Review of Autonomous and Remotely Controlled Ships in Maritime Sector

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This paper presents the extent of the currently achieved progress in autonomous and remotely controlled ships in the maritime sector. Major researches, statements from relevant sources and various anticipations on this subject are presented to outline a comprehensive scope of such progress.

The engine room on conventional merchant ships is used as a viewpoint because it comprises numerous and complex systems. The main purpose of this paper is to establish a link between the levels of autonomy and the engine room with its associated systems on a conventional ship. At each level, the link should describe the relations between autonomy and the systems which are commonly found in the engine room on conventional ships.

To create this link, comparison analysis uses the latest statements from the International Maritime Organization (IMO) and Classification Societies. Technical standards for autonomous and offshore vessels are derived from the guidelines provided by Classification Societies. Technical standards and requirements, related to the engine room of such ships, are individually described and compared to provide accurate and comprehensive scope of their current progress.

KEY WORDS
~ Classification societies
~ Autonomous ships
~ Remotely controlled ships
~ Autonomy levels
~ Engine room

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doi: 10.7225/toms.v08.n02.011

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1. INTRODUCTION

The concept of remotely controlled and autonomous ships reaches back to the 19th century (N. Tesla, 1898) when an idea about autonomy in the maritime traffic was established. This idea is described under the patent named "Method of and apparatus for controlling mechanism of moving vessels or vehicles". While the concept of remotely controlled and autonomous ships may not represent a new concept, the realization of this concept certainly does.

Lately, rapid progress is noted regarding the realization of this concept. Research of various literature reveals numerous reasons for the introduction of this concept into the maritime sector. Impacts that these types of ships will have can only be anticipated. The initial period of exploitation should determine the advantages and disadvantages of their introduction to maritime traffic. They should have the greatest impact on three aspects:

- Financial
- Environment protection
- Safety.

Safety should be of paramount importance. Figure 1 shows that from a total of 880 accidental events analyzed during the investigations, 62 % were attributed to a Human Erroneous Action, which was followed by equipment failure presenting 22 % (EMSA, 2016).

Also, it was noted that the shipboard operations represented the main contributing factor at 71 % of the total accidents. These data lead to the presumption that if human action is less involved in shipboard operations, the likelihood of accident occurrence should be reduced. A study from 2017 supports this presumption (K.Wróbel, J. Matewka, P. Kujala, 2017). This study analyzed 100 accidents that occurred from 1999 to 2015. The goal of this study was to assess the occurrence likelihood of an accident if

