The Application of COLREGs by Autonomous and Unmanned Vessels: Issues Raised by Situational Awareness, Night-Time Navigation and Good Seamanship

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***Abstract*— This paper intends to analyse autonomous and unmanned shipping from a transdisciplinary perspective and through the prism of COLREGs, singling out a few elements: situational awareness, night-time navigation and *good seamanship*. The emphasis will be put on regulatory requirements applicable to such aspects as well as the technical challenges derived therefrom.**

Keywords—international law, law of the sea, autonomous shipping, unmanned vessels, COLREGS, situational awareness, night-time navigation, good seamanship

I. Introduction

The emergence of unmanned vessels is at the forefront of a revolution in shipping and navigation practices, promising new levels of efficiency and safety [1, p. 363 *et seq.*]. Autonomous and remote shipping does not only represent a paradigm shift in maritime operations, but it also raises significant issues in terms of compliance and safety. It is imperative to ensure that these advanced navigation systems comply with existing provisions of the law of the sea and maritime law, such as the International Regulations for the Prevention of Collisions at Sea (COLREGs) [2]. These rules date back to 1972 but have a long history, reaching as far back as the 19th century. Rules to prevent collisions at sea were first developed after the introduction of steam-ships, bound to share the oceans with traditional sailing vessels. This technical evolution called for new provisions which could take the increasing speed of new ships into consideration [3, p. 5, 6].

The COLREGs as they exist nowadays are formulated in a general manner so as to be applicable to the most situations [4, p. 512]. This vagueness in turn does not make it possible to translate COLREGs one to one into algorithms conceived to apply them blindly [5, p. 5]. Moreover, these rules assume the presence of a human crew on board, for autonomous and unmanned vessels were not a reality fifty years ago [6, p. 714]. Thus, the use case underlying this article will be – out of vessels' different autonomy levels – the most subversive one, i.e. that of a vessel functioning fully autonomously, without a human crew, but whose system is under the supervision and can be overrode by a Remote Operation Centre (ROC) in case of danger.

The potential incompatibilities between unmanned vessels and COLREGs were already noted by the Maritime Safety Committee (MSC) of the International Maritime Organisation (IMO) in their Regulatory Scoping Exercise (RSE) for the use of Maritime Autonomous Surface Ships (MASS) [7]. In this RSE, the MSC analysed different IMO conventions through the prism of different levels of ship autonomy, the highest one enabling a vessel to make decisions and determine actions by itself. In that scenario, the MSC determined the need to amend COLREGs due to issues related to terminology, lights, shapes and sound signals, the role of master, the responsibility of the remote operator and distress signals. [7, p. 86, 87].

In order to delve deeper into some of the issues raised by the MSC, this article will focus its analysis on three core aspects of COLREGs: situational awareness (I), night-time navigation (II) and *good seamanship* (III). Other elements could have been discussed, however the choice was made here to focus on provisions which could prove particularly difficult to translate into technical terms for autonomous and unmanned vessels. Other authors chose to centre their analysis around different themes [3], [5].

For each of this article's parts, regulatory requirements and technical challenges will be examined. The analysis of regulatory requirements will be based on COLREGs but also on the guidelines on autonomous ships published by classification societies. As private entities entrusted by flag States administrations to carry out some of their missions, classification societies issue 'empirical standards and [apply] these standards through [their] licensing and approval systems' [8, p. 241]. The rules and guidelines they develop transpose IMO requirements on autonomous vessels and are thus highly relevant for this study, for they allow to bridge older conventions with new disruptive technologies. The technical challenges are the result of a preliminary work on this topic, brought by Klein and Stadermann [9]. They presented their findings in the framework of the Dreizack 23 Conference, held in Laboe, Germany and organised by the Deutsche Maritime Akademie as well as the Institut für Sicherheitspolitik an der Universität Kiel.

Both the presentation held previously and this article come within the scope of the MUM-Project, which consists in the development of a civil, autonomous and modular submarine [10] and of the LEAS-Project, which aims at designing, implementing and demonstrating an AI-based landside support system for mixed traffic of autonomous and conventional vessels [11]. This article's authors carry out legal research in the framework of these projects and stumbled upon specific issues which have not been developed extensively in the relevant literature, i.e. the compliance of autonomous and unmanned vessels with COLREGs. This observation gave rise to the conception of this article.

