

The Autonomous Shipping Era. Operational, Regulatory, and Quality Challenges

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ABSTRACT: The article provides a description of the Autonomous ship, studies existing relevant projects, and examines the related Operational, Regulatory, and Quality assurance challenges raised due to the development and actual deployment of such vessels in the near future. After reviewing the main operational procedures, existing regulations, and quality assurance standards, a number of possible solutions and approaches to overcome the identified challenges are indicated. Some of the conclusions may be used not only in the Autonomous ships but also in traditionally manned vessels.

1 INTRODUCTION

In recent years, a remarkable development has attracted the attention of the shipping and maritime sector, namely the “Unmanned” and/or “Autonomous” (AtS) ship projects. Combined and reinforced by Information and Communications Technology (ICT) inventions, these projects have brought revolutionary changes to traditional shipping practices and reveal a new dimension, leading owners, operators, and manufacturers to an innovative rethinking of shipping. (Lloyds Register, 2016).

These concepts have gained ground amongst the shipping industry’s research projects and, as a new trend, have generated several ongoing prototype and exploration endeavours. However, there are several issues to be addressed before they are fully functional and universally accepted as safe, secure, and viable means of transportation. An increasingly positive attitude in the shipping industry towards the issues of autonomy, automation, unmanned operations, Big Data, enterprise-grade connectivity, and analytics is

steadily expanding the shipping and maritime agenda.

Using the latest ICT systems, ships are built with enhanced control capabilities, communication, and interfaces, and they will soon be run by remote land-based or offshore services, whenever and wherever they are required. These systems have the potential to enhance the safety, reliability, and performance of shipping companies, but also pose challenges and risks that must be identified, understood, and addressed so that new innovative technologies integrate with the design and operation of the ships to ensure safety.

Because the Autonomous and Unmanned ships consist of several interconnected systems, and due to the rapid evolution of technology, it cannot be assumed that such vessels will be safe, based exclusively on knowledge gained from earlier systems. Therefore, a holistic system approach is needed (total systems) - a system that considers all the different systems (a system of systems) on board and ashore, how they are designed and installed, how

they relate, and how they will be managed and regulated.

Comparable to a drone, the unmanned vessel is already in use for military, aerospace, or scientific purposes. Submersible unmanned vehicles, such as the autonomous underwater vehicles (AUV) or the remotely operated vehicles (ROV) which are used for deep-sea exploration of the seabed or of wrecks, in addition to cruise missiles, surface to air missiles, air to air missiles, air to surface missiles, and intelligent torpedoes are all examples of a technology which is already in use and continues to develop.

The “Autonomous vessels” will be equipped with systems allowing self-steering by sensor-based detection of objects such as obstacles and will be able to self-initiate an action e.g. to avoid collisions with other objects. This may be achieved by technical systems installed on-board, which use programmed algorithms and input data gathered by sensors. The introduction of the Autonomous ship concept to the shipping industry might start a new era and become a game changer in terms of cost efficiency, accident prevention, and human resources. According to Rolls-Royce (a leading company in Autonomous ship research) and other supporters of the project, the main advantage of such ships is that they might reduce maritime accidents caused by fatigue and alcohol abuse (Rolls-Royce, 2015).

An important issue for the shipping industry, accidents are most often related to human factors, such as fatigue, due to an increasing workload and a decrease in the crew size per ship, and alcohol or drug abuse. Although the shortage of seafarers is becoming a global issue, a potential (and hopefully controlled) decrease in the number of seafarers needed on board could ease and resolve this problem.

Paradigms of applied unmanned systems can already be found in other modes of transport, such as airplanes, trains, and in the automobile industry, which is already trying to develop autonomous vehicles. However, a very distinct and serious problem exists in the shipping and maritime sectors, namely, the lack of Autonomous ships’ coverage and inclusion in relevant safety, security, and environmental protection conventions and regulations. The initiation of a new perspective is therefore needed before Autonomous ships can be introduced to commercial shipping, in order to ensure the prevention of maritime accidents and the protection of the environment.

2 BACKGROUND

The number of autonomous vehicles being used in the air, on the ground, and in the sea is increasing. As Mindel (2015) states, humans repeatedly find manned, “remote and autonomous vehicles evolving together, each affecting the other”.

There are already several small-size unmanned and autonomous crafts in the maritime sector which have been engaged in surface navigation, research and scientific activities, under water operations, and specific military activities. Proven safe, these vessels

are the path towards the elimination of human error and thus accident minimization [32].

The European Technology Platform describes the autonomous ship as a next generation modular control and communications technology system of systems which will “enable wireless monitoring and control functions both on and off board. These will include advanced decision support systems to provide a capability to operate ships remotely under semi or fully autonomous control” [31].

There are two generic alternatives that are combined in an autonomous ship, namely “the remote ship where the tasks of operating the ship are performed via a remote-control mechanism e.g. by a shore based human operator”, and “the automated ship where advanced decision support systems on board undertake all the operational decisions independently without intervention of a human operator”.

The Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) started in 2012 and ended in 2015. It was funded by the European Commission (EC), with the purpose of investigating the technical, economic, and legal feasibility of unmanned ships [31]. The most important characteristics of this project include the ability of the ship to be operated by an autonomous shipping system on board (while having the ability to be supervised and controlled by land operators), its ability to minimize the risk of collision and comply with the Convention on the International Regulations for Preventing Collisions at Sea (COLREG), and the fact that its safety and operation sensors can be used to search for objects.

This last characteristic does not satisfy Rule 5 of COLREG, which requires proper look-out by eye and ear on every ship to assess the situation and the risk of collision.



Figure 1. The MUNIN project. www.unmanned-ship.org (Accessed October 2017)

Another example of such a project is that of the Advanced Autonomous Waterborne Applications Initiative (AAWA). Launched by Rolls-Royce in 2015, its purpose is to bring together universities, ship designers, equipment manufacturers, and classification societies to explore the economic, social, legal, regulatory, and technological factors which need to be addressed in order to make autonomous ships a reality. It will produce the specification and preliminary designs for the next generation of

advanced ship solutions. “Autonomous shipping is the future of the maritime industry” argues Mikael Makinen, president of Rolls-Royce’s marine division, in a white paper published by the company. “As disruptive as the smartphone, the smart ship will revolutionise the landscape of ship design and operations” [35].

