AUTONOMOUS SURFACE VESSELS AND COLREGs: CONSIDERING THE AMENDMENTS

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Unmanned vessels have been receiving increasing attention over the past few years. In the research and development sector, Autonomous Surface Vessels have been used for over a decade with different degrees of autonomy. The most advanced vessels are already (circum) navigating the oceans, and the question is raised to what extent they are aligned with relevant international maritime legislation. Currently, there is a noted lack of concrete legal clarification on how to adapt Autonomous Surface Vessels to legal instruments such as the 1972 Convention on the International Regulations for Preventing Collisions at Sea (COLREGs). This paper examines to what extent a fully Autonomous Surface Vessel can comply with a possible amended version of COLREGs. The analysis is conducted from legal and technical perspectives.

***Keywords**: COLREGs; Autonomous Surface Vessels; ASV; unmanned vessels; autonomous vessels; regulatory changes.*

***Glossary*:**

AI – Artificial Intelligence

ASVs – Autonomous Surface Vehicles

AUVs – Autonomous Underwater Vehicles

CMI – Comité Maritime International

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COLREGs – 1972 Convention on the International Regulations for Preventing Collisions at Sea

IACS – International Association of Classification Societies

IMO – International Maritime Organization

ISO – International Organization for Standardization

MASS – Maritime Autonomous Surface Ships

MSC – Maritime Safety Committee

ROVs – Remotely Operated Vehicles

TRLs – Technology Readiness Levels

UK – United Kingdom

UMS – Unmanned Maritime Systems

1. INTRODUCTION

Introducing autonomous operation technology in the maritime domain is not a novel enterprise. In the underwater realm, generally, the first attempts of unmanned vessels date to the late 19th century with the first self-propelled torpedoes. Remotely Operated Vehicles (ROVs) have been used since the 1960s, initially for scientific purposes, followed by commercial exploitation (seabed and related operations). Autonomous Underwater Vehicles (AUVs) saw a boom in the 1990s[1] and are being used for many purposes. More precisely, on the surface level, the first remotely controlled small boat was tested by Nikola Tesla in 1898,[2] while the more frequent use of remotely controlled vessels began in the aftermath of the Second World War.[3] In recent decades, small Autonomous Surface Vehicles (ASVs)[4] have been used both for military and civilian applications, including oceanography, hydrographic surveys, seabed mapping, inspection, and surveillance.

1 Curtin, T. B.; Bellingham, J. G.; Catipovic, J.; Webb, D., Autonomous Oceanographic Sampling Networks, *Oceanography*, vol. 6 (1993), no. 3, pp. 86-94.

2 Tesla, N., Method of and Apparatus for Controlling Mechanism of Moving Vessels or Vehicles, Patent US613809a, 1898, https://patents.google.com/patent/US613809A/en (15 December 2021).

3 National Research Council, *Autonomous Vehicles in Support of Naval Operations*, National Academies Press, Washington, 2005.

4 Sometimes also referred to as Unmanned Surface Vehicles/Unmanned Surface Vessels (USVs) or Autonomous Surface Crafts (ASCs).

Until now, limited regulatory attention has been given to these, primarily small, ASVs. However, as Veal *et al.*[5] mention, the small size and the restricted operational areas may justify the lack of specific (international and/or domestic) regulation. Indeed, the fact that such vessels do not generally engage in international voyages makes each state responsible for the regulation of ASVs operating in their respective internal waters. While this can be advantageous for stimulating research and development, allowing for various and unlimited testing opportunities, the lack of concrete regulation can be problematic in the long run,[6] especially considering the projected widespread adoption of such vessels in commercial trade.

In recent years, small ASVs have undertaken international voyages (including circumnavigating the globe), highlighting the need for a proper global framework. Simultaneously, medium-size and larger ASVs are emerging both for military and civilian purposes, and the shipping industry is expressing an interest in using them.[7]

5 Veal, R.; Tsimplis, M., The Integration of Unmanned Ships into the Lex Maritima, *Lloyd's Maritime and Commercial Law Quarterly*, Part 2 (2017), p. 306.

6 Veal, R.; Tsimplis, M.; Serdy, A., The Legal Status and Operation of Unmanned Maritime Vehicles, *Ocean Development & International Law*, vol. 50 (2019), no. 1, p. 26.

7 Blanke, M.; Henriques, M.; Bang, J., A Preliminary Analysis on Autonomous Ships, Technical Report, *Technical University of Denmark*, 2016, https://dma.dk/growth-and-framework-conditions/maritime-digitalization/regulation-and-reports-about-maritime-technology (15 December 2021); Rylander, R.; Man, Y., Autonomous Safety on Vessels – An International Overview and Trends within the Transport Sector, Technical Report, *Lighthouse*, 2016, https://lighthouse.nu/en/publications/lighthouse-reports/autonomous-safety-on-vessels (15 December 2021); Danish Maritime Authority, Analysis of Regulatory Barriers to the Use of Autonomous Ships, Final Report, Danish Maritime Authority, 2017, https://dma.dk/growth-and-framework-conditions/maritime-digitalization/regulation-and-reports-about-maritime-technology (15 December 2021); One Sea, DIMECC Opens the First Globally Available Autonomous Maritime Test Area on the West Coast of Finland – One Sea Implementation Moves Forward, 2017, https://www.oneseaecosystem.net/dimecc-opens-first-globally-available-autonomous-maritime-test-area-west-coast-finland-one-sea-implementation-moves-forward/ (15 December 2021); Nikkei, Japan Aims to Launch Self-piloting Ships by 2025, 2017, https://asia.nikkei.com/Business/Deals/Japan-aims-to-launch-self-piloting-ships-by-2025?page=1 (15 December 2021); Mayflower Autonomous Ship, 2021, https://mas400.com/ (15 December 2021); Ringbom, H.; Collin, F.; Viljanen, M., Legal Implications of Remote and Autonomous Shipping, in *AAWA White Paper, Remote and Autonomous Ships: The Next Steps*, Rolls-Royce plc, 2016, https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/aawa-whitepaper-210616.pdf (15 December 2021); ABB, ABB Enables Groundbreaking Trial of Remotely Operated Passenger Ferry, 2018, https://new.abb.com/news/detail/11632/abb-enables-groundbreaking-trial-of-remotely-operated-passenger-ferry (15 December 2021); Rolls-Royce, Rolls-Royce and Finferries Demonstrate World's First Fully Autonomous Ferry, 2018, https://www.rolls-royce.com/media/press-releases/2018/03-12-2018-rr-and-finferries-demonstrate-worlds-first-fully-autonomous-fer-

The International Maritime Organization (IMO)[8] has recently defined such vessels as Maritime Autonomous Surface Ships (MASS), stating that such vessels can, to a varying degree, operate independently of human interference, with various (four) levels of autonomy.[9] The IMO initiated a scoping exercise within its Maritime Safety Committee (MSC) in 2017 to assess which of the presently adopted and enforced international maritime legislation could potentially include MASS without any need for legislative change, which legislation would require possible amendments, and whether there is international legislation in force that cannot accept the operation of MASS.[10] In addition, classification

ry.aspx (15 December 2021). For reviews of unmanned and autonomous ships, innovative applications, potential business models, challenges and threats, see Komianos, A., The Autonomous Shipping Era. Operational, Regulatory, and Quality Challenges, *TransNav, The International Journal on Marine Navigation and Safety of Sea Transportation*, vol. 12 (2018), no. 2, pp. 335-348; Munim, Z. H., Autonomous Ships: A Review, Innovative Applications and Future Maritime Business Models, *Supply Chain Forum: An International Journal*, vol. 20 (2019), no. 4, pp. 266-279; Felski, A.; Zwolak, K., The Ocean-Going Autonomous Ship—Challenges and Threats, *Journal of Marine Science and Engineering*, vol. 8 (2020), no. 1. For discussions on their safety and the human factor, see Hoem, Å.; Porathe, T.; Rødseth, Ø.; Fjørtoft, K.; Johnsen, S. O., At Least as Safe as Manned Shipping? Autonomous Shipping, Safety and "Human Error", in Haugen, S.; Barros, A.; Gulijk, van C.; Kongsvik, T.; Vinnem, J. E. (eds.), *Safety and Reliability – Safe Societies in a Changing World, Proceedings of ESREL 2018*, CRC Press, London, 2018, pp. 417-425; Hoem, A. S.; Fjørtoft, K.; Rødseth, Ø. J., Addressing the Accidental Risks of Maritime Transportation: Could Autonomous Shipping Technology Improve the Statistics?, *TransNav, The International Journal on Marine Navigation and Safety of Sea Transportation*, vol. 13 (2019), no. 3, pp. 487-494; Ramos, M. A.; Utne, I. B.; Mosleh, A., Collision Avoidance on Maritime Autonomous Surface Ships: Operators' Tasks and Human Failure Events, *Safety Science*, vol. 116 (2019), pp. 33-44.

8 International Maritime Organization, Maritime Safety Committee (MSC), 98th session, 7-16 June 2017, https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MSC-98th-session.aspx (15 December 2021).

9 International Maritime Organization, IMO Takes First Steps to Address Autonomous Ships, 2018, https://www.imo.org/en/MediaCentre/PressBriefings/Pages/08-MSC-99-MASS-scoping.aspx (15 December 2021).

10 Other bodies have, since then, taken part in the exercise, including the Legal Committee and the Facilitation Committee. Nonetheless, the IMO MSC scoping exercise, while being an essential step towards the development and regulation of MAAS, has not been without criticism in the literature. For instance, in Veal, R., Maritime Autonomous Surface Ships: Autonomy, Manning and the IMO, *Lloyd's Shipping & Trade Law*, vol. 18 (2018), no. 5, p. 3, the author identifies the possibly missed opportunity to precisely clarify the concept of autonomy and its relationship with ship manning. Indeed, even if they are provisional, the four degrees of the scoping exercise mix the autonomy level and the presence of humans on board. It would be possible to have a fully autonomous ship with humans on board, but the definition of level four is not clear about this. Similarly, the degree of autonomy between level two and three does not change considerably if the presence

societies have been taking steps to publish studies, position papers, codes,[11] and guidelines for autonomous and remotely controlled ship design, construction, and cybersecurity.[12] For instance, the International Association of Classification Societies (IACS) has concluded that 47% of IACS-relevant regulations require humans on board.[13] In addition, the International Organization for Standardization (ISO) has established a Working Group ISO/TC8/WG10 on Smart Shipping.