II. Situational Awareness

A. Regulatory requirements

A central provision within the COLREGs when it comes to situational awareness is Rule 5 on Look-out which states:

> Every vessel shall at all times maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision.

As mentioned earlier, the COLREGs were drafted with the assumption of a human crew on board [6, p. 714]. Thus, the question can be raised whether the wording 'sight and hearing' in Rule 5 can also be extended to autonomous systems' sensors on board an unmanned vessel. It should be noted that even nowadays, seafarers also rely on technical means to obtain information about their surroundings. Wróbel *et al.* explain that radars and Automatic Identification Systems (AIS) are capable of complementing human senses in this regard [5, p. 7, 8].

Authors who wrote on the subject generally agree that Rule 5 can accommodate 'sight and hearing' to be carried out by technical means, however their opinions differ on the methodological means to enact the shift in how the provision is to be read. Zhou *et al.* argue that even if 'computer vision' can fulfil the 'sight and hearing' requirement of Rule 5, an amendment of the provision is necessary to take in technical novelties [6, p. 716, 717]. Authors such as Stępień and Trowers indicate that Rule 5 can be interpreted so as to encompass technical means to fulfil situational awareness [3, p. 8], [12, p. 231, 232]. This is due in part to the vague wording of the provision and the fact that there is no legal definition to 'sight and hearing' to be found in the COLREGs [3, p. 7, 8].

In the context of situational awareness, the guidelines published by classification societies are essential to understand what could come to be expected from autonomous and unmanned vessels. It can be observed that the standards contained in such rules are quite high and tend to replace entirely the human senses on board [13, p. 87]. For instance, on top of requiring a 360° field of vision around the vessel [13, p. 54], Det Norske Veritas (DNV) establishes the following:

> In order to obtain an equivalent capability for the remote operator to detect objects, the image transmission would need to be continuous with resolution, frame-rate, colour depth and field of view providing an equivalent level of detection capability compared to a manned bridge [13, p. 56].

Bureau Veritas expects the sensors to detect a life raft or a person in the water up to several hectometres [14, p. 26].

B. Technical challenges

The previous part established that there are high standards to be upheld by autonomous and unmanned vessels when it comes to situational awareness. The numerous technical challenges existing to the application of such requirements as well as the resulting estimations have been delineated in one of these authors' preliminary study [9].

The main technical challenges outlined here are linked to the necessity to distinguish distant objects at sea, such as buoys, lighthouses, persons in distress or different ships' types. This can only be ensured by complex camera systems providing a 360° look-out with a very high resolution. If it is to be assumed that the sensors should be able to detect objects as far as 5 kilometres (km) with a resolution of over 100 Megapixels (MP) and that a fluid video stream in the ROC would require 30 frames per second (FPS), the resulting data rate would comprise around 150 Megabits per second (Mbit) [9, p. 38, 39]. This represents a considerable amount of data that no satellite or middle range radio cell can accommodate, even when taking modern compression algorithms into consideration [9, p. 39].

The delay in the information transmission from the vessel to the ROC should also be considered. If the ship finds itself in an emergency situation pushing the personnel on shore to override the system, they could only do so considering in turn some steerage delay. Such low flexibility in the response to be brought to a potential danger cannot guarantee the ship's safety [3, p. 8].

The classification society DNV is aware of these issues and made the following observation regarding the enormous quantity of raw data that a continuous video stream would represent:

> This is believed to be a challenging solution for a whole voyage, considering latency and the capacity limitations in communication links. It may however be relevant for parts of a voyage, e.g. for docking operations [13, p. 56].

III. Night-Time Navigation and Detection

A. Regulatory requirements

Night-time navigation proves to be more challenging due to the lack of visibility. In this situation, seafarers have to rely on light signals emitted by other vessels. There are numerous provisions throughout COLREGs which give insights into how to navigate safely by night, for instance:

- Rule 13(b) on Overtaking indicates that a vessel is deemed to be overtaking if only its sternlight is visible but neither of the sidelights.
- Rule 14(b) on Head-on situations establishes that a vessel is deemed to arrive head-on if its masthead lights are to be seen in a line and/or its sidelights.
- Part C gives indications on lights and signals depending on ships' types and sizes.

- Part D contains rules on light signals (different flashes, colours, positions) to be addressed to other vessels in order to warn them or draw attention.