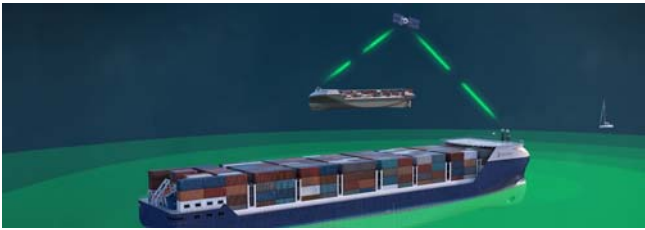


Figure 2. The Advanced Autonomous Waterborne Applications Initiative. Image from the Rolls-Royce www.rolls-royce.com (Accessed October 2017)

A third project is the ReVolt, an unmanned, 60-metre-long, zero-emission, short sea vessel, developed by DNV GL. The vessel is crewless, fully battery powered, autonomous, and, according to the company’s web page¹, it offers “a solution to the growing need for transport capacity”. The project was started in order to manage the traffic congestion in urban areas on the EU’s road network. This became an issue because population growth has created a demand for transportation that exceeds the capacity of existing roads.

To ease these problems, administrations all over the EU are “trying to move some of the freight volume from roads to waterways. However, profit margins in the short-sea shipping segment are small”.



Figure 3. ReVolt dock arrival Image from <https://www.dnvgl.com> (Accessed September 2017)

The result of a multi-disciplinary, team-based development project, ReVolt is based on an assessment of current requirements along short-sea routes. The ship will operate at a speed of 6 knots with a range of 100 nautical miles and a cargo capacity of 100 twenty-foot containers. Being crewless, there will be no need for accommodation which usually forms the vessel’s superstructure. Compared to a diesel-run ship, the vessel could save up to USD

34 million during its estimated 30-year lifetime, saving more than a million USD annually, due to the resulting increase in loading capacity and the low operating and maintenance costs. The vision of DNV-GL is the extension of the project to involve land-based charging facilities and capacities as well.

The endeavour developed by Lloyd’s Register (LR) is named the Cyber-enabled ship project, which discusses the procedures and guidance for autonomous ship operations. Under LR guidance for Cyber-enabled ships “Deploying information and communications technology in shipping – Lloyd’s Register’s approach to assurance”, the cyber-enabled ship is perceived as a “system of systems” [28].

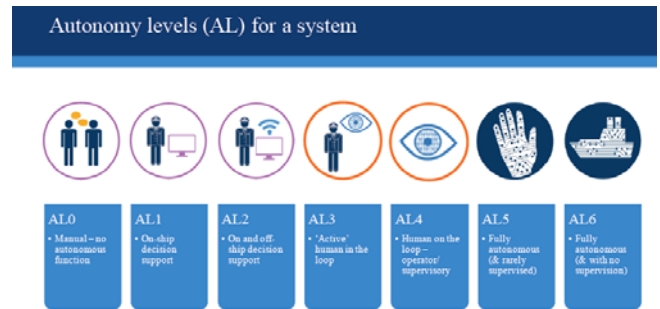


Figure 5. Lloyd’s Registered Levels of Autonomy www.lr.org/cyber Accessed Oct 2017

As such, six main risks have been identified, namely the System, the Human-system, the Software, the Network and communications, the Data assurance, and last but not least the Cyber security. For each of these risks, the guideline describes the aspects which should be studied in addition to a short description of cyber-enabled systems. Furthermore, “Cyber-enabled ships: Ship Right procedure – autonomous ships” was developed, naming seven levels of autonomy ranging from a Manual-no autonomous function to a fully autonomous operational mode.

This approach identifies the proper actions needed, based on the desired level of autonomy. More specifically, during the *Manual – no autonomous (AL 0)* function, all actions and decisions (such as navigation, surveillance, etc.) are performed manually by humans on board, although some systems may have a level of autonomy, with ‘human in/on the loop’ such as the Periodical Maintenance System (PMS) and the engine control.

Regarding *On-ship decision support (AL 1)*, the crew on board decides and acts with the optional aid of decision support tools on the ship such as the Dynamic Positioning (DP) capability. The *On and off-ship decision support (AL 2)* is similar to (AL 1) with the addition of a data provision option, provided by systems on board or from a shore facility, e.g. routing planning (on board) and weather routing (shore based guidance).

With regards to ‘Active’ *human in the loop (AL 3)*, all decisions and actions on board are performed autonomously under human supervision. Data may

¹<https://www.dnvgl.com/technology-innovation/revolt/index.html>

be provided as in (AL 2), but decisions which may seriously impact the safety and security of the vessel require human intervention.

Similarly, as regards the *Human on the loop – operator/supervisory (AL 4)*, human supervision may intercede and over-ride autonomously performed decisions and actions which may have a serious impact. A *Fully autonomous (AL 5) system*, which allows some access during a mission, is an unsupervised or rarely supervised operation during which decisions and actions are made by the system. Finally, a *Fully autonomous (AL 6) system*, which allows no access during mission function, is a totally unsupervised operation during which decisions are made and actioned by the system.

Another relevant project is the *Autonomous Marine Operations and Systems (AMOS) Project 3*, which was developed by the Departments of Marine Technology and Engineering Cybernetics at the Norwegian University of Science and Technology (NTNU) in collaboration with international and national partners. It is related to the unmanned ships and focuses on the following topics: Autonomous system and payload architectures, Coordinated operation of a sensor network of unmanned vehicles and floating nodes, Integrated underwater navigation and mapping, Autonomous object detection and tracking in marine environments using infrared sensors, Sensor-based guidance and path optimization, Coordinated and cooperative control architectures for intelligent task execution, and collision avoidance in uncertain maritime environments [32].



Figure 6. NTNU research areas. Image from www.ntnu.edu/amos (Accessed Sep 2017)

One of the latest projects related to the Autonomous Ship is the “YARA Birkeland” (YB). YARA and KONGSBERG have entered into partnership to build the world’s first fully electric container feeder vessel. The project started in 2017 as a manned vessel, is working towards remote operation by 2019, and is scheduled to go fully autonomous by 2020. By removing up to 40,000 truck journeys in populated urban areas, it will reduce NOx and CO2 emissions, improve road safety, alleviate traffic congestion, and will thus contribute to the achievement of UN sustainability goals².