In parallel to the IMO work, there have been other developments, both national and international. In particular, the Nordic countries are very active. Sweden, Denmark, Finland, and Norway support investments in this field. In particular, the Norwegian Forum for Autonomous Ships and the International Network for Autonomous Ships have been established to exchange knowledge and expertise. Test areas have been created in Finland,[14] Norway, Belgium, the Netherlands,[15] the United States, and Canada. At the European level, the European Defence Agency created in 2012 (updated in 2015) the Safety and Regulations for European Unmanned Maritime Systems that produces practices for the handling, operations, design, and regulation of Unmanned Maritime Systems

of seafarers on board does not affect the control system. Another work (Ringbom, H., Regulating Autonomous Ships—Concepts, Challenges and Precedents, *Ocean Development & International Law*, vol. 50 (2019), no. 2, pp. 141-169) criticises the fact that the scoping exercise currently does not include grades of autonomy or partial removal of crews. This author concurs with the abovementioned work concerning the possible confusion generated by the mix between levels of autonomy (in grades one and four) and manning (two and three). These issues are part of the reason the current paper addresses only the fully autonomous case.

11 See, for example Lloyd's Register, LR Code for Unmanned Marine Systems, Guidance Document, 2017, https://www.lr.org/en-gb/unmanned-code/ (15 December 2021).

12 See, for example DNV GL, Class Guideline DNVGL-CG-0264 Autonomous and Remotely Operated Ships, 2021, https://rules.dnv.com/docs/pdf/DNV/CG/2021-09/DNV-CG-0264.pdf (15 December 2021); Bureau Veritas, Guidelines for Autonomous Shipping. Tech. Rep., 2019, https://erules.veristar.com/dy/data/bv/pdf/641-NI_2019-10.pdf (15 December 2021); Lloyd's Register, Cyber-enabled Ships: ShipRight Procedure Assignment for Cyber Descriptive Notes for Autonomous & Remote Access Ships, Guidance Document Version 2.0, 2017, https://www.lr.org/en/cyber-safe-for-marine/ (15 December 2021).

13 Reilly, G., IACS high level Position on MASS, *5th Maritime Autonomous Systems Regulatory Working Group Conference: Maritime Autonomous Surface Ship (MASS) Regulation – The Tide Has Turned*, 2020, https://www.maritimeuk.org/documents/528/George_Reilly.pdf (15 December 2021).

14 One Sea, *op. cit*.

15 De Vlaamse Waterweg nv, Smart Shipping Code of Practice for Testing in Flanders. Tech. Rep., 2018, https://www.vlaamsewaterweg.be/sites/default/files/download/smart_shipping_code_of_conduct.docx (15 December 2021).

(UMS).[16] More recently, the European Maritime Safety Agency has commissioned a study on the emerging risks and regulatory gaps following the introduction of various degrees of autonomy in ships.[17] A few years ago, the Comité Maritime International (CMI) created a Working Group on Maritime Law for Unmanned Crafts that produced a position paper[18] and a questionnaire.[19] The United Kingdom (UK) Maritime Autonomous Systems Regulatory Working Group issued a Code of Conduct in 2016[20] and a Code of Practice for MASS up to 24 metres in length in 2017, updated yearly.[21] The latest version requires that vessels operating outside UK waters are registered as UK vessels.[22] The UK has been a pioneer in this area as the first unmanned vessel was registered in the UK Ship Register in late 2017.[23]

According to the Global Marine Technology Trends 2030 Autonomous Systems report,[24] the way forward should include a mixture of self-regulation and formal regulation. The report highlights the need to distinguish between operational uses and tests, and to assess the risk posed by developing national

[16] European Defence Agency, Working Paper – Best Practice Guide for UMS Handling, Operations, Design and Regulations. EDA SARUMS Working Paper, 2012.

[17] European Maritime Safety Agency, Maritime Autonomous Surface Ships (MASS), 2021, https://emsa.europa.eu/mass.html (15 December 2021).

[18] Comité Maritime International, CMI International Working Group Position Paper on Unmanned Ships and the International Regulatory Framework, 2018, https://comitemaritime.org/wp-content/uploads/2018/05/CMI-Position-Paper-on-Unmanned-Ships.pdf (15 December 2021).

[19] Comité Maritime International, CMI Questionnaire on Unmanned Ships, 2017, https://comitemaritime.org/wp-content/uploads/2018/05/CMI-IWGUS-Questionnaire-24-03-2017.docx (15 December 2021).

[20] UK Marine Industries Alliance, The Maritime Autonomous Systems Surface, MAS(S) Industry Code of Conduct, Technical Report, Society of Maritime Industries, 2016, https://www.maritimeuk.org/documents/228/UK-MIA-MAS-CoC-2016.pdf (15 December 2021).

[21] Maritime UK, Being a Responsible Industry: An Industry Code of Practice Version 3, Technical Report, Society of Maritime Industries, 2019, https://www.maritimeuk.org/documents/478/code_of_practice_V3_2019_8Bshu5D.pdf (15 December 2021).

[22] Cartwright, A., Vessel Standards, 5th Maritime Autonomous Systems Regulatory Working Group Conference: Maritime Autonomous Surface Ship (MASS) Regulation – The Tide Has Turned, 2020, https://www.maritimeuk.org/documents/521/Alan_Cartwright.pdf (15 December 2021).

[23] UK Ship Register, UK Ship Register Signs its First Unmanned Vessel, 2017, https://www.ukshipregister.co.uk/news/uk-ship-register-signs-its-first-unmanned-vessel/ (15 December 2021).

[24] Lloyd's Register, QinetiQ, University of Southampton, Global Marine Technology Trends 2030 Autonomous Systems, 2017, https://www.lr.org/en/insights/global-marine-trends-2030/technology-trends/ (15 December 2021).

rules separately, followed by harmonising such rules globally. Certain authors[25] suggest that regulatory considerations must consider different vessels and their inherently different Technology Readiness Levels (TRLs). Simultaneously, standardisation is needed across all aspects of ASVs/MASS. Standardisation is also included in the effort made by the IMO MSC. The IMO has published Interim Guidelines regarding the conducting of trials.[26] These Guidelines define a trial as an "…experiment or series of experiments, conducted over a limited period, to evaluate alternative methods of performing specific functions or satisfying regulatory requirements prescribed by various IMO instruments, which would provide at least the same degree of safety, security, and protection of the environment as provided by those instruments".[27] The focus is placed on the safety and the need for MASS to be as safe as their manned counterparts.[28] The Guidelines require a risk assessment to be continuously reviewed and that trials be stopped whenever safety parameters are not respected.[29] At the same time, the Guidelines allow for some flexibility and

25 Veal, R. *et al.*, The Legal …, *op. cit.*, pp. 23-48.

26 International Maritime Organization, Interim Guidelines for MASS Trials MSC 1/circ. 1604, 2019, https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/MSC.1-Circ.1604-InterimGuidelinesForMassTrials(Secretariat).pdf (15 December 2021). The first trial following these Guidelines took place in Japan in September 2019. See NYK, NYK Conducts World's First Maritime Autonomous Surface Ships Trial, 2019, https://www.nyk.com/english/news/2019/20190930_01.html (15 December 2021).

27 *Ibid*., p. 2.

28 According to some authors, the societal perception of risk and acceptance of Artificial Intelligence (AI) will need to increase, and technology will need to be able to demonstrate the ability to avoid failure, or fail at least less than humans do in practice (as one of the reasons to use MASS is the avoidance or minimising of human error). For more, see Veal, R. *et al*., The Integration …, *op. cit*, p. 335. In accordance with some studies, society at large better accepts accidents caused by humans than accidents caused by machines. See, for example Bergström, M.; Hirdaris, S.; Valdez Banda, O. A.; Kujala, P.; Sormunen, O. V.; Lappalainen, A., Towards the Unmanned Ship Code, in Kujala, P.; Lu L. (eds.), *Marine Design XIII, Proceedings of the 13th International Marine Design Conference (IMDC 2018)*, CRC Press/Balkema, London, vol. 2 (2018), p. 885. Some authors go beyond this and require proof that MASS/ASV operational safety is higher than manned vessels precisely because of the sceptical public. See, for example Pritchett, P. W., Ghost Ships: Why the Law Should Embrace Unmanned Vessel Technology, *Tulane Maritime Law Journal*, vol. 40 (2016), no. 1, p. 224.

29 Risk-based regulation and certification are also proposed by Johnsen, S.; Hoem, Å.; Stalhane, T.; Jenssen, G.; Moen, T., Risk-based Regulation and Certification of Autonomous Transport Systems, in Haugen, S.; Barros, A.; Gulijk, van C.; Kongsvik, T.; Vinnem, J. E. (eds.), *Safety and Reliability – Safe Societies in a Changing World*, *Proceedings of ESREL 2018*, CRC Press, London, 2018, pp. 1791-1799.

note that"…compliance with the intent of mandatory instruments should be ensured…", allowing for "… alternative methods" concerning compliance with IMO instruments.[30] This flexibility is essential when reviewing MASS compatibility with the current regulatory schemes. The Guidelines also require appropriate means for communication and data exchange that are seen as vital aspects at all levels of autonomous operation as they allow for human remote control.

As emphasised in the Guidelines, safety is of utmost importance. Several international treaties deal with safety at sea, including the 1972 Convention on International Regulations for Preventing Collisions at Sea (COLREGs).[31] Due to the paramount importance of COLREGs – relevant for collision avoidance between vessels – this paper will focus on that Convention, offering a possible interpretation and *pro futuro* modification of COLREGs regarding small ASVs that already achieve higher TRL (or commercial maturity). The paper does not address the verification process of compliance as per Part F, COLREGs.[32] Neither are the issues of liability, insurance,[33] or maritime cybersecurity considered.