None of the aforementioned provisions expressly require the detection of light signals by the human eye, which leads authors to reach the conclusion that here too, nothing speaks against sensors observing such signals. STĘPIEŃ indicates for example that the wording 'to see only the sternlight' in Rule 13(b) is not defined to only be carried out by humans [3, p. 7]. Thus, autonomous and unmanned vessels can theoretically uphold these standards.

In the context of signals at sea, another organisation should be mentioned: The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA). This organisation issued a recommendation on Maritime Buoyage Systems (MBS) which establishes different indications at sea thanks to buoys and corresponding light signals in the night-time. Such signals have different colours and rhythmic characteristics which should be recognised by vessels in their surroundings [15, p. 8].

The classification society DNV gave some insight into the application of such rules to autonomous and unmanned vessels, writing:

> It shall be possible to detect and recognise lights and shapes as described in COLREG Part C, and sound and light signals as described in COLREG Part D [13, p. 54].
>
> It shall be possible to detect all external objects of interest for safe navigation, such as ships, buoys and lighthouses in any direction when the vessel is pitching and rolling [13, p. 54].

Both citations establish that autonomous and unmanned vessels should be able to uphold standards contained both in COLREGs and in IALA recommendations, so as to recognise the types of vessels encountered as well as to be made aware of potential dangers at sea.

B. *Technical challenges*

The technical challenges faced by autonomous and unmanned vessels in the context of night-time navigation and detection are twofold. They are of a spatial and of a temporal nature.

Challenges from a spatial perspective are related to the ability a vessel must have to identify a light signal in spite of bad sea conditions. If the ship is pitching and rolling, the sensors may have difficulties singling out a light signal when its position changes [9, p. 40]. The autonomous system should be able not to consider a single light source from different angles as distinct signals.

Temporal challenges are a consequence of some of the COLREGs and IALA rules presented earlier. Depending on the message to be transmitted, a light signal may showcase a special rhythmic frequency. For instance, the light signal corresponding to Preferred Channel marks consist in two plus one flashing [15, p. 11]. An autonomous system should thus be able to capture the signal over an extended period of time, attribute meaning to it and decide whether they belong to single, multiple or related objects. Indeed, there is a risk to understand two flashings as distinct signals when they actually belong to the same frequency [9, p. 40]. It should also be noted that many of these light signals have different colours which should also be differentiated by the sensors. For instance, the Preferred Channel marks mentioned earlier can be red or green [15, p. 11]. Issues related to bad sea conditions mentioned in the previous paragraph also apply here.

The difficulties mentioned in this part speak for the existence of a form of plausibility check in order to ensure the accuracy of the signal detected by the sensors. This could be done crossing information with AIS or nautical charts, which requires the integration of data from multiple sensors (data fusion) and the use of accurate vessel positioning information to ensure reliable detection and identification. The ability of unmanned vessels to meet these night-time navigation challenges depends on the development of sophisticated sensor systems and algorithms that can adapt to the complexities of the maritime environment, ensuring safety and compliance with navigation rules. [9, p. 40].

IV. GOOD SEAMANSHIP

A. *Regulatory requirements*

Removing the human element from decision-making on board a ship will also raise uncertainties with regard to the role traditionally endorsed by the master and the crew in the framework of COLREGs, as based on their experience as seafarers. Indeed, those rules do not only entail provisions requiring precise courses of action. They are also infused by another less precise concept, more difficult to grasp: that of *good seamanship*. This notion, also found in literature on the topic, can be mentioned in COLREGs as 'ordinary practice of seamen'. Both wordings are synonymous [12, p. 229].

Some of the COLREGs provisions relying on *good seamanship* are the following:

- Rule 2(a) establishes the responsibility of the master or the crew to observe 'the ordinary practice of seamen' even when COLREGs provisions are silent on a specific situation [16, p. 323].
- Rule 2(b) allows seafarers to depart from COLREGs provisions in order 'to avoid immediate danger'. In doing so, seafarers should 'exercise [their] best judgement' [17, p. 8, 9]
- Rule 8 mentions actions to avoid collision, which have to be carried out 'with due regard to the observance of good seamanship'.

Even when the term *good seamanship* itself is not mentioned expressively, the application of several provisions depends directly on acting upon that concept, such as Rule 7 on Risk of collision, Rule 13 on Overtaking or Rule 17 on Action by stand-on vessel [12, p. 228-239], [16, p. 323, 324], [17, p. 6, 7].