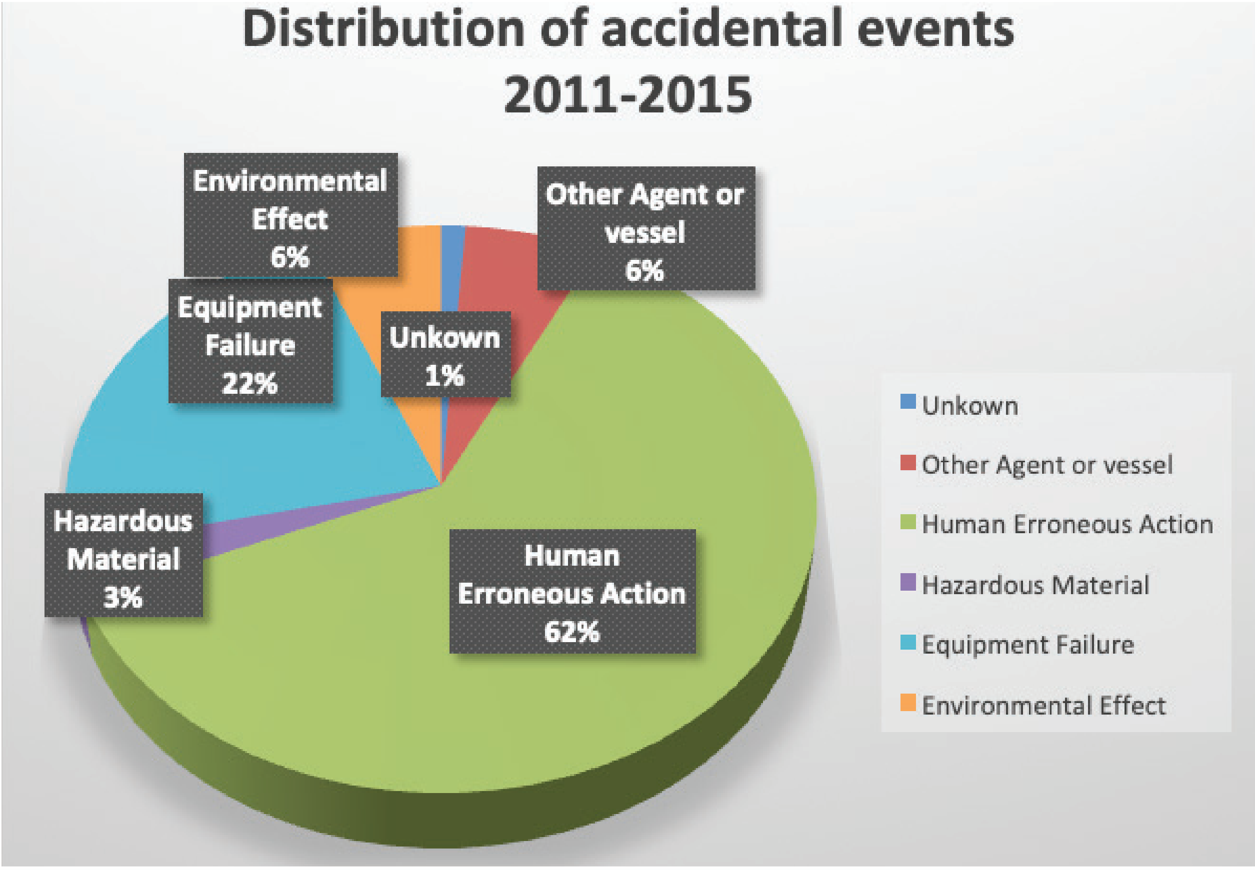

Figure 1.
Distribution of accidental events 2011-2015 (EMSA, 2016).

the vessel had been unmanned. The results showed that the likelihood of grounding and collisions might have significantly decreased, while severe consequences might occur in case of some accidents, such as a fire on board.

Also, a study among ship operators was conducted to determine the technology impact on safety. It is noted that the higher the level of automation and technological processes, the fewer crewmembers are needed. The aim of higher levels of technological processes and automation is to improve the efficiency of the vessel. The result of the study led to the conclusion that changes in work organization on board and technology advancement could add to the occurrence of human error (D. Mišković, T. Bielić, J. Čulin, 2018).

This paper aims to provide a cross-section on the technical standard which Classification Societies have stated regarding the autonomous and remotely controlled ship as well as to relate autonomy levels with the engine room that can be found on such ships and compare this link with the engine room on a conventional ship.

2. PRESENT RESEARCHES (LITERATURE REVIEW)

The terms "unmanned" and "autonomous" ships, while having a different meaning, are often used as synonyms. Therefore, it is essential to describe the terms used. According to Rødseth and Nordahl (2017), the term "autonomous ship" refers to a ship that can perform a set of defined operations without or with reduced supervision by the bridge crew. "Unmanned ship" refers to a ship on which the crew can be on board, but are not present on the bridge for performing or supervision of the ship´s functions. Figure 2 shows the classification of autonomous ship types with the associated terminology.

Maritime Autonomous Surface Ship (MASS) is a provisional term proposed by International Maritime Organization (IMO), and that is the reason why this term can often be used as a general term for referring and defining an autonomous ship. The analysis of terminology provides a basis for a comprehensive approach. In Table 1, the term MASS is additionally classified.