Section 2 describes the state of the art in the application of COLREGs to ASVs, both from the legal and technical aspects. Section 3 discusses the use of small, potentially fully autonomous ASVs. Section 4 briefly presents the different approaches for the modification of COLREGs in line with ASVs/MASS as discussed

30 International Maritime Organization, Interim Guidelines…, *op. cit.*, p. 2.

31 Convention on the International Regulations for Preventing Collisions at Sea, 1972, United Nations Treaty Series 1050, 1977, p. 16.

32 Compliance is briefly discussed at the end of Section 2. Part E of COLREGs deals with exemptions. There may be a need for new exemptions for ASVs, but this should come from the needs of the industry and performance testing results. Part F of COLREGs would need to be updated accordingly once it is agreed who the certification and compliance verification authority will be.

33 These have been widely treated in the literature, including discussions regarding which type of liability regime should apply for what level of autonomy. See Ferreira, F.; Alves, J.; Bertolini, A.; Bargelli, E., Liability Issues of Unmanned Surface Vehicles, *OCEANS 2018,* MTS/IEEE, Charleston, 2018, pp. 1-6; Veal, R.; Tsimplis, M.; Serdy, A.; Quinn, S.; Ntovas, A., Liability for operation in Unmanned Maritime Vehicles with Differing Levels of Autonomy, Technical Report, European Defence Agency, 2016, https://www.academia.edu/38566149/Project_title_Liability_for_operations_in_Unmanned_Maritime_Vehicles_with_Differing_Levels_of_Autonomy_Deliverable_Final_Report (15 December 2021). Recently, some companies have started to offer insurance policies for autonomous maritime vessels. See Howse, T., Maritime Autonomous Surface Ships – Identifying and Covering the Risks, Gard, 2019, http://www.gard.no/web/updates/content/27188643/maritime-autonomous-surface-ships-identifying-and-covering-the-risks (15 December 2021); Shipowners' Club, Liability Insurance for Owners and Operators of Maritime Autonomous Vessels, 2018, https://www.shipownersclub.com/insurance/autonomous/ (15 December 2021).

in the literature. Section 5 focuses on issues related to the compliance of ASVs with (the possibly amended) COLREGs. Section 6 details possible clarifications and amendments. Finally, Section 7 provides concluding thoughts, including suggestions for future research.

2. STATE OF THE ART

One of the most challenging questions regarding ASVs/MASS is whether such vessels can be considered ships or vessels under the current regulatory framework. The terms "ship" or "vessel" vary from non-existent to unclear in several international treaties and national regulations.[34] In particular, when it comes to COLREGs, a vessel "… includes every description of watercraft, including non-displacement craft, WIG craft, and seaplanes, used or capable of being used as a means of transportation on water" (Rule 3.a). This definition requires the capability of being used as a means of transportation. Some authors[35] believe that ASVs could fall into this category as they regularly carry sensors that could be identified as cargo. This interpretation is disputed in the literature,[36] and other authors consider that the transportation requirement excludes ASVs from the noted definition.[37] According to others,[38] COLREGs cover ASVs even if they are not used as a means of transportation, such as dredgers and pipeline laying vessels. As the definition of a vessel does not require that an autonomous vessel is being used for any transportation purposes, but rather only to have the capacity of doing so (no matter what the actual object of carriage is), it is reasonable to assume that autonomous vessels do fall under the scope of the definition of a vessel per COLREGs.[39] It is worth pointing out that in practice

34 Allen, C., Determining the Legal Status of Unmanned Maritime Vehicles: Formalism vs Functionalism, *SSRN Electronic Journal*, Bristol, vol. 49 (2018), no. 4, pp. 17-20. See also Rodriguez Delgado, J. P., The Legal Challenges of Unmanned Ships in the Private Mar-itime Law: What Laws Would You Change?, in Musi, M. (ed.), *Maritime, Port and Transport Law between Legacies of the Past and Modernization, Diritto marittimo – Quaderni*, vol. 5, Bonomo, Bologna, 2018, pp. 498-502.

35 Showalter, S.; Manley, J., Legal and Engineering Challenges to Widespread Adoption of Unmanned Maritime Vehicles, *OCEANS 2009*, IEEE, Biloxi, 2009, p. 1.

36 Veal, R. *et al*., The Legal …, *op. cit.*, p. 43.

37 Veal, R. *et al*., The Integration …, *op. cit.*, p. 308.

38 Giunta, L., The Enigmatic Juridical Regime of Unmanned Maritime Systems, *OCEANS 2015*, IEEE, Genoa, 2015, p. 4.

39 Compare with the work of the International Working Group Maritime Law for MASS: Comité Maritime International, CMI IWG Submission to MSC 99COLREGs. Part A. General, Rule 1 – Application, 2018, https://comitemaritime.org/work/mass/ (15 December 2021).

many studies use COLREGs both in simulation[40] and in real tests.[41]

Even if COLREGs excluded ASVs due to the lack of transportation capabilities, some authors propose that they comply with COLREGs by following the good seamanship/duty of care principle as this principle is the overarching standard. For instance, the US Navy aims to ensure that their ASVs comply as much as possible with COLREGs even if they are not used as a means of transportation. See Kraska, J., The Law of Unmanned Naval Systems in War and Peace, *The Journal of Ocean Technology*, vol. 5 (2010), no. 3, p. 52. An alternative is to call ASVs devices, but UNCLOS (United Nations Convention on the Law of the Sea, 1982, United Nations Treaty Series 1833, 1994, p. 396) does not define the term "device". Nevertheless, while this could work for some of the small ASVs treated here, it could not be extended to some of the larger ASVs/MASS. Another hypothesis suggested by the same author is to consider ASVs as equipment (launched by a ship for marine research). This option could work for some ASVs, but not all of them are currently launched by ships.

[40] Benjamin, M. R.; Curcio, J. A., COLREGS-based Navigation of Autonomous Marine Vehicles, *2004 IEEE/OES Autonomous Underwater Vehicles*, IEEE, Sebasco, 2004, pp. 32-39; Beser, F.; Yildirim, T., COLREGS Based Path Planning and Bearing Only Obstacle Avoidance for Autonomous Unmanned Surface Vehicles, *Procedia Computer Science*, vol. 131 (2018), pp. 633-640; Blaich, M.; Rosenfelder, M.; Schuster, M.; Bittel, O.; Reuter, J., Extended Grid Based Collision Avoidance Considering COLREGs for Vessels, *IFAC Proceedings Volumes*, vol. 45 (2012), no. 27, pp. 416-421; Campbell, S.; Naeem, W., A Rule-based Heuristic Method for COLREGS-compliant Collision Avoidance for an Unmanned Surface Vehicle, *IFAC Proceedings Volumes*, vol. 45 (2012), no. 27, pp. 386-391; Chiang, H. L.; Tapia, L., COLREG-RRT: An RRT-based COLREGS-Compliant Motion Planner for Surface Vehicle Navigation, *IEEE Robotics and Automation Letters*, vol. 3 (2018), no. 3, pp. 2024-2031; Hu, L.; Naeem, W.; Rajabally, E.; Watson, G.; Mills, T.; Bhuiyan, Z.; Raeburn, C.; Salter, I.; Pekcan, C., A Multiobjective Optimization Approach for COLREGs-Compliant Path Planning of Autonomous Surface Vehicles Verified on Networked Bridge Simulators, *IEEE Transactions on Intelligent Transportation Systems*, vol. 21 (2020), no. 3, pp. 1167-1179; Lee, S.-M.; Kwon, K.-Y.; Joh, J., A Fuzzy Logic for Autonomous Navigation of Marine Vehicles Satisfying COLREG Guidelines, *International Journal of Control Automation and Systems*, vol. 2 (2004), no. 2, pp. 171-181; Shah, B. C.; Svec, P.; Bertaska, I. R.; Sinisterra, A. J.; Klinger, W.; Ellenrieder, von K.; Dhanak, M.; Gupta, S. K., Resolution-adaptive Risk-aware Trajectory Planning for Surface Vehicles Operating in Congested Civilian Traffic, *Autonomous Robots*, vol. 40 (2016), no. 7, pp. 1139-1163.

[41] Bertaska, I. R.; Shah, B.; Ellenrieder, von K.; Svec, P.; Klinger, W.; Sinisterra, A. J.; Dhanak, M.; Gupta, S. K., Experimental Evaluation of Automatically-generated Behaviors for USV Operations, *Ocean Engineering*, vol. 106 (2015), pp. 496-514; Hagen, I. B.; Kufoalor, D. K. M.; Brekke, E. F.; Johansen, T. A., MPC-based Collision Avoidance Strategy for Existing Marine Vessel Guidance Systems, *2018 IEEE International Conference on Robotics and Automation (ICRA),* Gold Coast, 2018, pp. 7618-7623; Han, J.; Cho, Y.; Kim, J.; Kim, J.; Son, N-s.; Kim, S. Y., Autonomous Collision Detection and Avoidance for ARAGON USV: Development and Field Tests, *Journal of Field Robotics*, vol. 37 (2020), no. 6, pp. 987-1002; Kufoalor, D. K. M.; Johansen, T. A.; Brekke, E. F.; Hepsø, A.; Trnka, K., Autonomous Maritime Collision Avoidance: Field Verification of Autonomous Surface Vehicle Behavior in Challenging Scenarios, *Journal of Field Robotics*, vol. 37 (2020), no. 3, pp. 387-403; Kuwata, Y.; Wolf, M. T.;

The possible modification and utilisation of COLREGs for MAAS operations have been discussed over the years. One of the most relevant issues concerning MASS and COLREGs is not how well an autonomous vessel can comply with the existing (or slightly modified) COLREGs Rules, but, rather, does such a vessel have the capacity to think outside the box as is expected by ordinary seafarers as per Rule 2(b) (departure from COLREGs Rules when necessary) and other relevant norms?[42] At the moment, most theoretical and practical studies are centred on COLREGs compliance. One such recent example[43] demonstrates COLREGs compliance in an authentic maritime traffic scenario under the direction of independent authorities. Although that specific study and similar studies claim COLREGs compliance, the definition of such compliance for unmanned vessels remains a research question in itself. It is still unclear what the compliance of autonomous vessels with COLREGs means and what verification process would ensure such compliance. An additional difficulty with the noted assessment is the currently dubious availability of clear metrics (quantitative data) and a qualitative evaluation criterion necessary for a machine learning algorithm to successfully comply with the set rules and procedures of COLREGs. The issue is further complicated when considering the ramification of Rule 2(b) and other relevant norms. Some authors suggest[44] that any certification should be done by the same authority supervising manned vessels (Flag State responsibility), focusing on specific issues (electronic look-outs and detection capabilities). One

Zarzhitsky, D.; Huntsberger, T. L., Safe Maritime Autonomous Navigation with COLREGS, Using Velocity Obstacles, *IEEE Journal of Oceanic Engineering*, vol. 39 (2014), no. 1, pp. 110-119; Perera, L. P.; Ferrari, V.; Santos, F. P.; Hinostroza, M. A.; Guedes Soares, C., Experimental Evaluations on Ship Autonomous Navigation and Collision Avoidance by Intelligent Guidance, *IEEE Journal of Oceanic Engineering*, vol. 40 (2015), no. 2, pp. 374-387.

