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In the context of unmanned vessels : obstacles to the application of COLREGs and suggestions for its amendments

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IN THE CONTEXT OF UNMANNED VESSELS: OBSTACLES TO THE APPLICATION OF COLREGs AND SUGGESTIONS FOR ITS AMENDMENTS

By

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

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ABSTRACT

Title of Dissertation: **In the Context of Unmanned Vessels: Obstacles to the Application of COLREGs and Suggestions for Its Amendments**

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COLREGs, which guide to take collision avoidance actions, is the critical rule for vessels sailing at sea. It is formulated based on the navigation experience of mankind over the past hundreds of years. But the basic characteristic of unmanned vessel, no crew on board, determines that there are obstacles to the application of COLREGs.

These obstacles and countermeasures to the application of specific provisions for unmanned vessels in shore-based control mode and fully autonomous mode are discussed.

Unmanned vessels should be scoped in COLREGs. It belongs to the extension of the definition of “vessel”. Unmanned vessel is not “vessel not under command” nor “vessel restricted in her ability to manoeuvre”, there is no “priority” for it. The “lookout” mainly relies on human “sight and hearing” and the “electronic lookout” is more effective. “Good seamanship” is based entirely on human experience, and AI algorithms are needed to develop to achieve the same effect.

The concepts of “electronic lookout”, “equivalent results principle”, and “electronic vision” are proposed to explore the possible means to amend COLREGs. The scope of the definition of “vessel” should be expanded. According to the “equivalent results principle”, the equivalent standards for “lookout” and “good seamanship” should be developed.

KEYWORDS: unmanned vessel; COLREGs; obstacles; amendments; good seamanship

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LIST OF ABBREVIATIONS

AAWA	Advanced Autonomous Waterborne Application
ABB	Asea Brown Boveri Ltd.
AI	Artificial Intelligence
AIS	Automatic Identification System
AUV	Autonomous Underwater Vehicle
BV	Bureau Veritas
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea
CMI	Committee Maritime International
ECDIS	Electronic Chart Display and Information System
GPS	Global Positioning System
IMO	International Maritime Organization
IWG	International Working Group in Unmanned Ships
MARPOL	International Convention for the Prevention of Pollution from Ships
MASS	Maritime Autonomous Surface Ships
MSS	Maritime Surface Ships
MAXCMAS	MAchine eXecutable Collision regulations for Marine Autonomous Systems
MSC	Maritime Safety Committee
OOW	Officer On Watch
MUNIN	Maritime Unmanned Navigation through Intelligence in Networks
SBO	Shore-Based Operator
SOLAS	International Convention for the Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
UAV	Unmanned Aerial Vehicle
UNCLOS	United Nations Convention on the Law of the Sea
VHF	Very High Frequency
WIG	Wing-In-Ground

CHAPTER 1 INTRODUCTION

1.1 Research background

1.1.1 The future of shipping industry: unmanned vessel

Benefiting from the rapid development of science and technology, transportation tools such as vehicles and aeroplanes move towards unmanned development. And so does the shipping field. Unmanned vessels are inevitable trends in the development of the shipping industry.

If unmanned vessels can become the main force of ship transportation in the future, it can realize the application of artificial intelligence (AI) in navigation, achieve autonomous navigating, energy-saving, and efficiency improvement; reduce the cost of human resources; eliminate the hull space necessary to the seafarers working and living on board; limit the effects of “human factors” to improve the maritime safety.

But not everyone is optimistic about unmanned vessels. Some sceptical experts are of the opinion that the safety of maritime transportation could be jeopardized, instead of improved, by the introduction of autonomous ships (Wróbel et al., 2017).

The actual condition is that unmanned vessels have been put on the scientific research agenda in many states, institutes, and enterprises. At present, some countries such as China, Japan, several research institutions, as well as large companies such as Rolls-Royce, ABB, and KONGSBERG are conducting systematic research on unmanned vessels.