² <https://sustainabledevelopment.un.org/?menu=1300>



Figure 7. The “YARA Birkeland”/ www.km.kongsberg.com (Accessed October 2017)

This 120 TEU (Twenty-foot Equivalent Units) open top container vessel will be battery-powered (fully electrical) and is prepared for remote control and autonomous operation. During the first stage of the project, a bridge with crew facilities will be used in a containerised form.

This compartment will be lifted off during the autonomous operation phase. Electric cranes and relevant equipment will be used for automatic load and unload cargo operations. Instead of ballast tanks, the ship is designed to use her battery packs as permanent ballast. Additionally, she will be able to be berthed automatically or go underway without any human intervention by using an automatic mooring system, which will not require any special dock structure or extra port facilities.

The vessel will be programmed to sail within 12 nautical miles of the Norwegian coast, between three ports of the country’s southern area which is safely covered by The Norwegian Coastal Administrations’ VTS system at Brevik. Three control centres with diverse operational profiles will handle all operational issues in addition to any emergency situations, or other safety and security aspects.

In addition to the above-mentioned projects, a number of research papers are very informative. “*The production of unmanned vessels and its legal implications in the maritime industry*” University of Oslo (UiO Faculty of Law), argues that any legal problems posed by unmanned vessels are of an organizational rather than a technical nature [38].

This kind of ship design is so new, due to the rapid scientific developments in the maritime industry, that such vessels are not yet covered by any international rule or regulation. The International Maritime Organization (IMO) has not given any approval for this type of vessel nor has it received any proposal from the contracting governments to regulate unmanned vessels.

Given the lack of proper regulatory framework for unmanned vessels, the research focused on “*how the unmanned vessels comply with the framework set by present international maritime Conventions such as SOLAS and ISM Code 6*”. The paper concluded that although the existing maritime technology may cover any safety, environmental, and commercial concerns, the lack of a proper regulatory framework may delay the actual use of such vessels.

This regulatory vacuum generates various issues such as the inability of the classification societies to

certify the vessels. Lacking the classification certificates, the vessels cannot be insured, thus they cannot sail, and eventually they will not be chartered. Although some regulatory aspects of manned vessels are also applicable to unmanned vessels, such as specific clauses of the ISM Code, there are several international regulations that need to be amended.

“A pre-analysis on autonomous ships” (2016) by M. Blanke, M. Henriques, J. Bang, the Technical University of Denmark (DTU), is the response of the Technical University of Denmark (DTU) to a request from the Danish Maritime Authority. The concept included research into the “connection and planning of tasks to be included in coming efforts to shed light on the importance of unmanned ships to Blue Denmark”. The paper briefly describes various levels of operation, ranging from the completely manual (lowest), to higher levels of decision-support, where automation fulfils more tasks, up to the level of total autonomy. The study, besides other scientific inputs, was based on self-propelled cars, unmanned aircraft experience, and knowledge from ongoing similar autonomous ship projects.

“Existing conventions and unmanned ships – need for changes?” (2016), by Tomotsugu Noma, the World Maritime University (WMU), researches the necessity for changes in existing conventions when the unmanned ships are introduced into the maritime transportation system and, among other subjects, his research focuses on survey schemes, especially with respect to regulations of SOLAS Chapter V. Having studied existing survey schemes and having identified the challenges related to surveys and technical, operational, administrative, and regulatory problems, the paper provides definitions of unmanned ships, listing the main characteristics [32].

The implementation of an autonomous vessel will provide the opportunity to increase the efficiency of ship operation as well as enhance the ‘sustainability’, which is the greatest driver in any industry [37].

As Ben Cuckson of Lloyd’s Register argues, minimal safety risk, minimal environmental impact, and maximum commercial benefits are the most important dimensions of a sustainable development in the shipping world. These factors are illustrated in Figure 8.



Figure 8. Marine industry’s sustainable development factors (Source: Cuckson, 2015)

Reports from Drewry Shipping Consultants predict that economies of scale (which gave birth to the Mega-ships’ construction and use) will soon be in decline. A McKinsey analysis calculated that “slow steaming had added around 3 days to transits, costing shipping customers \$5.7 billion in additional annual inventory and obsolescence costs worldwide” (Autonomous Ship White paper, 2016). The construction of intelligent vessels would change this situation, creating a better, more profitable, and, hopefully, safer shipping market. In an earlier United States Coast Guard (USCG) report, the marine casualties caused (to some extent) by human error was between 75-96% [36].

Burmeister et al. claimed that the development of autonomous vessels such as those in the MUNIN Project will offer a wide-ranging solution to meet the main challenges of the maritime transport industry, resulting in a decrease in the operational expenses, better environmental protection practices, and human fatigue minimization [4]. However, there are several challenges to be overcome before such vessels are commercially accepted in the international frameworks observing the IMO’s (International Maritime Organisation) rules and regulations on the seas.

Although highly advanced technologies which enable the design and construction of autonomous vessels already exist in the market, these systems create a number of challenges especially in the social, economic, and regulatory areas. On the other hand, the upcoming introduction of autonomous ships in the market reinforces the expectations of a potential decrease in accidents caused by human error and a likely cost reduction, and intensifies the anticipation of better services in shipping operations.

Studies conducted by Bryant [3], McCallum et al.[30], and Rothblum [36] amongst others, discovered that the proportion of maritime accidents caused by human error was as high as 64% to 96%. These errors were the result of fatigue, poor maintenance and standards, inadequate knowledge and information, and poor communication skills [36]).

Regarding the expected cost reduction, the main ship operation expenses consist mostly of fuel cost and crew compensation. According to the 2011 Drewry report, crew costs were “on average between 31 and 36% of the total ship operation costs” for bulk carriers.

Apart from the previously mentioned challenges which may arise from the introduction of the autonomous ships to the maritime industry, Zakirul argues that new designs and technological features, while affecting the new building costs, the availability and robustness of systems, cyber security, and harmonised standards developments, “are not primarily caused by technical obstacles and they are arguably the integration of the autonomous ship into the existing maritime operation”[40].

Regarding the human element in the automatic systems, Endsley & Jones consider the “human-out-of-the-loop syndrome” to be an important issue because an Autonomous ship may be regarded as riskier compared to a traditionally manned vessel, and the “social acceptability” factor must be very

seriously considered especially in passenger ships. In addition, a massive shift in the future from manned to semi- autonomous or unmanned ships may produce unwanted results, such as high unemployment in the seafaring profession and social discomfort to sea nations [11].