42 See Karbowska-Chilinska, J.; Koszelew, J.; Ostrowski, K.; Kuczynski, P.; Kulbiej, E.; Wolejsza, P., Beam Search Algorithm for Ship Anti-collision Trajectory Planning, *Sensors*, vol. 19 (2019), no. 24, pp. 1-15. This paper highlights the current situation where, in many cases, COLREGs are not and cannot be respected, either in critical situations or when vessels do not fulfil safe speed requirements due to massive delays and interruptions of port and vessel schedules. While it is possible to depart from COLREGs if needed (the situation forecast in Rule 2(b) of COLREGs), the algorithm presented in Karbowska-Chilinska, J. *et al.* departs from COLREGs in other situations besides Rule 2(b). Not respecting COLREGs at all times can result in fuel savings and shorter routes while still keeping a safe distance (when compared to a COLREGs based navigation system). This algorithm is something worth exploring for the more distant future when all ships may become autonomous.

43 Kufoalor, D. K. M. *et al.*, Autonomous Maritime…, *op. cit.*, pp. 387-403.

44 Woerner, K., COLREGS-compliant Autonomous Collision Avoidance Using Multiobjective Optimization with Interval Programming, Master's Thesis, Massachusetts Institute of Technology, Department of Mechanical Engineering, Cambridge, MA, 2014, http://hdl.handle.net/1721.1/92956 (15 December 2021).

characteristic of such studies is that authors regularly conclude that a MASS/ASV should be as safe as a vessel operated by a human crew. However, it has not been demonstrated yet (although many trials are being conducted[45]) that both the equipment and the machine learning algorithm behind it can follow and interpret the COLREGs Rules as intended. For cases where COLREGs anticipate a deviation from the set rules, the current state of machine learning cannot fully satisfy all the open-ended questions mentioned above.

3. USE CASE

There are many different unmanned or autonomous vessels with varying degrees of autonomy. As noted earlier, this paper focuses on small research ASVs that already satisfy the highest levels of autonomy (remotely monitored or fully autonomous). Small ASVs are wholly unmanned (with no space for a crew), and some can stay in the ocean for weeks or months with minimal monitoring/remote control. For safety and legal reasons, these ASVs are remotely monitored, but their operation and decision-making are autonomous with minimal human intervention in the event of emergencies.

For example, two Wave Glider ASVs[46] performed over 9,000 nautical miles (16,668 km) in a trans-Pacific voyage crossing from San Francisco, California, to Australasian. Combined with solar energy utilised as power for electronical

[45] A real-time evaluation of COLREGs compliance performed for interactions between manned and unmanned vessels is available in Woerner, K. L.; Benjamin, M. R., Real-Time Automated Evaluation of COLREGS-Constrained Interactions between Autonomous Surface Vessels and Human Operated Vessels in Collaborative Human-Machine Partnering Missions, *OCEANS 2018*, MTS/IEEE Kobe Techno-Oceans, Kobe, 2018, pp. 1-9. A discussion on how to quantify COLREGs protocol evaluation included to establish compliance metrics is available in Woerner, K.; Benjamin, M. R.; Novitzky, M.; Leonard, J. J., Quantifying Protocol Evaluation for Autonomous Collision Avoidance: Toward Establishing COLREGS Compliance Metrics, *Autonomous Robots*, vol. 43 (2019), no. 4, pp. 967-991. The authors go further by proposing a "road test" framework to be used by testing and certifying agencies. See Woerner, K. L.; Benjamin, M. R.; Novitzky, M.; Leonard, J. J., Collision Avoidance Road Test for COLREGS-Constrained Autonomous Vehicles, in *OCEANS 2016*, MTS/IEEE Monterey, 2016, pp. 1-6. Other work that quantitatively evaluates an automatic collision avoidance system and compares it to veteran captain performance can be found in Nakamura, S.; Okada, N., Development of Automatic Collision Avoidance System and Quantitative Evaluation of the Maneuvering Results, *TransNav*, vol. 13 (2019), no. 1, pp. 133-141. Comparing ASV performance to a human-based helm could be fundamental in showing that the ASV can navigate as safely as a human captain.

[46] Hine, R.; Willcox, S.; Hine, G.; Richardson, T., The Wave Glider: A Wave-Powered Autonomous Marine Vehicle, *OCEANS 2009*, IEEE, Biloxi, 2009, pp. 1-6.

equipment, their wave-powered propulsion allowed for more than one year of operation at sea.[47] Long-term autonomy ASVs are present nowadays and are increasingly used for many purposes. While such vehicles cannot be, by definition, considered fully autonomous due to remote human monitoring (with a remote-control option available), they can operate without human intervention in technical terms (a feature regularly included in modern commercial shipping, in a limited, automation form, with exact duration and operational functionality limitations). Pending policy and regulatory actions, such small ASVs that satisfy all technological, safety, security, and related requirements can become fully autonomous (no remote control, human monitoring).

Scientific debate continues related to the type of vessels most suitable for compliance with COLREGs (and other regulations). Some authors believe that remote-control vessels can comply more easily with COLREGs since humans are "in the loop" (control) and can act as remote pilots.[48] Others highlight the need for remote-operated vessels to have enough autonomy to navigate safely should they lose contact with a shore-based control centre[49] (i.e., slow down or stop if communication is lost). Indeed, reliable communications are among the most significant technological barriers, especially considering cybercrime risks associated with current satellite communication systems. Due to the latter point, some authors believe[50] that fully autonomous vessels could be more reliable as their decision-making process does not depend on communication links.

In terms of technology, not all ASVs are designed or ready to be considered as potentially COLREGs compliant, primarily due to their onboard sensor suite, their dynamics, or the lack of a suitable look-out. For example, in the MUNIN EC project, experiments have shown that the specific radar used in their testing could not achieve the desired detection range (4 nautical miles) for a small vessel.[51] However, it was able to detect at a smaller range (1.15 nautical miles), making such

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47 Other recent examples can be found in the literature concerning civilian and military use. See, for example L3 Harris, ASView Control System, L3 Harris, 2021, https://www.l3harris.com/all-capabilities/asview-control-system (15 December 2021); Offshore Sensing AS, Transatlantic Crossing 2018, 2018, http://sailbuoy.no/64-transatlantic-crossing (15 December 2021); Eckstein, M., Sea Hunter Unmanned Ship Continues Autonomy Testing as NAVSEA Moves Forward with Draft RFP, 2019, https://news.usni.org/2019/04/29/sea-hunter-unmanned-ship-continues-autonomy-testing-as-navsea-moves-forward-with-draft-rfp (15 December 2021).

48 Veal, R. *et al*., The Legal…, *op. cit*., pp. 38-40.

49 Ringbom, H., Regulating…, *op. cit*., p. 156.

50 Pritchett, P. W., Ghost Ships..., *op. cit*., p. 200.

51 MUNIN EU Project, D8.6 Final Report: Autonomous Bridge, 2015, http://www.unmanned-ship.org/munin/wp-content/uploads/2015/09/MUNIN-D8-6-Final-Report-Autonomous-Bridge-CML-final.pdf (15 December 2021).

vessels suitable only for shorter-range detection (thus, in a short-range operational area).[52] Moreover, different sensing modalities exhibit deficiencies depending on the weather and other sea-related circumstances. Radar performs poorly in rainy scenarios, high sea states, dense traffic, short ranges, and with small targets. Optical cameras are strongly affected by weather (good and bad weather, i.e., lighting variations), while lidar has a limited range and is affected by rain.[53] It is equally relevant to note that autonomous vessels will suffer additional issues already present in standard shipping. Collision avoidance systems can experience difficulties distinguishing between different types of vessels.[54] Different ASVs can have vari-

52 Nevertheless, shorter detection ranges could potentially meet the safety requirements of a small ASV due to its high manoeuvrability. While a tanker has high inertia, low manoeuvrability, and slow dynamics/response time and thus requires a higher detection range to avoid collisions, a small ASV can change course quickly to avoid any other vessels and thus can work with smaller detection ranges. Other systems already in use, such as the automated radar plotting aid (ARPA) that displays position, course, and speed for each target and signals when it detects a risk of collision, can be integrated with other sensors as well. On the other hand, as in manned vessels, if the gathered information is not enough to assess the situation, steps can be taken either to gather more information or decrease the requirements by adopting a lower speed or stopping in an extreme case.

53 Fralick, C., Challenges and Mitigations in Multi-modal Perception Systems for Unmanned Vessels, *5th Maritime Autonomous Systems Regulatory Working Group Conference: Maritime Autonomous Surface Ship (MASS) Regulation – The Tide Has Turned*, 2020, https://www.maritimeuk.org/documents/536/Chuck_Fralick.pdf (15 December 2021).