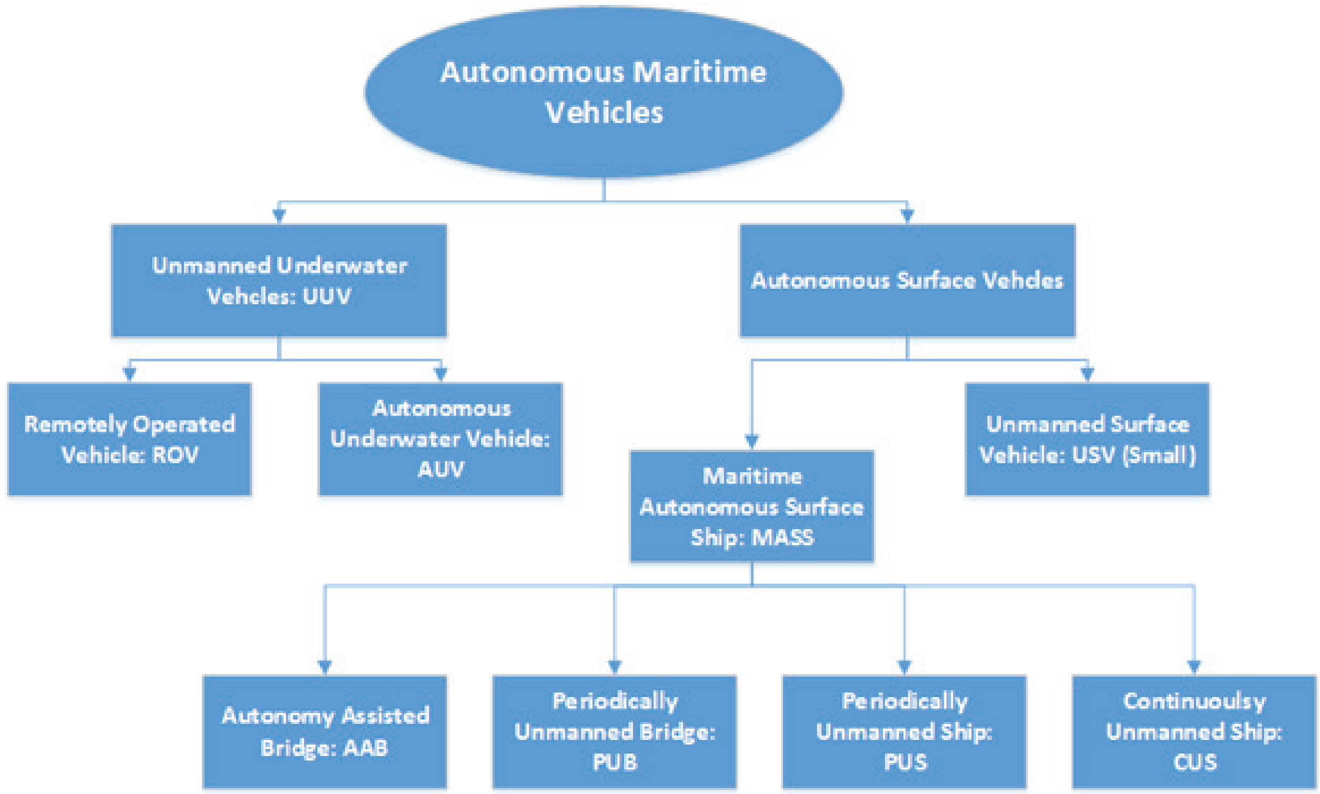

Figure 2.
Classification of autonomous maritime system and autonomous ship types (O.J. Rødseth, H. Nordahl, 2017).

Table 1.
Description of MASS subdivisions.
Source: Made by author, using data from the Definitions for Autonomous Merchant Ships (Rødseth and Nordahl, 2017).

Autonomy Assisted Bridge (AAB)	The ship bridge is always manned and the crew can immediately intervene in ongoing functions.
Periodically Unmanned Bridge (PUB)	The ship can operate without the crew on the bridge for limited periods, e.g. in the open sea and good weather. The crew is on board ship and can be called to the bridge in case of problems.
Periodically Unmanned Ship (PUS)	The ship operates without bridge crew on board for extended periods, e.g. during the deep-sea passage. Occasionally ashore personnel arrives to supervise ship.
Continuously Unmanned Ship (CUS)	The ship is designed for unmanned operation of the bridge at all times, except perhaps during special emergencies.

Also, actual researches and projects are presented to highlight the progress made regarding autonomous ships. "Maritime Unmanned Navigation through Intelligence in Networks" (MUNIN) is a project that lasted for 36 months. It achieved a technical concept for unmanned merchant (cargo) ship. According to Burmeister and Moraeus (2015), "*In a base scenario, the MUNIN bulker is found to improve the expected present value by mUSD 7 over 25 years compared to the reference bulker.*" Equating costs between the concept used in the project and the conventionally manned bulker are established as differences between additional investments (initial investments, shore services) and cost savings (crew expenses, fuel efficiency).

"Advanced Autonomous Waterborne Applications Initiative" (AAWA) is a project led by Rolls-Royce that consists of three phases. According to Laurinen (2016), this project "*aims to produce the specification and preliminary designs for the next generation of advanced ship solutions*." (Jokioinen et al, 2016). From this initiative, a collaboration between Rolls-Royce and FinFerries arose and resulted in a research project named "Safer Vessel with Autonomous Navigation" (SVAN). The result of this project was a demonstration of the first fully autonomous ferry named – "Falco" (2018 Rolls-Royce plc, 2018). The demonstration consisted of two voyages. The first voyage was autonomous, where the vessel was able to perform docking operations and avoid obstacles. The second voyage vessel was remotely controlled from Remote Shore Centre (RSC) located 45km away from the vessel.

Furthermore, collaboration between Rolls Royce and Svitzer resulted in the remote operation of a tug boat, *Svitzer Herold*. The operation of the vessel was conducted by the vessel´s captain from a remote land location. During this demonstration, remotely controlled maneuvers such as piloting, turning the vessel, berthing and undocking were safely performed (Maritime Cyprus admin, 2018).

YARA Birkeland is anticipated to be the first completely autonomous ship. Propulsion is intended to be fully electric and designed as an open-top type containership. Also, it is planned to have a capacity of 120 TEU (*twenty-foot equivalent unit*) and be used for commercial purposes. The ship should be free of exhaust gases and ballast waters. To achieve this, the ship is equipped with fully electric propulsion and uses a battery pack as permanent ballast. Ship´s operation is planned in between three ports and within 12 nautical miles from the shore. Figure 3 shows the development and planned operation of *YARA Birkeland*. The autonomy level is planned to be achieved gradually, throughout a few stages. The initial stage anticipates crew on board, the next stage is moving to a remote crew, and the final stage is complete autonomy, which should be achieved over several years.

Comparison between *YARA Birkeland* and a similar-sized conventional ship is used to predict significant cost savings. Such savings are anticipated on the basis that there will be no requirements for fuel or crew. Benefits from using electric propulsion should result in a reduction of greenhouse gas emissions (Kongsberg, 2017).