As for the compliance of the autonomous ships with existing regulations at sea such as SOLAS (Safety of Life at Sea) and COLREGS (Collision Regulations), there is a need to update or adjust existing international conventions to embrace the development of such systems. Updated technical and operational standards will be needed to cover the development of the autonomous systems including the commercial agreements e.g. chartering, management, and insurance [34]. Moreover, the member states of IMO must agree on the implementation of the autonomous vessels and the liability for any accidents in which these ships may be involved.

The cost impact for the operation of the autonomous ships seems to be concentrated mostly in new building expenses due to the novel designs and innovative technological features, without excluding new infrastructure requirements for the ship to shore command i.e. the control, communication, information, and operation centre (e.g. an advanced VTS centre). Although costs related to the crew on board the ship will be reduced, additional costs for land-based services such as the control centre, equipment, maintenance crews in port expenses, and shore personnel wages will be increased [4].

All autonomous vehicles should operate safely and effectively in a real-world environment while doing operations of direct commercial value and should be manufactured, maintained, deployed, operated, and retrieved at an acceptable cost [34]. Furthermore, Koopman & Wagner argue that the challenges of developing safe autonomous vehicles are significant [27]. Indeed, ensuring that vehicles are safe requires either following the ISO 26262 V process, or demonstrating that a set of equally rigorous process and technology practices has been applied. In October 2017, Rolls Royce marine announced that it will use Google's Cloud Machine Learning Engine *"across a range of applications, designed to both make today's ships safer and more efficient, and to launch the ships of tomorrow"*. The project is envisaged to produce a fully autonomous ship that will set sail by 2020 [12].

Just two years before this announcement, D. Mindel in his book *"Our robots ourselves, robotics, and the myths of autonomy"* (2015) he argues that, *"we have the myth of full autonomy, the utopian idea that robots, today or in the future, can operate entirely on their own. Yes, automation can certainly take on parts of tasks previously accomplished by humans, and machines do act on their own in response to their environments for certain periods of time. But the machine that operates entirely independently of human direction is a useless machine. Only a rock is truly autonomous, and even a rock was formed and placed by its environment"*.

3 ANALYSIS

The main Operational features of a sea adventure may be summarised as follows: Seaworthiness, desirable Propulsion and Electric Power, pre-planned Endurance, safe Navigation, proper Maintenance, reliable Communications, Collision and Grounding avoidance, continuous Risk Assessment, danger Mitigation, timely Response to ANY safety or security issues, Environmental protection, safe and on-time Delivery of the Cargo, and Liability / Insurance coverage.

Regarding the most important Regulations that apply to the shipping industry, no uniform sea safety, security or environmental protection rules for international shipping had initially existed since the creation of the IMO (International Maritime Organization) in 1948 under the auspices of the United Nations (Churchill R. and Lowe A., 1992). This oversight was corrected by creating a framework of regulations for the shipping industry that is "fair and effective, universally adopted and universally implemented"³. A brief outline of the most important signed conventions follows:⁴

- The Safety of Life At Sea convention (SOLAS).
- The International Management Code for the Safe Operations of Ships and for Pollution Prevention (ISM code).
- The International Convention of Standards of Training, Certification and Watchkeeping for Seafarers (STCW).
- Convention on the International Regulations for Preventing Collisions at Sea (COLREG)
- The International Convention for the Prevention of Pollution from Ships (MARPOL).
- The International Convention on Maritime Search and Rescue (SAR).
- The International Convention on Load Lines (CLL 68/88) which defines the minimum freeboard, watertight integrity, and survivability of ships.

Other important regulatory and technology innovation factors that strengthen the safety culture of international shipping include:

- The International Convention of the Maritime Satellite Organization (INMARSAT).
- The International Convention for Safe Containers.
- The Double Hull/ Double Bottom (DH/DB) regulation, which plays an important role in oil spill prevention and the Inert Gas System (IGS) which operates in such a way that it renders the atmosphere of the cargo tanks non-flammable and maintains incombustibility.

The minimization of human factor errors⁵ (due to poor judgment, stress, inadequate staffing, poor living conditions, fatigue, etc.) by improving training, safety, the culture of environmental awareness, and communication between multicultural and multilingual crews and Port State Control (PSC), an internationally agreed regime which has been an

³www.imo.org (Accessed 20 September 2017)

⁴With no policing powers the IMO can only argue the implementation of these conventions and rely on the efficacy of flag and port state control.

⁵The U.S Coast Guard defines human error as acts or omissions or personnel which affect successful performance.

important safety and security compliance tool since 1982, "have also contributed to safety and security in the maritime industry.

The main Quality assurance issues identified through the research are, in short, the vessel's construction, design, equipment, information technology, data processing, software, algorithms, communications, training of shore based personnel, safety and security procedures.

3.1 SOLAS

The Convention on Safety of life at sea (SOLAS) specifies the minimum acceptable standards for construction, equipment, operations, and required certifications of ships. The responsibility of compliance is given to the flag states, in addition to the inspection right of foreign vessels visiting their ports. (Adopted: 1974 - Into force: 1980). Following the Titanic immersion, it was initially entered into force in 1914 and properly amended to its latest version. Contracting Governments (Flag States), must ensure that all ships under their flag satisfy the requirements of SOLAS. When the requirements are met, a certificate of compliance is issued [20].

In the event that a ship or its equipment breach (or there is a suspicion of violation of) these requirements, a Port State Control (PSC) authority is allowed to inspect the ship when entering the area of PSC's responsibility. One of the most important issues which may challenge the very essence of the Autonomous ship is Chapter V Regulation 14 of SOLAS, regarding the manning of ships. The other one is Regulation 33 (Distress Situations: Obligations and Procedures) of the same chapter, which will be analysed under paragraph 3.5 Search And Rescue.

The Autonomous ship is not excluded from Chapter I, thus the phrases "*shall be sufficiently and efficiently manned*" and "*shall be provided with an appropriate minimum safe manning document or equivalent*", means that somehow these requirements must be fulfilled, otherwise the rule must be adapted to reflect the new reality of a ship without crew on board. On the other hand, as already mentioned, most of the Autonomous ship projects incorporate at least one Remote Control Centre (Yara Birkeland project will use three). These remote stations will (hopefully) be manned with sufficient personnel, while the "efficiency" requirement may be covered by the wide range of high-tech systems (various sensors, computers, automations, remote controlled machines etc.). This combination will assist the remote command and control of the vessel, and will fulfil the requirements of Regulation 14.