54 Veal, R. *et al*., The Integration…, *op. cit*., p. 326. The same is true despite mechanisms such as sensor fusion techniques, the Automatic Identification System, Global Navigation Satellite Systems, the Global Positioning System, and others. It must be noted that the mentioned systems are not all immune to spoofing, jamming, hacking and other issues. Quantum positioning is emerging as a secure, hack-proof technique for navigation, possibly offering a more secure system. For more on this point, see Duan, S.; Cong, S.; Song, Y., A Survey on Quantum Positioning System, *International Journal of Modelling and Simulation*, vol. 41 (2020), no. 4, pp. 265-283. Among the technological issues, several authors mention that advances in the above water acoustic recognition are still needed to quickly recognise all sounds emitted by other vessels (Woerner, K., COLREGS-compliant..., *op. cit*., pp. 119-121; Fralick, C., Challenges…, *op. cit*.). This recognition is affected by ambient noise and can suffer in high traffic areas. However, this may be achievable in the short term, as music recognition algorithms show (Fralick, C., Challenges…, *op. cit*.). Similar hearing requirements have been addressed since the introduction of enclosed bridges (Ringbom, H., Regulating…, *op. cit*., p. 153). The way the SOLAS Convention (International Convention for the Safety of Life at Sea, 1974, United Nations Treaty Series 1184, 1981, p. 2) addressed this was to require a sound reception system. A similar technique can be used for ASVs. Other possible areas of improvement are Very High Frequency (VHF) simulated voice communications and speech processing (Woerner, K., COLREGS-compliant..., *op. cit*., pp. 122-124), and there are promising experiments in this area as well. See Namgung, H.; Jeong, J. S.; Choi, J.-C.; Geun-ung, K.; Sun-Young, K., An Experimen-

ous types of sensors and TRLs. Potentially, small ASVs could even be exempted from using expensive sensors.[55]

Additionally, different performance requirements could apply to ASV/MASS perception systems. Larger vessels should have higher performance systems. Defining minimal requirements for the sensor suite and quantifying each ASV collision avoidance system and its compliance with the different COLREGs Rules are a challenge. Still, a roadmap to that end does exist.[56] However, a legal framework should be ready when small ASVs start flooding the market and are technologically ready to comply with all the COLREGs Rules. The next section will therefore present a hypothetical scenario where a small ASV has successfully satisfied the technological (both equipment and machine learning) challenges discussed above and is ready to be examined according to regulatory compliance with COLREGs.[57]

4. COLREGs ADAPTATION

There is a need to determine to what extent ASVs (and MASS in general) are compliant with the current regulatory regime. Such vessels and their autonomous and unmanned characteristics pose various issues and open-ended questions. The current regulation heavily depends on human presence onboard, with automation processes viewed as an auxiliary service. To be more precise, the ASV autonomy factor is different from more straightforward automation already addressed by IMO (i.e., autopilot or Dynamic Positioning). On that point, Ringbom[58] suggests that out of the three essential bridge functions – operational tasks, situational awareness, and decision-making – only the automation of decision-making represents genuine autonomy. By introducing autonomy in the decision-making process, the human element is relegated to an auxiliary role (in remote-controlled vessels, monitored vessels) or eliminated (fully autonomous vessels).

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tal Result on Information Exchange Using USV Communication Relay System, *Journal of Physics: Conference Series*, vol. 1357 (2019), 012043.

55 Fralick, C., Challenges…, *op. cit.*

56 Woerner, K. L. *et al.*, Collision…, *op. cit.*, pp. 1-6.

57 Despite the obvious obstacles, primarily focused on machine learning algorithms and decision-making when departure from COLREGs is required, there are some companies that are boldly claiming that their ASVs are compliant with the original COLREGs. See L3 Harris: ASView Control System. White Paper, *op. cit.*

58 Ringbom, H., Regulating…, *op. cit.*, p. 149.

COLREGs are among several regulations that make the human element, as the current wording stands, indispensable. While some authors argue for entirely new instruments, as shown previously, in practice, many trials apply COLREGs when testing ASVs. Therefore, it is beneficial to consider the feasibility of using COLREGs and, possibly, to adapt them through clarifications and amendments. Such possible clarifications and amendments can only be acceptable when technological means, especially machine learning capabilities, allow for a straightforward comparison with an ordinary and/or good seafarer's capacity. As noted above, this paper presents a hypothetical scenario where such technological alignment has been satisfied, thus focusing on *pro futuro* legal considerations.

As noted by Allen,[59] COLREGs require a formal approach to any potential interpretation and/or amendment. Given their relevance for global shipping, it is of paramount importance that they are interpreted and applied globally and uniformly. The difficulty with such an approach is the perceived complexity behind any attempt to reach new wording that would satisfy a relevant number of signatories for the changes to take effect. A slightly more straightforward but equally formal approach, as suggested by some authors,[60] is, rather than amending COLREGs, to adopt an annex to COLREGs that would apply to fully autonomous vessels.[61] Although such an approach could be a workaround to a lengthy, formal, rule-by-rule amendment, some authors are critical,[62] pointing out that in the long term, with more and more autonomous vessels navigating the oceans, having a set of rules for manned vessels and an annex for autonomous vessels may not make much sense.[63] A somewhat

59 Allen, C., Determining the Legal Status…, *op. cit.*, pp. 28-29.

60 Cain, F.; Turner, M., New Ships, Old Rules: Updating IMO Rules to Cover Autonomous Ships, 2018, https://www.roboticslawjournal.com/analysis/new-ships-old-rules-updating-imo-rules-to-cover-autonomous-ships-56804504 (15 December 2021).

61 Other authors distinguish the cases of fully autonomous and remote-controlled vessels when it comes to the need for legal adjustment. For instance, Cain (*ibid.*) suggests that either soft law guidance (through clarifications) or modest amendments could be enough for remote-controlled vessels while for fully autonomous ones, significant amendments are needed. This suggestion may be correct when considering large MASS and conventions such as SOLAS, but it is not necessarily true for small, fully autonomous ASVs and COLREGs.

62 Ringbom, H., Regulating…, *op. cit.*, p. 162.

63 *Ibid*. As Ringbom mentions, rule-by-rule amendment could be problematic. One option proposed by this author is to stipulate flexible nonbinding solutions in the short term (for example, by establishing the conditions under which a ship can be autonomous, remote-controlled, or by specifying particular functions that can be automated. See Rødseth, Ø. J.;

bolder approach[64] recommends a set of different regulations for different types of autonomous vessels, depending on their size and transportation capabilities. Finally, several authors support the notion of a completely separate regulation, an example of which being the goal-based Unmanned Ship Code.[65] Such an approach assumes that the requirements, such as manning, watchkeeping, rescue and salvage, and other issues prevent the current legal framework

Lien Wennersberg, L. A.; Nordahl, H., Towards Approval of Autonomous Ship Systems by Their Operational Envelope, *Journal of Marine Science and Technology*, vol. 27 (2022), no. 1, pp. 67-76). It could be argued that these conditions and the weather/sea conditions could be left out of the COLREGs amendment and be implemented as part of the classification and certification process conducted by classification societies and flag states. One possible course of regulatory action worth noting could potentially simplify the compliance difficulties by establishing clear priorities between autonomous and manned vessels. Extreme solutions, such as considering autonomous vessels as "not under command" at all times are impractical. The same applies to the suggestion of considering these vessels as restricted in their ability to manoeuvre or the opposite robot ethical approach according to which autonomous vessels should always give way to manned ships. According to Rule 18, a vessel "not under command" has navigational priority. In the context of autonomous vessels, this could potentially be used for remote-control vessels that lose communication.

64 Veal, R. *et al*., The Legal…, *op. cit.*, p. 40.

65 Bergstrom, M. *et al*., *op. cit*., pp. 881-886. Another option is to follow the IMO guidelines in what regards compliance with the intent of IMO instruments. However, as mentioned in Veal, R., IMO Guidelines on MASS Trials: Interim Observations, *Lloyd's Shipping & Trade Law*, vol. 19 (2019), no. 8, p. 3, one of the issues is to define intent, especially looking at each provision within a given instrument. It is easier to deduce intent if one analyses goal-based approaches to regulation, but most IMO MSC instruments do not adopt that approach (including COLREGs). Indeed, several authors propose using a new goal-based instrument to encompass unmanned ships similar to what has been done with the Polar Code (Eder, B., Inaugural Francesco Berlingieri Lecture Unmanned Vessels: Challenges Ahead, 2018, https://comitemaritime.org/wp-content/uploads/2018/05/Sir-Bernard-Eder-Berlingieri-Lecture-London-Assembly-2018-geconverteerd.pdf (15 December 2021); Ringbom, H., Regulating…, *op. cit*., p. 164; Bergstrom, M. *et al*., *op. cit*., p. 881). The advantage of a goal-based instrument is its flexibility and reduced level of prescription. Under a goal-based instrument, the regulations state goals and functional requirements do not specify the means to achieve those goals and requirements. That becomes the work of flag states, classification societies, and ship constructors. Inspired by the Polar Code, Bergstrom, M. *et al.* follow the same approval principle. However, while the Polar Code only supplements current regulations, the Unmanned Ship Code would also replace existing regulations (particularly when it comes to manning functions). Same authors also propose an "Unmanned Ship Certificate" stating the ship's operational limitations such as type of fairway, traffic density, and weather conditions. They additionally propose reducing the autonomy level and involving a shore-based control centre whenever the operational limitations are exceeded. Still, this approach conflicts with the COLREGs prescriptive approach and the current autonomous ASVs that may or may not be easily controlled from a shore-based control centre.

from accepting the ASV/MASS unmanned component. As noted earlier, organizations like the IMO and CMI are performing legislative scoping exercises where one of the goals is to assess what approach would better serve not just the legal compatibility requirements but also practical navigational needs in terms of clear and, as far as possible, consistent rules for all types of vessels.

The recent conclusion of the IMO MSC Scoping Exercise[66] presented a possible avenue of development of a goal-based MASS instrument, the so-called "MASS Code", similarly to what was done with the Polar Code. Accordingly, the MSC invited State Members to submit proposals on moving forward. However, the same Committee highlighted that if the decision is made to amend existing instruments instead of using a new instrument, COLREGs should be part of the high-priority instruments.