With the mention of these few provisions, it has been established that *good seamanship* is a central element to COLREGs. ZHOU *et al.* even describe that concept as 'the spiritual core running through COLREGs' [6, p. 720]. Indeed, *good seamanship* intervenes 'where there is not a clear answer on how a vessel should operate in a specific situation' [12, p. 229]. However, no clear definition of the notion is to be found throughout these rules. Indeed, a single universally accepted definition does not exist [18, p. 4551]. TROWERS defines *good seamanship* in the following terms:

> Good seamanship refers to the skill and knowledge of a master and his crew in the work of navigating, maintaining, and operating a vessel. The standard of good seamanship that is required internationally is that of the average good master and crew. There is no requirement that a good seaman should have an extraordinary ability or unusually high degree of care and caution [12, p. 228].

Other authors choose to base their understanding of *good* seamanship on empirical elements instead, for several characteristics may exist, depending on different seafarers' perspectives. [18, p. 4551]. In a study led by AALBERG and BYE amongst a wide variety of seafarers, a few key elements emerge as constitutive of *good seamanship* [18]. For instance, safety onboard is viewed as the most important characteristic, i.e. the necessity for the crew to act responsibly [18, p. 4554]. Other elements such as the interactions and cooperation between crewmembers, or the skills and knowledge showcased by them are also essential to *good seamanship* [18, p. 4554].

The answers given by the respondents in the framework of this analysis depend strongly on the seafarers' age, the position they occupy on board or the type of vessel they operate on. For instance, younger seafarers seem not to consider *good seamanship* as important as their older counterparts. This tendency seems to also be correlated with the use of modern technologies on board: the more seafarers are versed into the handling of complex modern equipment, the less *good seamanship* appears to be relevant [18, p. 4552].

This observation implies that *good seamanship* is an evolving notion, dependent on technical developments within the seafaring world. The perspective taken by classification societies in the context of *good seamanship* and autonomous vessels seems to follow this consideration. Indeed, among the twelve members of the International Association of Classification Societies (IACS), the mentions made to *good seamanship* in guidelines on autonomous vessels are scarce. However, when this concept is mentioned, it is done so in relation to remote operation centres and their personnel.

Bureau Veritas writes for instance in their Guidelines for Autonomous Shipping:

> It is the crew and remote operators' responsibility to load and operate the ship in a proper manner.
>
> In particular, it will be assumed that:
>
> - […]
> - the speed and course of the ship are adapted to the prevailing sea and weather conditions according to the normal prudent seamanship [14, p. 25].

Mention is made here to 'normal prudent seamanship', which is not defined in the guidelines but can be assumed to correspond to what is coined in this article as *good seamanship*. Bureau Veritas expects here remote operators to hold themselves to 'normal prudent seamanship' when adapting the speed and course of the vessel. Going back to the defining elements of *good seamanship* detailed earlier, it seems Bureau Veritas understands safety to be at the core of this notion.

The American Bureau of Shipping (ABS) also mentions *good seamanship* in their Guide for Autonomous and Remote-Control Functions:

> The context of current regulatory guidance differs from the highly automated environment, but the remote operator must meet communications, timeliness of response, safety, and General Prudential Rule and Rule of Good Seamanship requirements at all times [19, p. 31].

Here, the requirement for remote operators to apply rules of *good seamanship* is worded more generally than in Bureau Veritas' guidelines. In either case, this concept is still meant to apply to humans and not the autonomous system in itself. This aspect departs from the scenario chosen for this article, according to which the vessel acts fully autonomously and the ROC's override only occurs exceptionally.

B. Technical challenges

The main challenges when it comes to translate *good seamanship* into technical processes based on autonomous decision-making reside in the lack of a proper legal definition. In an attempt to evaluate different planning strategies for autonomous ships in multi-vessel encounters, STANKIEWICZ *et al.* understand *good seamanship* through the lens of two characteristics: the ability to reduce risks of collisions and to take early and appropriate actions [20, p. 8310]. In general, authors working on the incorporation of collisions avoidance mechanisms into autonomous vessels' systems tend to base their reflexion on chosen provisions of COLREGs, leaving out essential parts of these rules such as *good seamanship* [6, p. 713].