The project, as mentioned earlier, are not isolated researches regarding autonomous ships, these are some other researches and project developed across the globe (B. Eder, 2018):

- • *Katana* - designed by Israel Aerospace Industries and represents an advanced, multi-purpose, unmanned surface vessel (USV). It is produced for military services, uses dual-mode operation, meaning that it can be used as unmanned or as a crew vessel.

Figure 3.
Development timeline of YARA Birkeland.
(Source: Made by the author, using data of Autonomous ship project, key facts about YARA Birkeland (Kongsberg, 2017).

- Joint research of Shenzhen HiSiBi Boats Company and Harbin Engineering University in China resulted with *Tianxing-1,* an unmanned surface vehicle (USV) primarily made for military operations.
- L3 ASV Company is a UK Company that currently provides surface vessels from 10 to 42 feet with matched control systems, software, and autonomous unmanned systems. Capabilities were time-tested and demonstrated on multiple types and sizes of vessel, throughout 1,500 operating days of service (ASV 2018, 2018)

Lately, in parallel with the accelerated and extended development of autonomous vessels, a need for testing areas arises. This indicates that testing areas are becoming a necessity for the safe introduction of these types of ships into maritime traffic. Current testing areas for autonomous and remotely controlled ships are (International Network for Autonomous ships, 2019):

- *Storfjorden, Horten*, and Trondheim test areas in Norway. The Trondheim fjord came to existence as the world's first test area for vehicles moving below, on and above the water surface and are remotely or autonomously managed.
- *Jaakonmeri* test area is located off the coast of Finland, and it has an additional offer for testing ships under ice conditions.
- *De Vlaamse Waterweg nv* has opened test area in Belgium.
- In 2018, the construction of the *Wanshan Marine Test Field* in China has begun. It is an offshore test field for unmanned surface vehicles (USVs). Upon completion, it will be the largest unmanned marine testing ground in the world.
- In the USA, the Smart Ships Coalition announced that *The Keweenaw Peninsula Waterway area* should be a testbed area for autonomous surface and sub-surface vehicles.

3. IMO AND AUTONOMOUS SHIPS

Highlighted researches and achievement indicate accelerated and continuous progress of autonomous and remotely controlled ships on a global level. Accordingly, that is why implementation, means of regulation, and legislative framework need to be appropriately addressed.

International Maritime Organization (IMO) sets global standards and regulations concerning international shipping. Consequently, IMO has a responsibility to make the introduction of these types of ships to international shipping safe, secure, and environmentally acceptable. In 2018, IMO began to investigate the introduction of autonomous and remotely controlled ships. It was announced that investigation will be conducted via regulatory scoping exercise. To address autonomous and remotely controlled ships, the term Maritime Autonomous Surface Ships (MASS) is proposed for this exercise. For regulatory scoping exercise, MASS is defined as: "A ship which, to a varying degree, can operate independently of human interaction."

After defining what autonomous ship is, the next issue is to define the degrees of autonomy. The degrees of autonomy, as defined by IMO, are set out for mentioned exercise (IMO takes first steps to address autonomous ships, 2018):

- "Degree one: Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
- Degree two: Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
- Degree three: Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.
- Degree four: Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself."

Safety, feasibility, and legislation are the main issues that need to be addressed. To resolve these issues safely, the Maritime Safety Committee (MSC), which is IMO´s technical body, has approved research of MASS. On the 99th session of MSC (Report of the Maritime Safety Committee on its ninety-ninth session, 2018), the framework for researching was endorsed, which will be realized through regulatory scoping exercise. The completion date for this exercise is targeted for 2020. For the exercise, correspondence group and methodology are established, holistic approach is proposed, whereas the extent should cover risks and benefits concerning any aspect of safety. Any MASS definitions and concepts of different types and levels of autonomy, automation, operation, and manning should be provisional. The working orientation of this exercise should be focused on the user, not technology.

The scoping exercise consists of two steps. In the first step, present provisions for IMO´s instruments list need to be recognized. IMO´s instrument list consist of (IMO takes first steps to address autonomous ships, 2018):

- The International Convention for the Safety of Life at Sea – SOLAS.
- The International Regulations for Preventing Collisions at Sea – COLREG.
- The International Convention on Load Lines – CLL.
- The International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers - STCW, and STCW-F – concerning training of fishers.
- Search and Rescue – SAR.
- International Convention on Tonnage Measurement of Ships.
- Convention for Safe Containers – CSC.
- Special trade passenger ship Agreement - STP.

During this step, the application of these instruments to the MASS needs to be assessed. Additional information about the deployed methods, results, and exact time needed for each step is anticipated for MSC 102 session, scheduled for May 2020. For instruments associated with autonomy degrees and maritime safety, the following is determined:

- Apply to MASS and prevent MASS operations.
- Apply to MASS and do not prevent MASS operations and require no actions.
- Apply to MASS and do not prevent MASS operations, but may need to be amended or clarified, and/or may contain gaps.
- Have no application to MASS operations.