1.1.2 Challenges to COLREGs

With the continuous deepening of research, the development and experiments of unmanned vessels have achieved preliminary results. But the related issues also appeared, that unmanned vessels challenge the current shipping legal system. At present, the laws and conventions applicable to unmanned vessels are still blank. As a product of new technology, unmanned vessels have, as yet, not been clearly defined and regulated, in terms of current domestic law or international conventions (Showalter, 2004). Due to the variety of unmanned vessels, however, and their wide range of applications, the legal status of unmanned vessels involved in different operations varies significantly (Norris, 2013a).

Unmanned vessels have also led to a series of existing international conventions and domestic laws challenges. Especially the application of COLREGs is a significant issue. The studies from marine accidents reports prove that 60% of accidents are caused by human error. Structure or mechanical failure has been a direct reason for an accident in 19% of cases. Only 10% has been caused by equipment failure (Demiral & Bayer, 2015), and About 89–96% of the maritime collisions are caused by human error of the mariners at least in part, and 56% of these collisions are caused by the violation of COLREGs formulated by IMO (Shen, 2019). Therefore, collision avoidance is critical for all types of vessels, including unmanned vessels, so this issue should be solved first.

However, the COLREGs is formulated on the basis of “human”, such as lookout, good seamanship. There are considerable obstacles to the application of unmanned vessels in these fields. Because when COLREGs was formulated, the legislators did not consider the situation of unmanned vessels or even the absence of crew on board. Some provisions of COLREGs are vague to unmanned vessels, and some are even impossible to implement at all.

In order to solve the issues, there are currently two views in the academic circles. One is to formulate a new unmanned vessel collision avoidance rule only for unmanned vessels. Most scholars believe the other one is that unmanned vessels should adapt to the current COLREGs and explore based on it. However, some provisions in COLREGs should be appropriately explained or amended. It not only solves the collision avoidance issues but also points out the direction for the development of unmanned vessels.

1.2 Literature review

In general, the current research on unmanned ships and international conventions is mainly focused on UNCLOS, SOLAS, STCW, MARPO. The systemic research on the application of COLREGs to unmanned ships is not extensive.

1.2.1 Research on algorithms

Most studies on the relationship between unmanned ships and COLREGs are discussed from the technical level, in particular, the research on the development of artificial intelligence algorithms for automatic collision avoidance for unmanned ships based on the relevant provisions of COLREGs. For example, the following research in recent years:

A certain amount of research was on the technological possibilities of collision avoidance (Statheros et al., 2008; Mei & Arshad, 2016; He et al., 2017), especially for automatic collision avoidance and path planning (Lyu & Yin, 2018; Singh et al., 2018a). Recently, some research is focused on integrating COLREGs in path planning algorithms (Naeem et al., 2016; Wang et al., 2018; Singh et al., 2018b; Lyu & Yin, 2019). However, most of the existing studies have only considered the basic rules of COLREGs, such as Rules 13, 14, 15, 16. Various external factors are ignored, such as Rule 2 and Rule 18. The MAXCMAS project has made many beneficial attempts and explorations (He et al., 2017; Varas et al., 2017). And there is a new way to quantify COLREGs and to establish notional algorithms for standard evaluation (Woerner et al., 2019).

1.2.2 Research on unmanned vessel and COLREGs

The research on the applicable legal aspects of the COLREGs clause for unmanned ships mainly focuses on the “good seamanship” clause, “responsibility and departure” clause, “lookout” clause, “be in sight of one another” clause and. Discuss the obstacles in COLREGs that require “human sense” and “empirical judgments” to be applied to unmanned ships