As noted earlier, this paper has adopted the interpretation/amendment approach, and intends to examine this avenue as a potential legislative pilot for any future legislative endeavours concerning the evaluation of the compliance of autonomous vessels with COLREGs. A secondary goal is to assess to what extent the current small, primarily research ASVs can comply with COLREGs, thus contributing to the narrowing of the legal gap in the regulatory regime of today's autonomous vessels.

5. COMPLIANCE ISSUES

As noted earlier, the COLREGs were drafted assuming direct human control. With the current state of technology, translating the COLREGs Rules into instructions that a machine can follow is difficult, especially when the goal is to have a machine learning algorithm behaving as an ordinary seafarer under the same or similar circumstances. For example, whereas the term "overtaking vessel must keep clear" is well understood by a trained seafarer, currently it is challenging to perceive how a machine algorithm would understand that term (i.e., when does an overtake begin, when does it end, and what course should the overtaking vessel take to keep clear?). Similarly, the definitions of safe speed, early action, considerable enough alteration, and others face the same difficulties when applied in practice by a machine learning algorithm utilised in ASV/MASS vessels. The meaning and application of particular terms can become

66 International Maritime Organization, IMO's Maritime Safety Committee Finalizes its Analysis of Ship Safety Treaties, to Assess Next Steps for Regulating Maritime Autonomous Surface Ships (MASS), 2021, https://www.imo.org/en/MediaCentre/PressBriefings/pages/MASSRSE2021.aspx (15 December 2021).

even more complex when considered from the perspective of different jurisdictions and different case law.

The principle of good seamanship, the ordinary seafarer standard, and the application of different skills and knowledge (endeavours, best endeavours, reasonable endeavours, and similar) are a crucial component of international legal instruments related to navigation. Without a machine learning algorithm capable of fully applying the noted principles and standards, it is impossible to discuss potential COLREGs amendments where algorithms are to replace roles and activities generally reserved for humans. The noted difficulty is especially pronounced concerning Rule 2(b) COLREGs and similar rules. It is expected that an experienced captain, officer, or crew member will deviate from COLREGs Rules to remedy dire navigational circumstances appropriately. Based on a subjective, cognitive reflection of combined training, expertise, and practical experience, this ability would be difficult to translate into objective rules contained in a programming code. Indeed, one of the more interesting questions concerning the interaction of COLREGs and autonomous vessels is the state of software development, and whether advanced algorithms are or will be able to apply ordinary or reasonable seafarers' practice successfully, based on a subjective seafarer's logic, when deviating from an objective norm/rule that requires specific actions or procedures.

The problem with good/ordinary seafarer practice is that such behaviour cannot be codified (or coded) permanently and comprehensively. Instead, good seafaring practice is prone to adaptation and case-by-case *post factum* (expert and/or judiciary) determination. Therefore, it is not reasonable to expect that the algorithm can be pre-programmed to consider all possible facts and circumstances of future cases when making a subjective determination on how to follow or deviate from an objective rule. The latter is further complicated as COLREGs contain numerous standards and qualifications purposely generalised or vague to allow constant scrutiny, vigilance, and adaptation to factual circumstances and technical novelties. Whether the software can be pre-programmed to apply specific rules successfully, circumnavigate other rules, decide on choosing between conflicting rules, or make rules "as it goes along", heavily depends on the advancement of machine learning and Artificial Intelligence (AI) capabilities in general. Whereas the former is a question of applying the correct or best suitable norm depending on the factual circumstances and available case practice, the latter heavily relies on the knowledge and expertise of seafarers who are asked to make independent decisions on how to act, not necessarily always within the scope of what COLREGs typically prescribe.

This issue, contained in Rule 2(b) COLREGs, is, perhaps, the most troublesome point when considering the application of COLREGs to fully autonomous vessels.[67] The question remains about how exactly and to what ends the machine learning algorithm will act once it recognises a need to deviate or depart from COLREGs Rules to avoid immediate danger.[68] The question is raised whether an algorithm is capable of detecting the need to depart from the Rules and choose the best possible action in line with what a reasonable seafarer would do. Until such an algorithm is devised (as noted earlier, such technology is being developed through various means[69]), tested, and certified, it is doubtful whether the general safety requirements would allow the operation of fully autonomous vessels outside restricted, controlled areas, routes, and lanes (duly respecting the fact that several jurisdictions have allowed the limited operation of autonomous vessels, usually for testing purposes[70]).

Another point that needs to be considered is the software's prediction of the course of action taken by the opposing manned vessel. When assessing the correct application of COLREGs, the unmanned vessel's algorithm must consider how the other vessel will behave, pending the application of different rules as per different factual circumstances, all, presumably, under the assumption that the

[67] Pasino, A., ColReg, Liability for Collision between Ships and Autonomous Navigation / ANALYSIS, Associazione degli Studi Legali Associati, 2019, https://www.themeditelegraph.com/en/markets/regulation/2019/08/22/news/colreg-liability-for-collision-between-ships-and-autonomous-navigation-analysis-1.38068587 (15 December 2021).

[68] Porathe, T., Maritime Autonomous Surface Ships (MASS) and the COLREGS: Do We Need Quantified Rules or Is "the Ordinary Practice of Seaman" Specific Enough?, *TransNav, The International Journal on Marine Navigation and Safety of Sea Transportation*, vol. 13 (2019), no. 3, pp. 511-518.

[69] It is possible to imagine establishing these principles by a retrospective assessment of the conduct of the unmanned ship or ASV under the circumstances. This assessment is done currently for manned vessels. The simulators can allow for extensive testing of complicated situations (Pedersen, T. A.; Glomsrud, J. A.; Ruud, E. L.; Simonsen, A.; Sandrib, J.; Eriksen, B. O. H., Towards Simulation-based Verification of Autonomous Navigation Systems, *Safety Science*, vol. 129 (2020), 104799). Current simulators used for training pilots could potentially be used to train autonomous navigation algorithms. The large amount of historical data could be used to train machine learning algorithms (Scheidweiler, T.; Burmeister, H. C.; Hubner, S.; Jahn, C., Dynamic "Standing Orders" for Autonomous Navigation System by Means of Machine Learning, *Journal of Physics: Conference Series*, vol. 1357 (2019), 012046). This technique can also be useful to provide AI with vast amounts of data regarding seafarers' knowledge and expertise. If the safety concerns are addressed cautiously (i.e., large numbers for the closest point of approach), it will be easier to consider ASVs as COLREGs compliant.

[70] See, for example Kongsberg Maritime, Autonomous Ship Project, Key Facts about YARA Birkeland, 2021, https://www.kongsberg.com/maritime/support/themes/autonomous-ship-project-key-facts-about-yara-birkeland/ (15 December 2021).

algorithm's capacity to apply COLREGs is superior to that of a human seafarer. In that case, it is possible to imagine a "machine error" when holding a human to a machine standard. In other words, in such situations, the software should review the circumstances and COLREGs from a reasonable seafarer's perspective or standard to properly assess the manned vessel's behaviour. The apparent dilemma is that until all seaborne vessels are autonomously controlled, the "human standard" will continue to play a significant role in machine behaviour, no matter the extent to which the "machine standard" is superior. The interesting issue is to what extent the algorithm will be able to predict human action and human error (either based on erroneous behaviour or based on the human condition, cognitive preparedness at any given moment, and limited capabilities to respond in time) and accept such behaviour on the side of the manned vessel, despite its possible/actual deficiencies when making its determination on what course of action to take. The question is raised, therefore, whether the machine can adopt the human cognitive rationale with all its deficiencies[71] and allow erroneous or below-standard behaviour, usually contrary to how the machine would act, to become grounds for taking specific action (i.e., Rule 5, requirements on situational awareness). While it can be challenging for the machine to follow the human cognitive rationale, the machine can be programmed, when such a situation is detected, not to insist on following the ordinary course of action but to adapt to the situation and depart from COLREGs if necessary. This most certainly raises several issues of responsibility and liability (as noted, outside the scope of this paper) regarding the responsible person, damage compensation (contract, tort), insurance, loss of profit, and other issues.

Furthermore, when COLREGs refer to or indicate some level of human participation and perception, such as the situational awareness requirements as codified in Rule 5 or common-sense reasoning as required per Rule 13 and Rule 14,[72] the objection raised about the compliance of fully autonomous vessels with COLREGs does not preclude the algorithm's data collection capabilities. However, it currently (until international standards say differently) does preclude the ability to implement the necessary level of data evaluation and subsequent decision-making processes in line with what a trained and certified seafarer is capable of doing. The CMI, for example, warns that requirements like "sight" and "hearing" strongly indicate the need for human involvement, rendering a pure algorithm,

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71 Porathe, T., Safety of Autonomous Shipping: COLREGS and Interaction between Manned and Unmanned Ships, in Beer, M.; Zio, E. (eds.), *29th European Safety and Reliability Conference (ESREL 2019)*, Research Publishing Services, Singapore, 2019, p. 4149.

72 Benjamin, M. R. *et al*, COLREGS-based*…*, *op. cit*., pp. 35-36.

at least currently, inadequate.[73] Even if the COLREGs wording does allow for technical equipment to replace crew as data collection instruments, until thorough trial and error methodology (i.e., utilising the IMO guidelines) certifies an algorithm capable of doing what ordinary/reasonable seafarers are doing, it would appear that several Rules within COLREGs remain inherently connected to human presence, either physically or virtually. Until such time, semi-remotely controlled autonomous vessels where seafarers take real-time control when required by COLREGs are an option that would allow for the full compliance of the discussed interaction, provided that the communication system with the Shore-based Control Centre is reliable. Even with the most complex autonomous systems, it is still possible to enable a remote reserve option that will remain available in the event of a system failure or other impediments, where qualified personnel from an on-shore or other location will be able to assume control and command.[74] This emergency option may fall into line with the "all available means", "particular circumstances of the case", "departure from these Rules", "action as will best aid to avoid a collision", and similar requirements necessitated by COLREGs and strongly associated with human intervention.