The objective of the next step is to determine the most suitable way of addressing MASS operations. It is achieved by conducting analysis in which the human element, technology, and operational factors are taken into account. The main goals of the analysis are to determine the necessity for (Maritime Safety Committee, 100th session, 2018):

- Equivalences as provided for by instruments or developing interpretations and/or
- Amending existing instruments and/or
- Developing new instruments and/or
- None of the above as a result of the analysis.

Aside from IMO´s statements, during the 99th session of MSC, additional considerations on definitions for levels and concepts of autonomy were suggested. Regarding definitions and levels of autonomy, six suggestions were proposed. Proposals were given by two Classification Societies, two industry/research associations, one company involved in autonomous technologies, and one consultant. In Table 2, four suggestions are shown because all the suggestions given by Classification Societies are examined in a separate table.

In this session, the background was presented to point out the progress that has been marked regarding autonomous ships. It was underlined that a few projects were conducted on autonomous maritime traffic, such as MUNIN and AAWA project, emphasizing the progress achieved in this aspect. Project *One Sea – Autonomous Maritime Ecosystem*, which is a collaboration between shipyards and ship owners, is highlighted as ongoing work on the subject of autonomous maritime traffic. Also, a recently achieved joint point of view regarding levels of autonomy in the automotive industry was mentioned. This achievement outlines potential direction concerning levels of autonomy in shipping (Considerations on definitions for levels and concepts of autonomy, Submitted by Finland, 2018).

Table 2.
Proposals on levels of autonomy presented during MSC´s 99th session.
(Source: Made by the author using data from Considerations on definitions for levels and concepts of autonomy, Submitted by Finland, 2018).

The UK Marine Industries Alliance

Level of autonomy	**Description**
Level 0 - Manned	Ship/craft is controlled by operators aboard.
Level 1 - Operated	Under Operated control, all cognitive functionality is within the human operator. The operator has direct contact with the unmanned ship over, for example, continuous radio (R/C) and/or cable (e.g. tethered UUVs and ROVs). The operator makes all decisions, directs, and controls all vehicle and mission functions.
Level 2 - Directed	Under Directed control, some degree of reasoning and ability to respond is implemented into the unmanned ship. It may sense the environment, report its state, and suggest one or several actions. It may also suggest possible actions to the operator, such as, for example, prompting the operator for information or decisions. However, the authority to make decisions is with the operator. The unmanned ship will act only if commanded and/or permitted to do so.
Level 3 - Delegated	The unmanned ship is now authorized to execute some functions. It may sense the environment, report its state and define actions, and report its intention. The operator has the option to object to (veto) intentions declared by the unmanned ship during a certain time, after which the unmanned ship will act. The initiative emanates from the unmanned ship and decision-making is shared between the operator and the unmanned ship.

Level 4 - Monitored	The unmanned ship will sense the environment and report its state. The unmanned ship defines actions, decides, acts, and reports its action. The operator may monitor the events.
Level 5 - Autonomous	The unmanned ship will sense the environment, define possible actions, decide, and act. The unmanned ship is afforded a maximum degree of independence and self-determination within the context of the system's capabilities and limitations. Autonomous functions are invoked by the on board systems at occasions decided by the same, without notifying any external units or operators.
The Ramboll	
Level of autonomy	**Description**
M - (Manual)	The operator (master) is on board controlling the ship, which is manned as per current manning standards. Subject to sufficient technical support options and warning systems, the bridge may at times be unmanned with an officer on standby ready to take control and assume the navigational watch.
R - (Remote)	The ship is controlled and operated from shore or another ship, but a person trained for navigational watch and maneuvering of the ship will be on board on standby ready to receive control and assume the navigational watch.
RU - (Remote, unmanned)	The ship is controlled from shore or another ship and does not have any crew on board.
A - (Autonomous)	The operating system of the vessel calculates consequences and risks. The system can make decisions and determine actions. The operator onshore is only involved in decisions if the system fails or prompts for human intervention.
The Norwegian Forum for Autonomous Ships (NFAS)	
Level of autonomy	**Description**
Decision support	Decision support and advice to crew on the bridge, the crew decides.
Automatic bridge	Automated operation, but under continuous supervision by the crew.
Remote ship	Unmanned continuously monitored and direct control from shore.
Automatic ship	Unmanned continuously monitored and direct control from shore.
Constrained autonomous	Unmanned, partly autonomous, supervised by the shore.
Fully autonomous	Unmanned and without supervision.
Rolls-Royce	
Level of autonomy	**Description**
Level - 0 No autonomy	All aspects of operational tasks performed by the human operator, even when enhanced with warning or intervention system. The human operator safely operates the system at all times.
Level 1 - Partial autonomy	The targeted operational tasks performed by the human operator but can transfer control of specific sub-tasks to the system. The human operator has overall control of the system and safely operates the system at all times.
Level 2 - Conditional autonomy	The targeted operational tasks performed by an automated system without human interaction and the human operator performs the remaining tasks. The human operator is responsible for its safe operation.
Level 3 - High autonomy	The targeted operational tasks performed by an automated system without human interaction and the human operator performs the remaining tasks. The system is responsible for its safe operation.
Level 4 - Full autonomy	All operational tasks performed by an automated system under all defined conditions.