If it were possible to summarise the concept of *good seamanship* to a set of well-rounded provisions and courses of action, developing a rule-based process, knowing when and how to apply them autonomously given a specific set of circumstances should not represent an insurmountable challenge [12, p. 230]. However, as seen in the previous part, *good seamanship* can hardly be boiled down to only a few characteristics, for they also encompass a wide array of behaviours and unwritten rules based on seafarers' experience. Accordingly, a model driven by the influx of data, on which basis the autonomous system could process new experiences and learn from them could be considered [21, p. 3]. This could for instance take the shape of an AI based on machine-learning [5, p. 5]. A third way could consist in a hybrid model which would rely on pre-set rules as well as a certain quantity of data helping the system to make decisions. There are still many technical challenges to be faced with such a solution. Indeed, the many data to be fed to the system will have to be based on human experience. This will require developers to be accompanied in that process by personnel showcasing the qualities of 'good seafarers.' Moreover, the decisions made by the system will be hardly traceable, which could hamper the societal acceptance of autonomous and unmanned vessels [21, p. 4, 9].

All in all, from a technical perspective, *good seamanship* as applied by an autonomous system seems to remain a blind spot, worthy of deepened research. The question of whether it is reasonable to even try and transpose *good seamanship* requirements to fully autonomous vessels shall remain difficult to answer. Indeed, this would require developers to come up with systems able to apply *good seamanship*, when such developers are not expected and have no reason to display seafarers' qualities in the first place [5, p. 5]. Authors such as ZHOU *et al.*, defend the point of view that in applying Rule 2 of COLREGs on seafarers' responsibility to observe 'the ordinary practice of seamen' among other things, human intervention will always be required in decision making [6, p. 715]. It also seems to be the route chosen by classification societies, as seen earlier, which choose to transpose the duty of *good seamanship* to the ROC personnel. KOMIANOS also expects them to showcase such qualities when overseeing autonomous vessels [22, p. 342].

It will be interesting to witness how this concept, strongly based on an experience in seafaring, will be translated into the skills and behaviours expected from the land-based personnel of the ROC, arguably very different from those of a ship's crew. It could be imaginable that only personnel who have been at sea could assume tasks in the ROC, so as to ensure their upholding of *good seamanship* principles. However, in order for the ROC personnel to act based on the *good seamanship* requirements, the technical challenges detailed earlier linked to situational awareness and data transmission will also need to be addressed so as to ensure a speedy reaction in a dangerous environment.

V. CONCLUSION

Different findings were made throughout this article. Depending on the focus chosen, the inadequacy of COLREGs in the face of technical novelties brought about by autonomous and unmanned vessels was shown.

First, with regard to situational awareness, even if this article's authors and other insights throughout literature on the topic seem to indicate that COLREGs' 'sight and hearing' can be interpreted broadly so as to encompass technical means, there is dissent on how to proceed in the future. Some authors argue that a revision of Rule 5 is necessary [6, p. 716, 717], when others seem to rely on interpretation but recall the strong technical limitations still existing [3, p. 8]. The technical challenges were explained in this article. In this regard, authors argue that a human intervention will always be necessary at last resort [22, p. 342], even if tools such as radars or AIS could complement the expertise of seafarers as it is already the case nowadays [5, p. 8].

Second, when it comes to night-time navigation and detection, the article has shown that many different light signals have to be recognised by autonomous and unmanned vessels, may they be emitted by other ships or by objects such as buoys or lighthouses. In fact, many signals to be found at sea are overlooked by seafarers who can rely on the technology on board such as radars or AIS. The reason for this is the speed at which modern vessels can navigate, making a timely response to a potential collision complicated [3, p. 10], [5, p. 8]. Thus, despite the technical challenges detailed earlier, it can be observed that with regard to night-time navigation, seafarers already rely heavily on technical means. There may also be some dangers for conventional vessels when encountering autonomous and unmanned vessels at night. In such a scenario, STĘPIEŃ suggests that such ships be equipped with a specific light signal for other seafarers to identify [3, p. 10].

Third, it was also established in this article that only a system based on data-input, so as to make its own decisions could accommodate *good seamanship*, for it would showcase the ability to learn from its mistakes, the same way a seafarer would. Only then could it be said from the autonomous system that it is building some sort of experience, insofar as it would be possible for such a system to do so. However, a hybrid system functioning thanks to a set of pre-established rules should also come into consideration. Indeed, if there are some rules known to all seafarers based on *good seamanship*, these could already be fed to the system and would not have to be learnt artificially. Such a hybrid system would allow more transparency in the decision-making process [21, p. 9].

