. and Lagdami, K. (2022) "The port of Gothenburg under the influence of the fourth stage of the industrial revolution: Implementing a wide portfolio of digital tools to optimize the conduct of operations". *Maritime Technology and Research*, 4(3), p.253844. doi:<https://doi.org/10.33175/mtr.2022.253844>.

de la Pena Zarzuelo, I. (2021), "Cybersecurity in ports and maritime industry: Reasons for raising awareness on this issue", *Transport policy*, vol. 100, pp. 1-4.

Doelle, M., Johansson, T., Pastra, A. and Baskin, A. (2023) "Environmental Policy Frameworks for Ports: In Search of a Gold Standard". *Ocean Yearbook*, [online] 37(1), pp.457–480. doi:<https://doi.org/10.1163/22116001-03701019>.

IACS (1997) *Z17 procedural requirements for service suppliers - IACS*. International Association of Classification Societies, 1997/Rev.18 2023/Corr.1 2023 Available at: <https://www.iacs.org.uk/media/3190/ur-z17rev12.pdf> (Accessed: 01 January 2023).

Ibrahim, A.M. (2022) "The impact of neurotechnology on maritime port security—hypothetical port". *J Transp Secur* 15, 119–139 <https://doi.org/10.1007/s12198-022-00253-x>

Ichimura, Y., Dalaklis, D., Kitada, M. and Christodoulou, A. (2022) "Shipping in the era of digitalization: Mapping the future strategic plans of major maritime commercial actors". *Digital Business*, 2(1), p.100022. doi:<https://doi.org/10.1016/j.digbus.2022.100022>.

Karhoji, D., & Dwarakish, G. (2018) "Measuring port performance and productivity". *ISH Journal of Hydraulic Engineering*, 26, 1–7. <https://doi.org/10.1080/09715010.2018.1473812>

Johansson, T. (2022) "International Standards for Hull Inspection and Maintenance of Robotics and Autonomous Systems", in J. Kraska and Y.-K. Park (eds.) *Emerging Technologies and the Law of the Sea*. Cambridge: Cambridge University Press, pp. 184–213.

Johansson, T.M., Lennan, M., Fernández, J.E., Pastra, A., Dalaklis, D. (2023). Introduction to Smart Ports and Robotic Systems: Navigating the Waves of Techno-Regulation and Governance. In: Johansson, T.M., Dalaklis, D., Fernández, J.E., Pastra, A., Lennan, M. (eds) *Smart Ports and Robotic Systems* . Studies in National Governance and Emerging Technologies. Palgrave Macmillan, Cham. https://o-doi-org.pugwash.lib.warwick.ac.uk/10.1007/978-3-031-25296-9_1

Leclerc, Y., Ircha, M. (2023). Canada's Rapidly Evolving Smart Ports. In: Johansson, T.M., Dalaklis, D., Fernández, J.E., Pastra, A., Lennan, M. (eds) *Smart Ports and Robotic Systems* . Studies in National Governance and Emerging Technologies. Palgrave Macmillan, Cham. https://o-doi-org.pugwash.lib.warwick.ac.uk/10.1007/978-3-031-25296-9_9

Min, H. (2022) "Developing a smart port architecture and essential elements in the era of Industry 4.0," *Maritime Economics & Logistics* 24: 189–207, available online: <https://doi.org/10.1057/s41278-022-00211-3>.

Paddock, L. C., and Crowell, M. (2021) "Technology in environmental implementation, compliance and enforcement". Scott, K. N., Lindley, J., Techera, E., and Telesetsky, A. (Eds.). *Routledge handbook of international environmental law* (2 ed.). Routledge.

Pastra, A. Schauffel, N., Ellwar, T. and Johansson T. (2022) "Building a trust ecosystem for Remote Inspection Technologies in ship Hull Inspections", *Law, Innovation and Technology*, 14(2), pp. 474–497. doi:10.1080/17579961.2022.2113666.

Pastra, A. et al. (2023). Towards an International Guideline for RIT End-Users: Spearing Through Vessel Inspection and Hull Cleaning Techno-Regulatory Elements. In: Johansson, T.M., Dalaklis, D., Fernández, J.E., Pastra, A., Lennan, M. (eds) *Smart Ports & Robotic Systems*. Studies in National Governance and Emerging Technologies. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-031-25296-9_20

Poggi, L., Gaggero, T., Gaiotti, M., Ravina, E. and Rizzo, C.N. (2020) "Recent developments in remote inspections of ship structures", *International Journal of Naval Architecture and Ocean Engineering*, 12, pp. 881–891. doi:10.1016/j.ijnaoe.2020.09.001.

Rébé N (2021) Future military scenarios. *Artificial Intelligence: Robot Law, Policy and Ethics*. Brill Nijhoff

Talley, W. (2009). Container port efficiency and output measures. 50th Annual Transportation Research Forum 2009, 1. Available at: https://ageconsearch.umn.edu/record/207601/files/2009_31_ContainerPortEfficiency_paper.pdf (Accessed 25 May 2022)

Wang, J. (2021). "Blockchain technology for port logistics capability: Exclusive or sharing". *Transportation research. Part B: methodological* (0191-2615), 149 , p. 347.

World Maritime University (2019) Transport 2040: Automation Technology Employment - the Future of Work. Available at:
https://commons.wmu.se/lib_reports/58/

Yang, C.-S. (2019) "Maritime shipping digitalization: Blockchain-based technology applications, future improvements, and intention to use". *Transportation Research Part E: Logistics and Transportation Review*, 131, pp.108–117.
doi:<https://doi.org/10.1016/j.tre.2019.09.020>.