Numerous technical studies and plenty of research confirm that modern technology (to no small extent already heavily present in modern shipping, including automation mechanics) enables information gathering far superior to human capabilities. The noted advantage is an important point that must be considered when addressing the sensitive parts of COLREGs and their application to autonomous vessels, such as Rules 2, 5, 7, 8, 13, 14, 15, 16, 18 and others. However, the crucial question is how the software will assess the information gathered and how it will match the findings to the application of COLREGs. The clear advantage of software solutions is their capacity to collect vast amounts of data, handle these data simultaneously, and access all the relevant factual, legal, and expert information. The noted capacity, presuming that the code is well written, eliminates the chance of missing an electronic alert, warning, prediction, or other relevant information, and allows for superior and faster calculation as to the available courses of action. Such a software solution would, in turn, render situational awareness requirements such as those referred to in Rule 5 even more useful and robust and allow the collection of data far beyond ordinary

73 Work of the International Working Group Maritime Law for MASS: Comité Maritime International, Spreadsheet Regarding Conventions, 2018, https://comitemaritime.org/work/mass/ (15 December 2021).

74 MUNIN EU Project, Research in Maritime Autonomous Systems Project Results and Technology Potentials (final brochure), 2016, http://www.unmanned-ship.org/munin/wp-content/uploads/2016/02/MUNIN-final-brochure.pdf (15 December 2021).

human perception. Whether or not machine learning or AI will develop to the point where it learns how to best comply with COLREGs is outside the current scope of examination. The considerations of possible clarification/amendments of COLREGs presented in this paper are projected to the time when the technology becomes ready (which for some categories of ASVs may be very close).[75] Successful AI in this respect would render the role of the judiciary as well as that of experts redundant. To what extent well-written software can avoid human error in applying COLREGs, or to what extent the software is prone to error as humans develop it – is something that only case practice will reveal.

Classification and certification are essential to maritime safety. Once unmanned vessels of various types and with various software capabilities start navigating both internal and international waters in more significant numbers, their algorithms will start to learn, among other things, how to apply COLREGs. Considering that numerous players in the industry are already engaged in the research and development of autonomous vessels, it is likely that the resulting algorithms applying and complying with COLREGs will vary, implementing COLREGs differently. Thus, it is no longer merely a question of how to approach a situation where a fully autonomous unmanned surface vessel heads on a collision course with a manned vessel, but also how to evaluate a situation where two autonomous vessels are about to adhere to COLREGs by applying two different programming implementations. The obvious solution is to make a joint effort to develop software certified by relevant competent authorities (i.e., classification societies' cyber/AI departments), ensuring that different programming platforms are, at least, interoperable and are producing similar outputs for the same situation. The European Parliament[76] stressed the need for interoperability and access to the source code of accident investigations. While the first is obvious, the latter can bring intellectual property issues. A possible solution is to establish standardised logging black-boxes.[77] An AI system governing a port, channel, or an area of

[75] Some authors are more optimistic regarding the technical feasibility of the compliance of algorithms with COLREGs, particularly for steering and sailing rules, even taking into account the uncertainty of other ships' actions (Ringbom, H., Regulating…, *op. cit.*, p. 155). It is also worth pointing out that these algorithms do not need to work all the time or be fit for all conditions. As suggested in Section 4, outlining the conditions for autonomous navigation depending on geographical, meteorological, traffic, and other conditions can be part of the classification and certification procedure to ensure that when an ASV is at sea, it can comply with COLREGs (for that sea state in that location with the current traffic).

[76] European Parliament Resolution on Civil Law Rules on Robotics, OJ C 252, p. 252.

[77] Ferreira, F.; Alves, J.; Leporati, C.; Bertolini, A.; Bargelli, E., Current Regulatory Issues in the Usage of Autonomous Surface Vehicles, *OCEANS 2018,* MTS/IEEE Kobe Techno-Oceans, Kobe, 2018, pp. 7-8.

sea could easily collect all information on incoming and outgoing vessels, make the necessary calculations and direct each vessel to the best course available, thus avoiding accidents arising from available information (something already planned for the comprehensive system of drones and connected autonomous road vehicles, as well as for the control centres of autonomous vessels).

6. COLREGs' COMPLIANCE ANALYSIS

Considering all previously stated caveats (*pro futuro* considerations when the technology allows for suitable and reliable algorithms), the present section examines the possibility of the interpretation and adaptation of COLREGs as per the potential compliance of small ASVs.

Rule 2 COLREGs allows for an allocation of responsibility to the vessel itself (Rule 2(a)) but specifically refers to the "ordinary practice of seamen" as a critical requirement both for compliance with COLREGs as well as deviation from the same (as per Rule 2(b)). The CMI Working Group, as well as several authors,[78] point out that a remotely operated vessel (or at least an autonomous vessel with remote control as a viable option) may satisfy the noted requirement, whereas a fully autonomous vessel may not, as the current state of technology is yet to prove its future capacity in this respect. The latter is complicated because it is currently not known how exactly the general requirement of good seamanship could be applied to ASVs.[79] Algorithms under development are attempting to incorporate multiple sources of simulation and historical data, coupled with enhanced machine learning capabilities in terms of analysis and decision-making in a new set of circumstances (which possibly includes AI's ability to create new knowledge, i.e., new practices and standards as per compliance with or deviation from COLREGs). At present, fully autonomous vessels cannot satisfy this requirement.

In contrast, remote-controlled vessels have this potential, pending further analysis of shore-based control operators' communication and response capacity. The same reasoning is relevant for Rule 7 (risk determination), which is even more challenging to assess in light of machine or deep learning algorithms, as it directly refers to technical deficiencies ("scanty radar information") known in practice. Rule 8 (collision avoidance) also refers to good seamanship and is equally prob-

[78] Ringbom, H.; Veal, R., Unmanned Ships and the International Regulatory Framework, *The Journal of International Maritime Law*, vol. 23 (2017), no. 2, p. 112; Veal, R. *et al.*, The Integration…, *op. cit.*, p. 325; Comité Maritime International, Position Paper…, *op. cit.*, p. 14.

[79] Cain, F. *et al.*, New Ships…, *op. cit.*

lematic regarding the application of algorithms.[80] The noted Rule is particularly relevant as it offers an opportunity to precisely determine the mandatory behaviour of autonomous vessels when opposed by manned vessels by requiring the autonomous vessels not to impede the passage or safe passage of (all) other vessels. Finally, it should be noted that several other rules (i.e., Rules 15, 16, 17 and 19) require decision-making that is not prescribed in advance, placing considerable reliance on good seamanship – the knowledge, skill, and experience of trained seafarers.

When defining a vessel, Rule 3(a) COLREGs emphasises any vessel capable of being utilised for transportation. Such a broad concept includes autonomous vessels (as even small ASVs can carry equipment). A specific definition of an unmanned vessel may prove helpful should other parts of COLREGs require additional clarification or amendments, explicitly pointing to autonomous vessels. For example, the CMI Working Group indicates the necessity (*a minimo*) to amend the rules related to lights and shapes (Part C), sound and light signals (Part D),[81] look-out requirements (as per Rule 5), and the terms "in sight of one another", "visually" and "restricted visibility".[82] In some cases, specific word-

80 Rule 8 uses the terms "early action" and "large enough alteration of course". COLREGs do not quantify these terms, which could represent an issue for ASVs. Moreover, the interpretation of what constitutes early action and considerable enough alteration depends on the situation and even the vessel's size/type/speed. Nonetheless, we can refer to existing cases and observe what the current practice for manned vessels is. Early action has been defined in some cases as within four to six miles. For more, see Allen Sr., C.; Allen Jr., C., *Farwell's Rules of the Nautical Road*, Naval Institute Press, Annapolis, 2020, pp. 256-257. Similar ranges should be attained by large MASS but, for small ASVs, smaller ranges can apply as the dynamics of these vessels are much faster than a large tanker. Instead, for a readily apparent course change, some ASVs use the typical range of values between 30° and 35° according to decisions by the US Coast Guard and the English Admiralty Court even if, in some cases, this value has been defined as 60°. There is no need to quantify these values for ASVs as they are not even quantified for manned vessels. Case law should continue to inform us about what they mean in practical terms. In this sense, trials according to IMO guidelines will also provide essential feedback on the capabilities of MASS/ASVs to perform in a similar way. New typical values will possibly emerge for ASVs and their interaction with manned vessels, but they will not need to be introduced in the COLREGs' treaty.

81 Comité Maritime International, Spreadsheet…, *op. cit.*

82 *Ibid*. Part C of COLREGs is dedicated to Lights and Shapes, while Part D presents Sound and Light Signals. The various Rules in these Parts can act as a performance test for any electronic look-out as an ASV would need to detect other vessels through these signals. There is some flexibility as Governments can accept "closest possible compliance" for "vessels of special construction or purpose" when it comes to the lights, shapes, and sound signalling appliance (Rule 1e). Nonetheless, smaller ASVs can have issues comply-

ing for autonomous vessels may prove to be an efficient addition. For example, as per Rule 3(k), an additional (k.a) point may be added, stating: "Autonomous vessels shall be deemed to be in sight of one another only when the onboard sensor and radar equipment can observe one from the other".[83] The exact definition should be modelled depending on the type of equipment used for situational awareness data collection and analysis. As per the term "restricted visibility" (Rule 3(l)), it would appear that the wording better reflects the human condition as affected by natural phenomena. Whereas some of the occurrences enumerated in COLREGs can affect the equipment, it is relatively safe to assume that the list should be amended or clarified to incorporate such causes of malfunction inherently linked to technology. Such amendment may require that: "In the case of autonomous vessels, the term 'restricted visibility' additionally applies similar causes restricting the functionality of onboard sensors and radar equipment".[84]

ing with some of the lights' requirements. Thus, more consideration is required. For instance, the Navigation Safety Advisory Council, Resolution 11-02 – Unmanned Vehicles/Vessels, 2011, and Navigation Safety Advisory Council, Resolution 12-08 – Unmanned Vehicles/Vessels, 2012, propose amendments to Rule 27 (Vessels not under command or restricted in their ability to manoeuvre) for whenever the size of an ASV prevents full compliance with this rule and for vessels below 12 metres. In the first case, a different set of lights would be used, while, in the latter, vessels would be exempted from complying with the lights and shapes in Rule 27, except those engaged in diving operations. Similarly, Woerner (Woerner, K., COLREGS-compliant..., *op. cit.*, p. 126) proposes an amendment to Rule 32 to clarify what is to be considered artificial sight, which would apply to all the rules in this part (i.e., Rule 34 specifically refers to "in sight of one another"). The technical annexes would need to be amended according to the amendments performed in Parts C and D. In particular, digital signals should be added to the list of signals. This need for amendment is especially relevant in Annex IV (Distress Signals), where new digital distress signals are to be added. While this is perhaps less relevant for small ASVs, once the large MASS start to operate as cargo or passenger carrying vessels, it becomes imperative to quickly recognise a digital distress signal by manned vessels.