3.2 STCW

The STCW (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers) established the basic international

standards in this field [21]. The Convention was adopted in 1978 and went into force in 1984.

Today it is applicable to personnel on board a ship (a.k.a. seafarers, crew etc.) not persons who are responsible for operating an Autonomous ship from a remote-control centre (RCS) based onshore or at any other relevant location other than the ship herself, nor the programmers who have pre-programmed her autonomous course before she goes underway. These personnel are not regulated by STCW, although they have been delegated the authority to control Autonomous ships.

Additionally, under UNCLOS, Art.94(4)(b), flag states must ensure that each ship is "*in the charge of a master ... who possess[es] appropriate qualifications, in particular in seamanship, navigation, communications and marine engineering*". As Veal and Tsimplis argue [39], the obvious question is "*whether it is possible for an unmanned ship, by its very definition, to have a master*". Furthermore, the workload of the onshore personnel for the Remote-Control Centres is expected to be quite heavy. A "shore based master" assisted by one to three operators may control a small flotilla of autonomous vessels simultaneously. The minimum number of such vessels which are allowed to be handled at once has not yet been determined.

The conditions, which vary depending on the geographical area, the types of cargo, the weather conditions, whether a vessel is arriving at or sailing from a port, the safety, the security, the fatigue of the operators, what the accepted minimum previous experience on board same or similar types of ships is, and the updated competency tests, all have to be seriously considered. These prerequisites must be incorporated into existing STCW, or a similar convention specifically tailored for the needs of Autonomous ships. In addition, training requirements and certification schemes must be adopted in line with the internationally accepted standards similar to those which apply to the Vessel Traffic Services (VTS) operators.

Finally, although labour law would apply to the operators of the Remote Control Centres or the pre-programmers of a totally Autonomous ship, specific rules similar to those applicable to seafarers (such as the duty to report signals of distress, etc.), may need to be adjusted and applied as well.

3.3 COLREG

The Convention on the International Regulations for Preventing Collisions at Sea (COLREG) (Adopted: 1972 - Into force: 1977), revised the International Regulations for preventing Collision at Sea of 1960⁷. They are published by the International Maritime Organization (IMO) and among other issues, they define the navigation rules (a.k.a "Rules of the road") to be followed by ships and other vessels at sea to prevent collisions between two or more vessels [5].

⁶Vessels using port facilities may be subject to inspections and additional control measures.

⁷Marsden, Reginald. G, (2003), Collision at sea, Sweet and Maxwell

They apply to all vessels upon the high seas and in all waters connected therewith navigable by seagoing vessels. Under Rule 3 "General Definitions" paragraph (a), the explanation of the word "vessel" is given as "every description of water craft, including non-displacement craft and seaplanes, used or capable of being used as a means of transportation on water." This definition does not exclude the Autonomous ship from being characterised as a "vessel". Rules 2, 5, 6, 7, 8, 17, 19 and 20 will be analysed in relation to Autonomous ship operations.

Rule 2: This rule must be adjusted to reflect the absence of master and crew on the Autonomous ship. A possible "transfer" of responsibility from the on-board master and crew to the shore (or elsewhere) based personnel (e.g Control Centre etc.) must cover the "ordinary practice of seamen". This seems to oblige any future Control Centre manning scheme to include personnel with adequate seamanship experience.

Rule 5: Although it may be possible to substitute the human "sight and hearing" with technical means such as super sensitive microphones and ultra-high analysis and vision cameras, this Rule is the subject of much debate regarding the effectiveness of such means. The expression "proper look-out by sight and hearing" followed by the phrase "as well as by all available means appropriate in the prevailing..." indicates that ALL other technical means have already been considered, and the importance of human senses (in particular the faculty of sight, and hearing by which the body perceives external stimuli), judgment and experienced reaction, is deemed necessary as a last resort to avoid a collision.

Rule 6: The definition of "safe speed" and "proper and effective action" is related to the collision avoidance. In the event that a collision finally occurs, the speed that was chosen would be characterised as "unsafe" because of the result. This rule combined with previous rule, Rule 5, makes it essential to adjust the expression or define other protective measures. A suitable amendment might read, 'an autonomous ship with such characteristics (shape, cargo load, etc.) sailing under these weather and sea state conditions, must stay clear of any other vessel by a distance of x when underway with speed of y .'

Rule 7: This rule, combined with Rule 5 and Rule 6 dictates the importance of appropriate judgement and seamanship to "determine if risk of collision exists". Although it is plausible for this kind of risk assessment and mitigation to be generated from a remote-control station, the "scanty radar information" phrase indicates once again the importance of the audio and visual information to a human presence on board.

Rule 8: As in Rule 2, good seamanship is deemed essential for the prevention of collision. The International Convention of Standards of Training, Certification and Watchkeeping for Seafarers (STCW) which introduced the basic international standards in this field, must be the guide (in part or at least as a good reference) for the basic training of the shore-based operators of the Autonomous ships.

Rule 17: There is doubt concerning the efficient and effective "manoeuvre of the last second" without the intervention of a human presence on board.

However, there is the physical delay of the human brain as it decides the execution of the manoeuvre. Absolutely reliable, safe, and delay-free communications coupled with secure and fast data transfer between the autonomous ship and the control centre must exist.

Rule 19: The hearing of the fog signal of another vessel as described in Rule 19, obliges the vessel in question to take all appropriate measures for altering her speed and / or course in order to navigate in such a way that will avoid the collision. Once again and similar to Rule 5, the word "hears" implies the need of a human presence on board.

Rule 20: Navigational lights and shapes are paramount to the safety of the ships when underway. In a hypothetical scenario where all available electromagnetic and electroacoustic navigational and surveillance means of the ships in question are operating properly, safe navigation and collision avoidance are mostly assured. Unfortunately, there are plenty of recorded accidents at sea where the above were true, but the operators (Officer of the watch, Navigator, Radar operator etc.) due to fatigue or other reasons, failed to properly evaluate or process the "message" from the machines. Fortunately, there are numerous other examples of last-second course and/or speed alteration and collision avoidances due to the recognition of the navigational lights and shapes shown "with the keeping of a proper look-out".