In addition, it was noticed how suggested levels of autonomy varied numerously as well as in their definitions. During this session, definite number or definitions were not achieved, but it was noted that levels of autonomy should be comprehensive, applicable to real projects, and numerously minimalized if possible.

4. CLASSIFICATION SOCIETIES AND AUTONOMOUS SHIPS

As mentioned, IMO has already started to identify the safety, security, and environmental aspects of MASS operations in line with the existing IMO standards. In parallel with MASS introduction, the need for a new and possibly additional level of technical requirements arose. The International Association of Classification Societies (IACS) aims to contribute to this subject by designing requirements and processes for identified emerging areas and gaps (Position paper MASS, 2019). IACS included this MASS agenda on its strategic Action Plan:

- Review of all IACS Resolutions and Recommendations to recognize possible requirements that might obscure technical development of MASS.
- Address possible issues that might obscure the technical development of MASS.
- Also, IACS has conducted several initiatives on this matter, such as:
- Internal review of all Resolutions (2017)
- Pilot project for selected IACS Resolutions (2018)
- Basic Principles for drafting New and revised IACS Resolutions (2018)
- Establishment of IACS Task Force on MASS (2019)
- References to IACS' Leadership or Participation in external Meetings/Activities

According to Musonov (2018), shifting from ships with personnel to autonomous ships will evolve gradually. It is hardly realistic to expect that fully autonomous vessels commence worldwide operation in a short period, such as several years. Shifting should be perceived as a step-by-step process in which the phased implementation of various technologies is observed. As the main technical advisor to IMO, IACS intends to contribute in future work by:

- Continuing its participation in the IMO Working Group at MSC 101 (June 2019) and MSC 102 (May 2020) as well as at scheduled Intersessional MSC Working Group on MASS (September 2019).
- Monitoring the development of Guidelines on MASS trials initiated by MSC 100, and providing comment as necessary.
- IACS intends to continue its active participation in IMO regulatory scoping exercise on MASS (February 2019 – February 2020).
- IACS plans to monitor ISO/TC8/WG10's work program on the development of new ISO standards related to MASS terminology and concepts for ship autonomy.

Figure 4.
International regulations and technical standards for autonomous ships (Source: Made by the author, using data Guidelines for Autonomous Shipping (2017), LR Code for Unmanned Marine Systems (2017), Autonomous and remotely operated ships (2018), Guidelines for autonomous cargo ships (2018).

Table 3.
Autonomy levels, according to Classification Societies.
(Source: Made by the author using data of Guidelines for Autonomous Shipping (2017), LR Code for Unmanned Marine Systems (2017), Autonomous and remotely operated ships (2018), Guidelines for autonomous cargo ships (2018).

Bureau Veritas

Level of autonomy		**Definition**	**Acquisition**	**Analysis**	**Decision**	**Action**
0	Human operated	Human makes all decisions and controls all functions.	System Human	Human	Human	Human
1	Human directed	System suggests actions Human makes decisions and actions.	System	System Human	Human	Human
2	Human delegated	System invokes functions Human can reject decisions during a certain time.	System	System	System Human	Human
3	Human supervised	System invokes functions without waiting for human reaction.	System	System	System	System Human
4	Fully autonomous	System invokes functions without informing the human, except in case of emergency.	System	System	System	System

Lloyd´s Register

Level of autonomy	**Description**
0 / *AL 0	1) No cyber access – no assessment – no descriptive note – included for information only. 2) Manual: No autonomous function. All action and decision-making performed manually (N.B. systems may have level of autonomy, with Human in/ on the loop.), i.e. human controls all actions.
1 / AL 1	1) Manual cyber access – no assessment – no descriptive note – included for information only. 2) On-board Decision Support: All actions taken by human Operator, but decision support tool can present options or otherwise influence the actions chosen. Data is provided by the systems on board.
2 / AL 2	1) Cyber access for autonomous/remote monitoring. 2) On & Off-board Decision Support: All actions taken by human Operator, but decision support tool can present options or otherwise influence the actions chosen. Data may be provided by systems on or off-board.
3 / AL 3	1) Cyber access for autonomous/remote monitoring and control (on board permission is required, on board override is possible). 2) `Active´ Human in the loop: Decisions and actions are performed with human supervision. Data may be provided by the system on or off-board.
4 / AL 4	1) Cyber access for autonomous/remote monitoring and control (on board permission is not required, on board override is possible). 2) Human on the loop. Operator/Supervisory: Decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human Operators the opportunity to intercede and over-ride.
5 / AL 5	1) Cyber access for autonomous/remote monitoring and control (on board permission is not required, on board override is not possible). 2) Fully autonomous: Rarely supervised operation where decisions are entirely made and actioned by the system.
AL 6	2) Fully autonomous: Unsupervised operation where decisions are entirely made and actioned by the system. *AL – Autonomy level (stands for second set of levels of autonomy and their definitions)

Det Norske Veritas Germanischer Lloyd & China Classification Society

Degrees of autonomy	Description
1	Ship with automated processes and decision support.
2	Remotely controlled ship with seafarers on board.
3	Remotely controlled ship without seafarers on board.
4	Fully autonomous ship.