83 Also, potentially applicable to Rules 11, 13 and 14.

84 Unless technology renders such causes irrelevant. Algorithms work in restricted visibility and can perform better in certain restricted visibility situations. See, for example Szlapczynski, R., Evolutionary Planning of Safe Ship Tracks in Restricted Visibility, *The Journal of Navigation*, vol. 68 (2015), no. 1, pp. 39-51; Zhou, X.-Y.; Huang, J.-J.; Wang, F.-W.; Wu, Z.-L.; Liu, Z.-J., A Study of the Application Barriers to the Use of Autonomous Ships Posed by the Good Seamanship Requirement of COLREGs, *The Journal of Navigation*, vol. 73 (2020), no. 3, pp. 710-725. An additional amendment that could potentially be included (see, for example Navigation Safety Advisory Council, Resolution 16-01 – Unmanned Maritime Systems Best Practices, 2016, https://maddenmaritime.files.wordpress.com/2016/06/navsac-resolution-16-01-unmanned-maritime-systems-ums-best-practices-final-05-may-2016.pdf (15 December 2021)), as a safety measure introduces automatic identification systems (AIS) for ASVs. Indeed, AIS helps navigation and can help detect objects and a potential collision earlier than human (or virtual) sight or hearing.

Rule 5 is one of the more debated questions in the literature, as it contains the terms "sight and hearing" and "proper look-out". The CMI Working Group argues that reference to these two inherently human senses requires human input and that, therefore, fully autonomous ships cannot comply with the noted requirement.[85] Alternatively, and in the case of remotely controlled vessels, the CMI Working Group believes that such vessels could potentially comply with Rule 5, pending further technological demonstrations that such remote control from a human operator in an on-shore facility is adequate. More concretely, it should prove that it is as practical, timely, and can acquire full local awareness through the use of cameras, sound sensors, and other relevant equipment as would be the case with a human crew onboard.

The COLREGs definition also suggests that a proper look-out (situational awareness) requires utilisation of "all available means appropriate in the prevailing circumstances". As per the "restricted visibility" scenario, which in some cases can render human look-out capacity useless or significantly impaired, significant reliance on technology to achieve proper look-out in prevailing restricted visibility circumstances is already a viable option. In such cases, however, manned vessels take extra precautionary measures (i.e., slower speeds). In contrast, the same is not expected in the operation of autonomous vessels under ordinary circumstances (complete visibility scenario).

In this way, manned/autonomous vessels can alter their course in time to avoid a collision. However, according to Patraiko (Patraiko, D., Autonomy on Manned Vessels, *5th Maritime Autonomous Systems Regulatory Working Group Conference: Maritime Autonomous Surface Ship (MASS) Regulation – The Tide Has Turned*, 2020, https://www.maritimeuk.org/documents/530/David_Patraiko.pdf (15 December 2021)), AIS has poor standardisation and too many alarms. AIS is also prone to being hacked, and even if it is compulsory for ships above 300 gross tonnage and for passenger ships, ships turn off their AIS transmitters in many (malicious) cases. For a comprehensive analysis of the use of AIS in the context of anti-collision, see Felski, A.; Jaskolski, K.; Banys, P., Comprehensive Assessment of Automatic Identification System (AIS) Data Application to Anti-collision Manoeuvring, *The Journal of Navigation*, vol. 68 (2015), no. 4, pp. 697-717. Notwithstanding the issues with AIS, it remains a tool that can help prevent collisions. In the distant future when all ships are autonomous and connected, ship-to-ship communication could potentially replace it. Still, until then, an amendment stipulating the requirement to use AIS in ASVs could improve safety at sea. The use of AIS for avoiding collisions between submarines and surface vessels is studied in Ferreira, F.; Petroccia, R.; Alves, J., Underwater/Surface Collision Avoidance Using Underwater Acoustic Communications – A Preliminary Analysis, *OCEANS 2019*, IEEE, Marseille, 2019, pp. 1-10.

85 Comité Maritime International, Position Paper…, *op. cit.*, p. 14.

Some authors are not entirely convinced that Rule 5 requires an onboard look-out[86] or human presence onboard as an inherent part of a proper look-out,[87] suggesting that a human controller is "in the loop" at all times, thus achieving compliance with Rule 5. Others suggest that an electronic look-out is, performance-wise, comparable with if not superior to a human look-out.[88] They are of the opinion that terms such as "proper" and "appropriate" allow for some flexibility in Rule 5,[89] suggesting the use of electronic equipment instead of a human crew entirely.

However, this option is only viable when the technology reaches such levels that its efficiency is demonstrated and accepted by all relevant maritime stakeholders. *Pro futuro*, Rule 5 could potentially be amended as follows: "Every vessel shall at all times maintain a proper look-out by artificial or human sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions to make a full appraisal of the situation and the risk of collision".

As per Rule 6, several authors propose that the safe speed regulation should be calculated based on the remote-controlled or monitored vessels' communications delay.[90] However, other factors are relevant in cases of fully autonomous vessels, especially regarding the limitations of the look-out equipment, similarly to what is currently prescribed as per radar equipment (Rule 6(b)).

Finally, Rules 13 and 14 use the term "doubt" when referring to the assumption of overtaking another vessel. While the term doubt predominantly refers to the human cognitive state, a parallel meaning can be attributed to machine learning algorithms. In particular, when algorithms cannot make a conclusive assessment of a given situation or cannot process certain data (corrupted, cyber-attacked, etc.), there can be doubt, and autonomous vessels should take the same

[86] Constantino Chagas Lessa, J.; Vecchiu, T., Are Autonomous Vessels to Provide a more Safe and Secure Shipping in the Current Regulatory Framework? Let the Scramble Game Begin?, in Musi, M. (ed.), *Maritime and Transport Law Towards Open Horizons*, *Il Diritto Marittimo – Quaderni*, vol. 6, Bonomo, Bologna, 2019, pp. 219-252.

[87] Veal, R. *et al.*, The Integration…, *op. cit.*, pp. 326-328.

[88] It is worth noticing that in some cases (i.e., restricted visibility), it is harder to calculate mentally the trajectory of another vessel just by looking at radar observations, which for an electronic look-out is an easy task, mainly if an array of different sensors are used ("all available means"). Furthermore, ASVs can process more information faster than humans can, and warn about the risk of collisions (Cain, F. *et al.*, New Ships…, *op. cit.*).

[89] Ringbom, H., Regulating…, *op. cit.*, p. 153.

[90] Ringbom, H. *et al.*, Unmanned Ships…, *op. cit.*, p. 113; Comité Maritime International, Position Paper…, *op. cit.*, pp. 14-15.

precautions as manned vessels. Therefore, this and similar COLREGs norms may have to be overhauled with more precise wording when stipulating the algorithm's course of action.

7. CONCLUSION

This interdisciplinary study examines the applicability of COLREGs regarding the navigation of small ASVs which have been used for several years but lack regulatory attention due to their typically minor collision risk/damage. However, with the advent of MASS and larger ASVs, there is a need to regulate these unmanned vessels.

The paper describes the state of the art in technological capabilities and regulatory efforts. Small-scale ASVs have already achieved high TRL levels, and their market is expanding, with some manufacturers claiming compliance with the original COLREGs. However, it is currently not possible to verify this, as it is still unclear and it remains under preliminary review whether and to what extent ASVs/MASS should be regulated, either by introducing completely new regulatory instruments or by adapting the current ones.

After reviewing several ways of addressing this regulatory gap, the paper focuses on a way forward that allows self-regulation by the industry, classification societies, flag states, and potential COLREGs amendment methods. Finally, regarding the adaptation of COLREGs, the paper focuses on clarifications and possible amendments for the most relevant rules, leaving technical rules to the self-regulation efforts currently being made by the appropriate stakeholders.

The issue is still open for debate and future consideration, especially concerning large unmanned commercial vessels, commonly named MASS, and their remote operation from a shore-based control centre and/or autonomous operations. Such vessels and the human-in-the-loop principle raise different issues (such as communications reliability) that need to be considered in any adaptation of COLREGs and similar international instruments.

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Sažetak:

AUTONOMNA POVRŠINSKA PLOVILA I COLREG – RAZMATRANJE IZMJENA I DOPUNA

Plovila bez ljudske posade u posljednjih nekoliko godina privlače sve više pozornosti. U sektoru istraživanja i razvoja, autonomna površinska plovila različitih stupnjeva autonomije koriste se već više od desetljeća. Najnaprednija plovila već plove oceanima te se nameće pitanje njihove komplementarnosti s različitim pomorskopravnim međunarodnim dokumentima. Trenutačno nedostaje jasno pravno shvaćanje u vezi s prilagodbom autonomnih površinskih plovila pravnim instrumentima, poput Konvencije o međunarodnim pravilima za izbjegavanje sudara na moru iz 1972. godine (COLREG). Ovaj rad propituje u kojoj mjeri, eventualno izmijenjene i dopunjene odredbe COLREG-a mogu biti zadovoljavajuće za potpuno autonomna površinska plovila. Analiza se provodi iz pravne i tehničke perspektive.

Ključne riječi*: COLREG; autonomna površinska plovila; APP; plovila bez posade; autonomna plovila; zakonodavne izmjene i dopune.*