3.4 MARPOL

MARPOL (The International Convention for the Prevention of Pollution from Ships, 1973), as amended in 1978, sets the standards for the prevention of pollution by oil, chemicals, harmful substances, and garbage. It has been in force since 1983 and its objective is to preserve the marine environment from pollution [17]. Being crewless, an Autonomous ship will have no garbage and human waste of which to dispose.

In addition, the intentional pollution by oil, chemicals, and other harmful substances, which may occur with the complicity of some or all the members of a crew, is not possible. Strict regulations and record keeping of all electronic orders (e-Orders) from the Remote Control Centre to the Autonomous ship will prevent any such actions.

However, unintentional pollution, either as the result of an accident (collision, malfunction, cyberattack, virus, etc.) or due to unforeseen reasons (heavy weather, capsizing, explosion, etc.) would continue to be a problem. In such situations, a timely and efficient response is of paramount importance, and is further analysed in paragraphs 3.7 and 3.8.

3.5 SAR

The SAR convention (International Convention on Maritime Search and Rescue) was adopted in 1979 and is aimed at developing an international SAR plan [19]. The rescue of persons in distress at sea is coordinated by a SAR organization or by co-operation

between neighbouring SAR organizations when necessary. The obligation of ships to assist vessels in distress previously existed both in tradition and in international treaties such as SOLAS. With the adoption of the SAR Convention, an international system was created, covering search and rescue operations on a worldwide scale. SAR and Guidelines on the Treatment of Persons Rescued at Sea (RESOLUTION MSC.167(78) adopted on 20 May 2004) involve manned vessels and no reference is made to Autonomous ones.

SAR Regulation 3.1.9 specifically refers to the master of the vessel, while UNCLOS *Article 98(1) Duty to render assistance*, demands that every State *"require the master of a ship flying its flag, in so far as he can do so without serious danger to the ship, the crew or the passengers: (a) to render assistance to any person found at sea in danger of being lost; (b) to proceed with all possible speed to the rescue of persons in distress, ... (c) after a collision, to render assistance to the other ship, its crew and its passengers and, ..."*

Any seafarer who has ever been involved in a Search and Rescue operation, knows very well the mental, psychological, emotional, and physical stress, the challenges, and the difficulty in properly fulfilling such a task. This kind of operation involves the rescue of life in danger at sea and as such, generates not only operational and insurance obligations but also ethical ones. The responsibilities of Contracting Governments and Masters include the assistance and embarkation of rescued survivors on-board their vessels when possible and a number of other supportive actions in relation to the operation.

In the event that an Autonomous ship is close to such an instance, she most probably will not be able to provide the required assistance and it may also be difficult to avoid a man overboard or an unconscious castaway.

For the Autonomous ship, such actions range from being very difficult to being impossible to perform. A proper adjustment or an exemption of Autonomous ships from the Search and Rescue operations seems to be the most appropriate solution. However, it should be noted that an exemption of ANY kind of vessel at sea from the SAR involvement and obligations, may raise the concern of seafarers with respect to how the shipping industry, various regulatory bodies, and relative organizations regard the rescue of their lives at sea.

3.6 RISK ASSESSMENT AND RESPONSE TO EMERGENCIES

Extensive research on the topic of Risk Assessment and Response to Emergencies has already been conducted in the MUNIN project, including analysis of topics such as the Unmanned ship and Shore Control Centre, Unmanned maintenance and technical operation principles, Heavy weather implications, Sensor systems, and Cyber security.

Chapter two of "MUNIN D9.2: Qualitative assessment" describes in detail the risks related to the operation of an unmanned dry bulk carrier. Potential hazards were identified, the expected frequencies and consequences of incidents related to the hazards were

rated, and the risk was calculated as a function of the frequency and consequences of an incident. A complete list of the identified hazards with the results of the risk rating project can be found in Annex B: Hazard Analysis results of the MUNIN D9.2 paper.

In regard to the response of an Autonomous ship during an emergency situation, there are a number of issues that must be analysed. For example, under UNCLOS Article 98(1) assistance in distress situations is the obligation of all vessels sailing in the area of the incident, although the risks such assistance could pose to the crew, its passengers, and the ship itself must all be taken into consideration.

The Article delegates the authority and burden of initiating the task to the master, having in mind manned vessels and not a crewless ship. If we assume that this obligation is transferred automatically to the "master onshore", a new issue arises, that of the time needed for a response from shore during emergency situations (Hapag-Lloyd, 2016).

To tackle these situations, proper equipment could be installed onboard the Autonomous ship. After its efficacy had been verified, this particular solution would have to be accepted and it may increase the overall structural cost, minimizing the economic benefits of the crewless vessel.

3.7 MAINTENANCE

One of the most important factors of the safety and seaworthiness of a ship is the proper, daily, periodical, and timely maintenance of all her systems, structures, and hull.

A long list of periodical maintenance procedures, but also of emergency (or unforeseen failure) fixes exists onboard all ships. Well-trained experienced personnel are the key factor responsible for meeting these requirements successfully. The following rule sets the basic prerequisites for such actions.

A ship underway is a remote system usually sailing far from maintenance centres, shipyards, ports or other repair facilities. Although certain incidents or malfunctions may be repaired remotely either by software updates, or by the futuristic use of "robots inside a robot" (i.e. a remote-controlled maintenance robot on-board an Autonomous ship), there will be certain circumstances where the presence of an experienced human team would be indispensable. In such cases (if time constraints and the situation permit), there must be the required procedures in place, sufficient infrastructure facilities, and appropriate arrangements to receive such a team.

3.8 FIRE FIGHTING AND DAMAGE CONTROL

It is expected that a variety of sensors and systems, to deal with fire detection and extinguishment but also damage control and repairs, will be present onboard the Autonomous ship. The level of sophistication, the minimum requirements, and the accepted effectiveness shall be regulated and properly enforced.

The cost to protect the Autonomous vessel with such systems from potential fire, water inflow or other damage will most probably be considerable compared to the cost of methods already used on-board manned ships. In terms of area coverage, time efficiency, diversity of incident management, sequence of unpredictable factors, and effectiveness, it is difficult to duplicate the mobility and focused intervention of the firefighting groups and damage control parties (varying from one to eight depending on the type of the ship) who deal with these situations on manned vessels.