For example, Pritchett analyzed several international conventions and pointed out that unmanned ships must have rules to comply with, but it is difficult for unmanned ships to comply with the current COLREGs (Pritchett, 2015). Carey advocates that COLREGs should keep synchronization with technology, such as adding accessories specifically applicable to unmanned ships, amending the lookout clause, or treating unmanned vessels as “vessel restricted in her ability to manoeuvre” (Carey, 2017). Veal published a series of papers focusing on the legal status of unmanned ships and their operations. They discussed the applicability of unmanned ships, including ship lookout clauses and others (Veal et al., 2019). He also pointed out that the “not under command” state may include unmanned ships that have lost communication but not include the unmanned operations due to “special circumstances” (Veal & Tsimplis, 2017). Vojković & Milenković indicated how to apply the “responsibility” clause of COLREGs without crew onboard (Vojković & Milenković, 2020). Zhou et al. put forward the concept of “computer vision”, It is recommended to allow to rely on "computer vision" to make the "vessel be in sight of one another" (Zhou et al., 2020). Chang et al. mainly study the legal status of unmanned ships, point out the obstacles in applying COLREGs to unmanned ships, and believe that remotely controlled mode may better apply (Chang et al., 2020). In addition, LYU et al. propose to cancel the Head-on situation, and the encounter situation can be simplified into the overtaking situation and non-overtaking situation (LYU et al., 2020).

1.2.3 IMO instruments

As an international shipping industry legislative body, IMO has issued some guiding instruments and standards based on the related investigations and evaluations.

For instance, Committee Maritime International (CMI) established the International Working Group in Unmanned Ships (IWG) in 2015 to investigate and research the legal application issues arising from the advent of unmanned ships and released related questionnaires. In the 98th to 101st Maritime Safety Committee (MSC) sessions, a series of related instruments were formed to guide the development of unmanned ships. Some typical documents are as follows:

MSC 99/INF.3, in order to aid the work on the regulatory scoping exercise for the use of MASS, Denmark hereby offers an analysis of regulatory barriers to the use of autonomous ships (IMO, 2018a). MSC 99th Session, the submission includes a summary of the responses received from National Maritime Law Associations to the CMI IWG Questionnaire on Unmanned Ships and the work of the IWG on SOLAS, MARPOL, COLREGs, STCW, identifying provisions that may need to be clarified or amended and those provisions where no action is necessary (IMO, 2018b). MSC 100/INF.6, this document, submitted by China, provides information on the preliminary analysis of COLREGs, for the purpose of facilitating the ongoing regulatory scoping exercise for the use of MASS (IMO, 2018c).

1.3 Methodology

Reading of journal papers, conference papers, questionnaire analysis reports, research reports, which are related to the subject of this dissertation, has been conducted. In order to improve the validity of the literature, the authors try to extensively use articles from different sources and focus on fine papers, research, and IMO instruments.

It is the literature-based analysis of the purpose, the scope of application, and specific clauses of COLREGs, such as the “good seamanship” clause, the “lookout” clause, the “in sight of one another” clause, and the “vessel not under command” clause. Clarify the meaning, subject, requirements of each clause, and the main obstacles to the application of each one to unmanned vessels. And then, based on the salient features of unmanned vessels and the difference between the shore-based control mode and the fully autonomous mode, comprehensive analyses are conducted on related provisions of COLREGs for unmanned vessels.

Another analysis method is historical analysis. From the perspective of the development of maritime shipping practice, as well as the legislative background and history of COLREGs, this paper summarizes the lag and applicable issues caused by the development of the shipping industry and the emergence of unmanned vessels. The historical process of ship development from sailing vessels to power-driven vessels to unmanned vessels, as well as the corresponding revisions of COLREGs, are discussed. Based on the characteristics of unmanned vessels and the legislative purpose of COLREGs, suggestions for legal amendments are made to the current COLREGs.

There is also experiential analysis method, this paper use some sailing experience or typical cases, to demonstrate the argument and increase the persuasiveness of the standpoints. Since COLREGs is formulated through centuries of accumulated experience in history. It can be said that COLREGs are the summary of the navigation experience of centuries. Some typical cases are very valuable and can reflect the essence of COLREGs. In addition, the author has several years of marine experience so as to analyze some clauses of COLREGs from the crew's perspective.