Yet, building experience necessarily implies that mistakes will be made. As long as they do not pose a threat to human lives, it is acceptable to assume that seafarers make such mistakes, from which they will learn and will not reproduce [5, p. 5]. However, when it comes to autonomous systems, interrogations may rise from an ethical and societal acceptance perspective. Whether operators or users can accept a certain margin of errors committed by autonomous systems remains to be answered. If that were not to be the case, it would appear that, in a maritime context, such systems are held to higher standards than human seafarers.

In the context of *good seamanship*, other questions will be raised such as the evolving nature of that concept, strongly influenced by seafarers themselves [18, p. 4551]. Whether new seafaring practices will bring about the extension of the requirements linked to *good seamanship* to the on-shore personnel, remains to be answered. ZHOU *et al.* seem to accept this idea. However, they warn about the uncertainties this could raise when it comes to responsibility. Whether Rule 2 of COLREGs could also come to apply to 'shore-based operators, software developers and system producers' remains to be analysed [6, p. 714].

Overall, it appears that technology as it exists nowadays cannot quite meet the requirements expected from autonomous and unmanned vessels. Ways out of this are further technical developments or regulatory amendments so as to accommodate the novelties brought about by autonomous shipping. The COLREGs have already undergone amendments in the past to welcome new technologies, such as steam-ships. However, aside from minor changes, it has been fifty years since the last significant revision of COLREGs [3, p. 5, 6], [4, p. 512], [23, p. 235]. STĘPIEŃ is a strong proponent of a revision of COLREGs. She argues that it would benefit both autonomous and conventional vessels. The latter are – according to her – also impacted by the rules' vagueness. This could be an opportunity to introduce new concepts into COLREGs such as the ROC and its personnel [3, p. 1, 8].

However, when integrating autonomous and unmanned vessels into the COLREGs, one should be wary of trying to uphold such ships to the exact same standards as those expected from a crew and its master. Here, an approach based on the specificities of autonomous and unmanned vessels could prove more interesting, instead of trying to replace human senses artificially. Indeed, where seafarers are superior to autonomous systems for they can rely on their senses and experience in dangerous situations, a machine does not have to fight tiredness or attention lacking. Obviously, this paradigm shift shall not undermine the legitimately high safety standards by which conventional vessels are bound, in order to push the introduction of autonomous and unmanned vessels at all costs.

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[1] Ø. J. Rødseth, D. A. Nesheim, A. Rialland, E. A. Holte, "The Societal Impacts of Autonomous Ships: The Norwegian Perspective," in *Autonomous Vessels in Maritime Affairs - Law and Governance Implications*, T. Johansson, J. Fernández, D. Dalaklis, A. Pastra, J. Skinner, Eds. Cham: Palgrave Macmillan, 2023, pp. 357-376, doi: 10.1007/978-3-031-24740-8_18.

[2] Convention on the International Regulation for Preventing Collisions at Sea, concluded 20 October 1972, entered into force 15 July 1977, 1050 UNTS 16.

[3] B. Stępień, "Towards a New Horizon: 1972 COLREG in the Era of Autonomous Ships," *Ocean Development & International Law*, pp. 1-15, June 2024, doi: 10.1080/00908320.2024.2359908.

[4] T. Porathe, "Maritime Autonomous Surface Ships (MASS) and the COLREGS: Do We Need Quantified Rules Or Is 'the Ordinary Practice of Seamen' Specific Enough?," *TransNav, International Journal on Marine Navigation and Safety of Sea Transportation*, vol. 13, no. 3, pp. 511-517, Sept. 2019, doi: 10.12716/1001.13.03.04.

[5] K. Wróbel, M. Gil, Y. Huang, and R. Wawruch, "The Vagueness of COLREG versus Collision Avoidance Techniques—A Discussion on the Current State and Future Challenges Concerning the Operation of Autonomous Ships," *Sustainability*, vol. 14, no. 24, Art. No. 16516, Dec. 2022, doi: 10.3390/su142416516.

[6] X.-Y. Zhou, J.-J. Huang, F.-W. Wang, Z.-L. Wu, and Z.-J. Liu, "A Study of the Application Barriers to the Use of Autonomous Ships Posed by the Good Seamanship Requirement of COLREGs," Journal of Navigation, vol. 73, no. 3, pp. 710–725, May 2020, doi: 10.1017/S0373463319000924.

[7] *Outcome of the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS)*, MSC.1/Circ.1638, Maritime Safety Committee, International Maritime Organisation, June 2021.