Classification societies provide technical standards regarding construction and operation of ships and offshore structures. The required standards will apply to autonomous and remotely controlled ships. Also, compliance with the standards required by certain classification society is accomplished via regular inspections or additional surveys. As defined by the Classification Society, these types of ships need to comply with the same or higher standards than conventional ships.

Figure 4 shows progress regarding autonomous ships, which is provided by certain classification societies. Since, these guidelines represent the manifest of each classification society regarding autonomous ships, for the purpose of this paper contents and definitions of autonomy levels are extracted from each guideline.

Table 3 shows each level of autonomy described individually for a comprehensive overview. DNV GL and CCS have the same autonomy levels and definitions, which are replicated from IMO´s degrees of autonomy. In contrast, BV and LR have a different organization of autonomy levels and related definitions. BV´s levels of autonomy define the difference between the role of the human and the role of the system. The role of the human or the system is shared on four functions, which are based on a four-stage model of human information processing. These functions are (Guidelines for Autonomous Shipping, 2017):

Table 4.
Contents from different guidelines for autonomous ships.
(Source: Made by the author, using data of Guidelines for Autonomous Shipping (2017), LR Code for Unmanned Marine Systems (2017), Autonomous and remotely operated ships (2018), Guidelines for autonomous cargo ships (2018).

Bureau Veritas - *Guidelines for Autonomous Shipping*			**Lloyd´s Register - *LR Code for Unmanned Marine Systems***
Section 1-4			**Chapters 1-9; Annexes A, B**
General	*Guidelines for Functionality of Autonomous Systems*	*Guidelines for Reliability of Autonomous Systems*	Chapters • General • Structure • Stability • Control system • Electrical systems • Navigation systems • Propulsion and maneuvering • Fire • Auxiliary systems Annex A – Concept of operations Annex B – Verification methods
• General • Safety and • security conditions • Regulations *Risk and Technology Assessment* • General • Risk assessment • Technology assessment	• General • Navigation system • Communication network and system • Machinery system • Cargo management system • Passenger management system • Shore control center	• General • Navigation system • Communication network and system • Machinery system • Cargo management system • Passenger management system • Shore control center	

DNV GL - *Autonomous and remotely operated ships*		**CCS – *Guidelines for autonomous cargo ships***
Sections 1-7	**Appendixes A-E**	**Chapters 1-14**
• General • Main principles • Qualification and approval process • Navigations functions • Vessel engineering functions • Remote control centers • Communication functions	•List of potential minimum risk conditions (A) • List of potential autoremote functions (B) • Navigation systems – applicability of conventional carriage requirements for autonomous vessels (C) • Navigations systems – additional systems for autoremote vessels (D) • Simulator based testing (E)	• General • Situation awareness • Navigation control • Machinery installations • Mooring and anchoring • Electrical installations • Communication and signal equipment • Hull construction and safety • Fire-fighting • Environmental protection • Ship security • Remote operation center • Cyber security • Survey and certification

- Information acquisition.
- Information analysis.
- Decision and action selection.
- Action implementation.

LR´s levels of autonomy are shown as a duplicate to highlight their progress on this matter (Design Code for Unmanned Marine Systems, 2017). Differences that exist among levels of autonomy provided by Classification Societies are presented through comparison in Table 4. These differences are shown through:

- Numbers of levels of autonomy
- Definitions of autonomy levels
- Used terminology.

All autonomy level definitions do not refer to the engine room, which is an essential part of every ship. Also, some definitions (Ramboll) in their nature refer only to the bridge, i.e. to navigation. When comparing all definitions of autonomy levels, autonomy is most commonly referred onto the whole ship or a single system.

Table 4 shows the content of the guidelines provided by Classification Societies. This indicates how the provided guidelines, through technical standards, anticipate that numerous and miscellaneous systems will be fitted on such ships. The systems fitted on autonomous or remotely controlled ships may not mutually be at the same autonomy level, or with regard to the ship in general.

Also, all the contents include a variety of systems which are usually fitted to a conventional ship. As the applicability of autonomous and remotely controlled ships is brought closer to the merchant (cargo) ships, it is unlikely to expect that they may be defined and referred to as a single system. So, it is safe to presume that additional distributions or definitions of autonomy levels among ships and fitted systems, following the achieved progress will be needed. A similar conclusion is drawn during the MSC 99th session, where it is noted that marine ships are comprised of many systems and that autonomy among these systems can vary.