In summary, research on the relationship between unmanned vessels and COLREGs is a new topic. The effective way to study the topics of this dissertation is to conduct theoretical, qualitative analysis and discussion based on reading and understanding relevant literature, combined with typical cases or sailing experience.

1.4 Structure of the paper

This dissertation is divided into four chapters:

Chapter 1 introduce the research background and purpose of this research, literature review and research methods.

Chapter 2 mainly describes the relevant information of unmanned vessels and COLREGs. In terms of unmanned ships, there is a comprehensive description of their definition, classification, and some specific research programs. In terms of COLREGs, it contents the formulation and revision history, as well as main provisions of COLREGs and their evaluation.

Chapter 3 is the core chapter of this dissertation. It discusses the interaction between unmanned vessels and COLREGs. It concentrates on the obstacles and countermeasures of the application of COLREGs for unmanned vessels. The following issues are discussed, such as unmanned vessels and the definition of “vessel” in COLREGs; the “priority” of unmanned vessels; issues on “lookout”, “good seamanship” and “be in sight of one another”.

Chapter 4 summarizes this dissertation. The conclusion is given in this chapter.

CHAPTER 2 INFORMATION: UNMANNED VESSEL AND COLREGs

Before the discussion, some necessary information involved in the issues should be introduced first. It includes information about unmanned vessels and COLREGs.

2.1 Information about unmanned vessel

2.1.1 Definition of unmanned vessel

The definition of "unmanned vessel" has not yet been unified. Different countries, institutions, scholars, and international organizations have different definitions, and some are quite different. For instance, the U.S. Navy's combat manual defines unmanned surface vehicles (USVs) as automatic or remote-controlled vehicles launched from the ground, underground, or aerial platforms (Savitz et al., 2013). while some scholars in the United States also define USV as a craft built to navigate the ocean and provide defence on maritime fronts (Vallejo, 2015). Unmanned surface vessel (USV) has a vital role in ocean survey, ocean patrol, ocean operation, and other missions (Li & Zheng, 2020). The European States prefer "autonomous ships" to USVs. Germany defines "autonomous vessels" as vessels equipped with modular control systems and communication technology to enable wireless monitoring and control, including advanced decision support systems and the capabilities for remote and autonomous operation (MUMIN, 2016). European academics also use the concept of "unmanned ship". China adopts the concept of China Classification Society (CCS) "intelligent ship" or "smart ship", defined as ships which automatically perceive and obtain information and data on the ship itself, marine environment, logistics, and port by making use of sensors, communication, the

Internet of Things, the Internet and other technical means, and achieve intelligent operation in terms of ship navigation, management, maintenance, and cargo transportation based on computer technology (CCS, 2020).

International Maritime Organization (IMO) is the most authoritative organization in the global shipping industry. Thus, the definition formulated by IMO should be well considered. In May 2018, The Maritime Safety Committee (MSC) of the IMO held its 99th session and defined “Maritime Autonomous Surface Ships” (MASS) as a ship which, to a varying degree, can operate independently of human interaction. (IMO, 2018b).

It should be noted that because the word “vessel” is used in COLREGs, and this paper mainly focuses on COLREGs. Hence, the terms used in most places of the dissertation are “vessel”, not “ship”, such as “unmanned vessel”. Moreover, one more point should be explained that In this paper, the words “ship” and “vessel” have the same meaning. The “unmanned vessel” is equal to the “unmanned ship”.

2.1.2 Classification of unmanned vessel

Unmanned vessels are an inevitable trend in the development of ships. IMO, classification societies and some relevant companies have relatively consistent views in this regard, but their views on the degree of autonomy and development classification of unmanned vessels are different. Lloyd’s Register of Shipping classifies unmanned vessels into six levels, AL1 to AL6. The Bureau Veritas (BV) classifies unmanned vessels into four levels, Level 1 ~ Leve 4. Rolls-Royce company classifies unmanned ships into four steps.