[8] T. Solvang, "From the role of classification societies, to theories of norms and autonomous ships - some cross-disciplinary reflections," *MarIus*, vol. 519, pp. 239-256, 2019, uri: http://urn.nb.no/URN:NBN:no-80719.

.

[9] M. Stadermann and A. Klein, "Anforderungen der COLREGs an unbemannte Schiffe," in *Dreizack Tagung 2023*, H. Schilling, Ed., Laboe, Germany, Mar. 22-24 2023, pp. 37–42. Available: https://www.kielseapowerseries.com/en/der-dreizack/dreizack-2023-ispk-dma.html.

[10] "The MUM-Project – Large Modifiable Underwater Mothership". Available: https://mum-project.com/, accessed: Jul. 22 2024.

[11] "LEAS – shore-side decision support for traffic situations with highly automated or autonomous vessels using AI". Availaible at: https://www.kpler.com/research-projects/leas-shore-side-decision-support-for-traffic-situations-with-highly-automated-or-autonomous-vessels-using-ai, accessed: Jul. 22 2024.

[12] S. N. Trowers, "Uncharted Legal Waters: The Applicability of the Law on Seaworthiness & Good Seamanship to Autonomous Vessels," in *The Regulation of Automated and Autonomous Transport*, K. Noussia, M. Channon, Eds. Cham: Springer, 2023, pp. 203-242, doi: 10.1007/978-3-031-32356-0_7.

[13] *Autonomous and remotely operated ships*, DNV-CG-0264, Det Norske Veritas, 2021.

[14] *Guidelines for autonomous shipping*, NI 641, Bureau Veritas, 2019.

[15] *The IALA Maritime Buoyage System*, R1001, Edition 2.0, Interational Association of Marine Aids to Navigation and Lighthouse Authorities, 2023.

[16] H. Weber, "Seeverkehrsrecht," in *Handbuch Nautik – Navigatorische Schiffsführung*, 1st ed., B. Berking and W. Huth, Eds. Hamburg, Germany: Seehafen Verlag, 2010, pp. 319–359.

[17] A. N. Cockroft and J. N. F. Lameijer, *A Guide to the Collision Avoidance Rules – International Regulations for Preventing Collisions at Sea*, 6th ed. Oxford, United Kingdom, Burlington, MA, USA: Butterworth-Heinemann, 2004.

[18] A. L. Aalberg and R. J. Bye, "The intangible concept of good seamanship – A comparison of the ingredients of seafarers' descriptions using a hybrid qualitative-quantitative approach," in *Proc. of the 30th European Safety and Reliability Conf. and the 15th Probabilistic Safety Assessment and Management Conf.*, P. Baraldi, F. Di Maio, E. Zio, Eds., Venice, Italy, Nov. 01-05 2020, pp. 4551-4558, doi: 10.3850/978-981-14-8593-0.

[19] *Guide for Autonomous and Remote Control Functions*, American Bureau of Shipping, 2021.

[20] P. Stankiewicz, M. Heistand and M. Kobilarov, "Quantifying Good Seamanship For Autonomous Surface Vessel Performance Evaluation," in *2020 IEEE International Conference on Robotics and Automation (ICRA)*, Paris, France, 2020 pp. 8309-8315, doi: 10.1109/ICRA40945.2020.9197572.

[21] E. Kirchner and U. Schmid, "Hybride KI – Wissen und Daten kombiniert nutzen," Lernende Systeme – Die Plattform für künstliche Intelligenz, Munich, Germany, Nov. 2023. Accessed: Jul. 22 2024. [Online]. Available: https://www.plattform-lernende-systeme.de/files/Downloads/Publikationen/KI_Kompakt/PLS_KI_Kompakt_Hybride_KI.pdf

[22] A. Komianos, "The Autonomous Shipping Era. Operational, Regulatory, and Quality Challenges," *TransNav, International Journal on Marine Navigation and Safety of Sea Transportation*, vol. 12, no. 2, pp. 335-348, June 2018, doi: 10.12716/1001.12.02.15.

[23] E. Hannaford, P. Maes and E. Van Hassel, "Autonomous Ships and the Collision Avoidance Regulations – A Licensed Deck Officer Survey," *WMU J Marit Affairs*, vol. 21, pp. 233-266, June 2022, doi: 10.1007/s13437-022-00269-z.