Apart from this, in each content a segment regarding engine room is provided. In the cross-section of this segment, significant deviations are noted. Classification Societies state that each segment from Table 3 should at least match the same level of safety and performance as the same system on a conventional ship. Moreover, according to the provided technical standards, these ships when compared to conventional ships should ensure an equivalent or higher level of safety. Guidelines provided by BV and LR give mostly generic information on this segment. For this reason, a further comparison is conducted between the guidelines provided by DNV GL and CCS.

Regarding engine room, DNV GL in its guidelines differentiates Automatic Operation (AO) and Automatic Support (AS). Automatic Operation is defined as the operation of the vessel´s functions by automation systems, which do not need crew intervention. Automatic Support is defined as the operation of the vessel´s functions by automation systems that operate in combination with the crew.

If engine room machinery is under AO, then manual operations are replaced by automation systems. In that case, remote supervision and emergency control should be arranged in the Remote Control Centre (RCC). For resolving unexpected and abnormal events automation functions should be redundant or augmented by independent automatic safety systems. For example, a power management system on a conventional vessel is in general not provided with redundant control (Autonomous and remotely operated ships, 2018).

If engine room machinery is under AS, then manual operation on board will be performed by the remote engineering watch in RCC. For engineering watch to manage properly, functions that provide decision support should be properly arranged. Propulsion and steering system, along with associated auxiliary systems, can be automatically operated or supported.

In the case when propulsion or steering function is under AS, then:

- Propulsion and steering machinery is under engineering watch control and all actions are manually conducted.
- In the case of poor decision making, a warning should be issued by the decision support system.
- The decision support system should be integrated with other systems.

In the case when propulsion or steering function is under AO, then:

- Propulsion and steering machinery is completely controlled by automation systems as well as supporting auxiliary systems.
- Automation systems should be capable of issuing a notice in due time, before performing a certain order. Propulsion and steering system should be arranged so that manual control and intervention can be performed from the RCC. Restoration of propulsion and steering functions should be arranged in a way that now manual actions are needed.
- If unexpected failures and events are not eliminated by automatic control functions, then alerting, diagnostics, monitoring, and controlling functions should provide adequate data and control for the responsible personnel in RCC to manage the same.
- The engineering watch in RCC should be provided with sufficient monitoring, alerting, diagnostic functions and controls to intervene in case of unexpected events and failures which are not safely handled by the automatic control functions.

In its guidelines, CCS requires additional provisions regarding the engine room. It is stated that, unless provided otherwise, autonomous ships must comply with Chapter 4 of the Rules for Intelligent Ships (Guidelines for Autonomous Cargo

Ships, 2018). According to these rules, autonomous ships are provided with intelligent machinery system, which carries out condition monitoring and fitness management of:

- Main propulsion machinery
- Auxiliary machinery installations
- Boilers and machinery piping systems.

An intelligent machinery system should perform automatic recording of diverse information from all systems in the engine room. Some of this information is navigation instructions, respective action responses from the engine room, operational records specified by regulations, e.g. fuel change-over and maintenance records.

Additionally, intelligent machinery system needs to provide:

- Automatic reporting
- Automatic output of various records and reports
- Feedbacks to RCC.

Although DNV GL and CCS provide detailed information concerning the engine room, in spite of the differences all the presented guidelines provide sufficient basis in a form of technical standards for the development of autonomous ship and remotely controlled ships. From engine room aspect, when relating autonomous or remotely controlled ship concept to the currently deployed merchant or commercial ships, e.g. passenger or cargo ships, some difficulties arise. Such difficulties are mainly based on the complexity of the engine room and the need for personnel to perform maintenance during exploitation.

5. CONCLUSION

Even though human action is stated as the most common cause of accidents on board, it is an indispensable element needed for the exploitation of ships today. Due to their high level of development and thermal efficiency achieved, most commonly used propulsion systems in modern shipping are two-stroke diesel engines, steam and gas turbines or combination marine propulsion systems. These propulsion systems are comprised of heavy-duty machinery which for their operation use different types of fuel oil, lubricants, coolant medium with aggressive additives, etc. That is why engine room on conventional ships is comprised of numerous and complex systems, which require adequate personnel on board for constant monitoring and maintenance. As progress approaches closer to the complete autonomy, the number of crew on board will appropriately be reduced and labor organization on board will change. Therefore, the personnel involved in navigation and engineering functions on those types of ships should undergo specific training and education.

All these reasons emphasize that autonomous and remotely controlled ships cannot be observed exclusively through navigation or bridge autonomy. The autonomy levels mentioned in this paper may be sufficient for the current extent autonomy progress in shipping, i.e. smaller vessels listed in the introduction. Their main purpose is testing and ultimately proofing applicability of autonomy across entire shipping.

Therefore, currently provided guidelines for autonomous and remotely controlled ships, levels of autonomy and achieved progress in this field do not prove to be sufficient for creating a tenable relation of autonomy or remote control to the conventional merchant ships deployed in modern shipping.

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