3.9 ISPS CODE

In response to the terrorist acts of September 11th (2001) in the United States, the need to protect the international maritime transport sector against the threat of terrorism was recognised. Thus, on July 1st 2004, a new maritime security regulatory regime was introduced into the International Convention for the Safety of Life at Sea (SOLAS), namely chapter XI-2 on Special measures to enhance maritime security, which includes the International Ship and Port Facility Security (ISPS) Code. The ISPS Code entered into force in December 2002 and is the result of cooperation between Governments, Government agencies, local administrations, and shipping and port industries [16].

In particular, SOLAS Regulations XI-2 and XI-3 of Chapter XI-2 – “Special measures to enhance maritime security” preserves the International Ship and Port Facilities Security Code (ISPS Code). Part A of the Code is mandatory, while part B contains guidance on how to best comply with the mandatory requirements.

Under **Regulation XI-2/8**, “The master shall not be constrained by the Company, the charterer or any other person from taking or executing any decision which, in the professional judgement of the master, is necessary to maintain the safety and security of the ship. This includes denial of access to persons (except those identified as duly authorized by a Contracting Government) or their effects and refusal to load cargo, including containers or other closed cargo transport units”. Additionally, “If, in the professional judgement of the master, a conflict between any safety and security requirements applicable to the ship arises during its operations, the master shall give effect to those requirements necessary to maintain the safety of the ship. In such cases, the master may implement temporary security measures and shall forthwith inform the Administration and, if appropriate, the Contracting Government in whose port the ship is operating or intends to enter. Any such temporary security measures under this regulation shall, to the highest possible degree, be commensurate with the prevailing security level. When such cases are identified, the Administration shall ensure that such conflicts are resolved and that the possibility of recurrence is minimised.”

Other regulations in this chapter require all ships to be equipped with a ship security alert system, to provide information to the IMO, and to be in full control in port (which includes dealing with circumstances such as a delay, detention, and a restriction of operations, including movement within the port or expulsion of a ship from port).

In order to accomplish these objectives, SOLAS Contracting Governments, port authorities, and shipping companies “are required, under the ISPS Code, to designate appropriate security officers and personnel, on each ship, port facility and shipping company”. These security officers, designated Port Facility Security Officers (PFSOs), Ship Security Officers (SSOs), and Company Security Officers (CSOs) must assess, prepare, and implement effective security plans that are able to manage any potential security threat.

As far as the Autonomous ship is concerned, the absence of “security officers and personnel”, presents a serious security gap which must be remediated either by applying appropriate risk mitigation systems and methods, or by excluding this particular type of vessel from this obligation during deep-sea navigation. The latter may be achieved by assigning geographic areas close to the Port Limits where a team of properly trained, qualified personnel will attest that the vessel is safe and secure to leave or enter the port.

3.10 CYBER SECURITY

According to the Merriam Webster dictionary, the definition of cybersecurity is “measures taken to protect a computer or computer system (as on the Internet) against unauthorized access or attack”, while the online Oxford dictionary defines ‘cybersecurity’ as “The state of being protected against the criminal or unauthorized use of electronic data, or the measures taken to achieve this”.

ISO/IEC 27032 defines “Cybersecurity” or “Cyberspace security”, as the “preservation of confidentiality, integrity and availability of information in the Cyberspace”. The Cyberspace is defined as “the complex environment resulting from the interaction of people, software and services on the Internet by means of technology devices and networks connected to it, which does not exist in any physical form”⁸

The International Telecommunications Union (ITU), which is a **specialized United Nations agency for information and communication technologies**, in its ITU-T X.1205 (4/2008) document, defines cybersecurity as “the collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment and organization and user’s assets. Organization and user’s assets include connected computing devices, personnel, infrastructure, applications, services, telecommunications systems, and the totality of transmitted and/or stored information in the cyber environment. Cybersecurity strives to ensure the attainment and maintenance of the security properties of the organization and user’s assets against relevant security risks in the cyber environment. The general security objectives comprise the following: Availability, Integrity (which may include authenticity and non-repudiation) and, Confidentiality.”

Since the Autonomous ship concept will depend heavily on information technology systems on-board and ashore, there is a far greater likelihood of a cyber-

⁸http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?cnumber=44375

attack when compared to a conventional vessel, although this might not be the case under certain circumstances. The advance of technology has already “digitised” a wide spectrum of processes and procedures on board ships from steering, propulsion, and cargo control to ECDIS, GPS, AIS, and communication systems. All the above computerised processes are potential cyber-attack targets. On the other hand, marine insurance for cyber-attack perils is not new, and thus the autonomous ship concept may well be included in such provisions. Although the threat of a cyber-attack is generally excluded from the Institute Cyber Attack Exclusion Clause (CL380) 10/11/2003 (for loss, damage, or liability caused either directly or indirectly by the use of a computer and its associated systems and software), in the Protection and Indemnity Insurance sector, a limit of US\$30 million per ship exists to mitigate such threats (unless the attack is an act of terrorism or war). Although a plethora of definitions and a holistic approach to the issue exists, as has already been shown in the previous paragraph, on 23rd of November 2017, IHS Fairplay Daily maritime shipping news revealed that during February of the same year, hackers took control of a container ship’s navigational systems for almost 10 hours. The vessel was not an Autonomous or remote-controlled vessel, but a “conventional” container ship.

3.11 INFORMATION TECHNOLOGY

The Autonomous ship will be dependent on computer systems not only for the various required functions to sail with safety, but also for a series of updates related to the condition of the vessel when at sea, due to the fact that physical inspections will mainly be possible in port. As Rødseth, H., Brage Mo, B. (2014) observed, the use of Key Performance Indicators (KPIs) will be very useful in monitoring different parts of the ship.

Various data will be recorded, measured, and analysed in order to monitor the integrity of the ship’s structure and the functionality of the equipment and the machinery. The Remote Control Centre will play an important role during this process by coordinating and scheduling maintenance using the data received from the ship.

3.12 LIABILITY

Liability, as a part of the insurance system, protects the insured from the risks posed by lawsuits and claims alike.

Some of the most important areas covered are *the seaworthiness* (a ship’s ability to perform the contracted voyage safely, either under common law, or whenever the contracted parties voluntarily accept the ‘Hague-Visby’ Rules), *the charter-party* (a contract usually between a ship-owner and a charterer), *the bill of lading* (a document signed on behalf of a ship-owner regarding the loaded cargo’s quantity, condition, potential harmfulness, and other parameters), *the collision*, and *the liability of the master*.