MASS is also classified into four levels, level 1 to Level 4, which are replaced by L1 to L4 in this paper. We can see from Figure 1, the MASS at L2 and L3 are all remotely controlled ships; their autonomous navigation needs to be conducted with the support of the Shore-Based Control Centre. The MASS at L4 is a fully autonomous unmanned ship, which is the ultimate goal of the development of unmanned ships. It can independently identify obstacles to avoid collision and accomplish specified tasks considering its manoeuvring characteristics. So, based on these standards, some scholars have proposed a non-linear model of autonomy level and manning on board, that is, the higher the autonomy level, the fewer the staff on board, and the highest autonomy level is without crew on board (Ringbom, 2019).

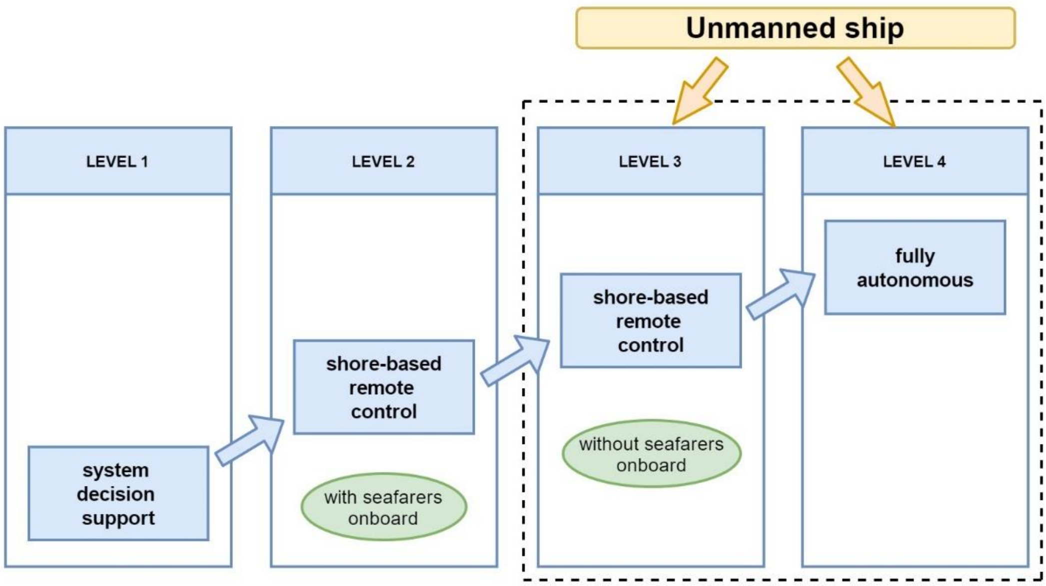

Figure 1. The process of development of MASS

Source: Author.

This paper adopts IMO standards. It is mainly discussed on MASS at L3 and MASS at L4. And the word “unmanned vessels” in this paper is equivalent to MASS at L3 and MASS at L4 together.

2.1.3 Representative project

The first decades of the 21st century have seen a large number of unmanned navigation projects, such as the Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) project (Burmeister et al., 2014) and the Advanced Autonomous Waterborne Applications (AAWA) Initiative (Rolls-Royce, 2016). These research projects were impressive in the shipping industry. They have made unmanned ships become the focus of the industry.

In recent years, DNV-GL and Kongsberg invented a type of concept ship named “ReVolt” (DNV-GL, 2018) for a short voyage, and it is also the first fully electric and autonomous container ship in the world, named “YARA Birkeland” (KONGSBERG, 2017).

In 2018, Wärtsilä successfully carried out the test at autonomous dock-to-dock operation without human intervention, visiting three ports serviced by “Folgefonn,” an 83-metre-long ferry (Wärtsilä., 2018a). And it was also used for the first autodocking tests of the world (Wärtsilä, 2018b). Wärtsilä also successfully tested remote control vessel from San Diego, California, to the North Sea.