Although maritime regulatory matters are usually enforced under the auspices of the IMO, liability issues are subject to various national jurisdictions.

The laws applicable to a marine dispute and the court to which this dispute may be brought, depend on factors such as where the episode happened, its nature, the flag of the vessels, and the nationality of the crews.

Additional contractual provisions and legal requirements such as The Hague-Visby Rules, require the implementation of certain responsibilities by the master and the crew, thus creating a dilemma for Autonomous ships.

For example, under The Hague-Visby Rules, Art.III r.2 the care of cargo requires a physical inspection and human intervention when required for some goods such as the dangerous ones. Whenever an unsafe or hazardous cargo needs to be jettisoned or neutralised while an Autonomous ship is underway, only the existence of a crew on-board is likely to prevent accidents and keep the vessel seaworthy.

3.13 INSURANCE

Marine insurance covers a wide spectrum of issues varying from the Hull, Machinery, and Cargo to other Third-Party liability coverage and is regulated through the Marine Insurance Act of 1906 (MIA), under English law. Not only does the Act affect marine insurance for ships, cargos, and the Protection and Indemnity cover, but it has also influenced the subject matter worldwide and has been adopted by other jurisdictions as well. Two modern statutes, the Consumer Insurance (Disclosure and Representations) Act of 2012 (“CIDRA”) and the Insurance Act of 2015, have made amendments to insurance law. The Insurance Act of 2015 in particular (2015 c.4, a United Kingdom Act of Parliament) makes significant reforms to insurance law.

A wide list of prerequisites is checked and agreed before a ship or its cargo (or both) are insured. One of the most important terms in marine insurance is the “seaworthiness” of a ship, which depends on various factors. Andrew Bardot (the executive officer of the International Group of P&I Clubs whose members insure 90 percent of the global fleet) argues that “*Unmanned ships are illegal under international conventions, which set minimum crew sizes. If drones don’t comply with such rules, they’d be considered unseaworthy and ineligible for insurance*”⁹.

3.14 QUALITY ASSURANCE

UNCLOS Art.94(4)(a) requires that “*each ship, before registration and thereafter at appropriate intervals, is surveyed by a qualified surveyor of ships*”. Although a number of classification societies are already preparing suitable checks and competent surveyors for Autonomous Ships, no standardisation has been agreed on or introduced. Another code of the utmost importance, not only for the safety but also for the Quality Assurance of the maritime industry is the ISM Code. The code and its compulsory nature will be analysed in more detail in Chapter 5, which follows.

⁹<http://www.synergy.ie/index.php/articles/health-safety/item/375-rolls-royce-are-developing-drone-ships>

In addition to these regulatory obligations, there are a number of Quality Standards, self-imposed by the industry, which are mostly based on the International Organization for Standardization (ISO), a Swiss-based private international standards development and publishing body composed of representatives from various national standards organizations with multiple committees. Such standards include amongst others the ISO 9000:2015 (International standards for quality management) series, the ISO 28007-1:2015 International standards for Ships and marine technology – Guidelines for Private Maritime Security Companies (PMSC) providing privately contracted armed security personnel (PCASP) on board ships (and pro forma contract), and the ISO/TS 29001:2010 International standards for Petroleum, petrochemical, and natural gas industries and Sector-specific quality management systems, laying down the Requirements for product and service supply organizations. As previously mentioned, some classification societies have already started to lay the basis for quality standards for the autonomous ship. However, there is not as yet a systematic approach to the subject.

4 ISM CODE AND THE AUTONOMOUS SHIP

The International Management Code for the Safe Operations of Ships and for Pollution Prevention (ISM), which forms chapter IX of SOLAS, was introduced after a number of serious pollution accidents. (Adopted: 1993 - Into force: 1998). This Chapter makes the International Safety Management (ISM) Code, which requires “a safety management system to be established by the ship owner or any person who has assumed responsibility for the ship (the “Company”)”, compulsory[15].

The objectives of the Code are the prevention of human injury or loss of life, the avoidance of damage to the environment, and to ensure safety at sea. Its aim is to apply a safety management system in order to train the personnel involved in the operation of a ship to react appropriately during possible emergency situations. Every organisation (shipping company) is allowed to develop its own Safety Management System (SMS) using policies, procedures, instructions, and internal audits in order to discover, report, and correct any deficiencies.

Paragraph 5 “Masters’ Responsibility and Authority”, and paragraph 6 “Resources and Personnel” of the Code must be either altered by including a definition of a “Shore-based” master and “crew / remote control operators” with the same responsibilities of the on-board Master and crew, or be adjusted to the new autonomous ship’s crewless nature by excluding such vessels from the responsibilities of paragraphs 5.1.1 to 5.1.4, 6.2, 6.6”, 6.7, and paragraph’s 7 phrase “the safety of the personnel”. Paragraphs 5.1.5, 5.2 and 6.1, 6.3, 6.4, 6.5 and 7 (without the phrase “the safety of the personnel”) should continue to apply, regardless of whether the crew is on board or in remote control centres.

5 CONCLUSIONS

- At present, international conventions, rules, and codes such as the UNCLOS, SOLAS, COLREG, MARPOL, STCW, ISM, and SAR (to name but a few) do not include the Autonomous ship concept as a definition, or as a potential modus operandi. Furthermore, the existing regulations and the traditionally used phrasing challenge rather than facilitate the operational deployment of such vessels in the future.
- A cautious review of all relevant regulatory, operational, and quality assurance frameworks, followed by the proper amendments is needed in order to legally shield and technically assure the Autonomous ship concept thus making it accepted by and favourable to the maritime community and the shipping industry alike.
- Throughout the research, it was observed that there were a number of accidents caused by human error, affirming the usefulness of the Autonomous ship concept. No near accidents or potential catastrophes prevented by human intervention were mentioned (although they very often occur), which makes any comparison to the disasters caused by human mistakes impossible. It is suggested that further examination of such near incidents will help in understanding the Autonomous ship’s real contribution to maritime safety.
- Finally, further research on issues such as the ethical concerns regarding the use of autonomous systems replacing humans, the psychological impact on seafarers of such a use, the degradation of seamanship, and the potential loss of time at sea that would be experienced by a significant number of competence mariners, should be considered.

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