In December 2018, the world’s first remotely-controlled trial took place using the existing ice-class passenger ferry “Suomenlinna II”, which was retrofitted with ABB Ability Marine Pilot Vision situational awareness solution (ABB, 2018).

At the end of 2018, the first fully autonomous ferry in the world, “Falco” which can be remotely controlled, navigate autonomously, and the auto dock was successfully demonstrated by Rolls-Royce and the Finnish state-owned ferry operator Finferries (Rolls-Royce, 2018).

2.2 Information about COLREGs

The 1972 International Regulations for Preventing Collisions at Sea (COLREGs) is one of the essential international conventions for maritime safety. It is the rule that vessels must comply with to avoid collisions at sea. It is a summary of centuries of sailing experience and the crystallization of human wisdom. COLREGs has 169 contracting parties, representing about 99% of world tonnage. The fundamental goals of COLREGs are establishing navigational standards to avoid the risk of collisions and ensure safety at sea.

2.2.1 Contents of COLREGs

COLREGs contents six parts. Part A stipulates the general provisions of applicability; Part B stipulates the detailed rules of manoeuvring and navigation; Part C stipulates the lights and signal type; part D stipulates the sound and light signals; Part E stipulates exemptions.

In addition, COLREGs are composed of nine articles of a general nature, followed by thirty-eight rules, establishing the traffic norms, and four annexes providing technical requirements. The normative structure is complex since the first articles oblige States to put into effects the enclosed provisions devoted to regulating the circulation of ships at sea (due to this, also colloquially called “Rules of the Road”) (Giunta, 2015).

COLREGs required that all vessels upon the high seas and in all waters connected there with navigable by seagoing vessels (IMO, 1972) should obey the rules, except for implementing local special rules in roadsteads, harbours, rivers, lakes, and inland waterways.

COLREGs specified the lights and shapes that the vessel should hoist under conditions of underway, at anchor, not under command, etc. In the action guidelines for collision avoidance, the actions under the condition of vessels “be in sight of one another” are stipulated, such as head-on situation, crossing situation, overtaking situation. On the other side, there are detailed regulations for navigation and collision avoidance under restricted visibility condition too. In addition, COLREGs also included clauses related to human experience and responsibility.

The set of rules is based on good seamanship and has been established through decades of marine operations. Although those operations have been performed by manned vessels and COLREGs, put all the required tasks and the responsibility on vessels’ crew officers of the watch and masters of sea-going ships (Felski & Zwolak, 2020).

2.2.2 History evolution

During the sailing vessel era, the content of the collision avoidance Rule was only about the actions of sailing vessels. Around two centuries ago, with the emergence of steamships, the Rule was developed. It formulated the actions not only between two power-driving vessels but also between the power-driven vessels and the sailing vessels. Besides, it still retained the relative provisions between two sailing vessels. It is noteworthy that, because of the co-existence of power-driven vessels and sailing vessels in the same environment, a unified set of rules had been developed for observance by both power-driven vessels and sailing ships, though different obligations for collision avoidance had been laid down for them according to their different manoeuvrabilities (Jurak, 2020).

The current COLREGs were formulated in 1972 and entered into force in 1977. So far, there were seven revisions in 1981, 1987, 1989, 1993, 2001 and 2007. These amendments are all negotiated and formulated after the emergence of new conditions or new technologies.

From the historical evolution of the rule, we can see the lag of the legislation. The birth of new things always precedes the constraints of the legislation. The new things usually come first, and then the legislators formulate laws to restrict them according to their characteristics, functions, and influences. It is the same for COLREGs. Due to the lagging nature of the legislation, the legislators did not consider unmanned vessels when formulating COLREGs.

2.2.3 Evaluation of COLREGs

As the norm to guide ships' collision avoidance and maneuvering at sea, the purpose of COLREGs is to ensure navigation safety. It is an essential rule formulated by IMO. COLREGs has dual natures, the nature of technical regulations and the nature of legal regulations, which has been affirmed and recognized by the shipping industry. As a technical specification, the role of COLREGs is mainly to guide navigators on how to take avoidance actions to avoid collision accidents. As a legal regulation, the primary function of COLREGs is to restrict the behaviour of vessels and serve as the fundamental law for judging collision liability. Hence, it is unique and irreplaceable the COLREGs is in the maritime field.

However, COLREGs is not perfect. It has some flaws. There are some subjective and ambiguous definitions in COLREGs. For example, some relevant clauses require seaman to manoeuvre the ship with “good seamanship”, but it does not accurately define “good seamanship”.

In addition, there are some obsolete clauses in COLREGs. For example, Rule 35 Paragraph (g) “A vessel at anchor shall at intervals of not more than one minute ring the bell rapidly for about 5 seconds. In a vessel of 100 metres or more in length the bell shall be sounded in the fore part of the vessel, and immediately after the ringing of the bell, the gong shall be sounded rapidly for about 5 seconds in the after part of the vessel" (IMO.1972). The author believes that this rule has little effect on modern merchant vessels. Almost no vessel does as this clause is required. These clauses cannot keep up with the current rapid development of the shipping industry. Even if it is not due to the advent of unmanned vessels, they still need to be amended.

CHAPTER 3 DISCUSSION: OBSTACLES AND COUNTERMEASURES

3.1 Interaction between unmanned vessels and COLREGs

3.1.1 Mixed navigation mode and COLREGs

The so-called "mixed navigation mode" or "mixed mode" refers to the navigation mode in which unmanned vessels and manned vessels coexist and navigate the same area of the sea with equal legal status.

This similar kind of "mixed mode" has also appeared in history and continued to the present. As mentioned above, the advent of steamships (power-driven ships) significantly impacted the global shipping industry. This mixed mode of power-driven vessels and non-power-driven vessels (such as sailing vessel) still exists today and may continue for a long time.

Therefore, the legislators also made corresponding amendments to COLREGs for the power-driven vessels to make it not only applicable to collision avoidance between two sailing vessels, between two power-driven vessels, but also between a sailing vessel and a power-driven vessel, such as Rule 18.

In the same situation, unmanned vessels, as the future of the shipping industry, will coexist with manned vessels for an extended period. It is the consensus in the maritime field. The shipping industry is very complex and traditional. Such as mentioned above, more than 200 years after the emergence of a power-driven vessel, sailing vessels are still existing and may never wholly replaced by power-driven vessels. People still need sailing vessels and rowing boats for recreation, fishing, and even transportation operations.

In the same way, even if unmanned vessels have developed to replace other ships completely, people still desire to perform leisure, fishing, and other operations on board. No one can stop human beings from boarding ships. Therefore, it may take a long process for unmanned vessels to replace manned vessels completely, and perhaps it is impossible. Development of rules of cooperation between manned and unmanned vessels is one of the biggest challenges of autonomous ships industry. (Felski & Zwolak, 2020)

3.1.2 New rule or current COLREGs

When unmanned vessels are put into operation, they face the issues of ship collision avoidance firstly. Some scholars believe that a new collision avoidance rule only for unmanned vessels can be formulated, and it can be used to coordinate collision avoidance operations between unmanned vessels. This method can coordinate two encountered unmanned vessels. And it can make the provisions of the new rule more simplified or even wholly quantified. But under the context of long-term mixed mode, it also brings new issues, e.g., if a MASS is required to meet a set of new rules in an encounter with another MASS, and to meet the existing rules in an encounter with an MSS, uncertainty and incoordination would also arise (IMO, 2018b). when unmanned vessels and manned vessels encountered, they can not determine which rule should be followed, the COLREGs for manned vessels or the new rule for unmanned vessels, nor to quickly determine the vessel encountered is an unmanned vessel or a manned vessel. Therefore, it is imperative to follow uniform rules.

The unified adjustment of COLREGs to manned and unmanned vessels plays a significant role in maintaining maritime safety in anticipation of hazards and manoeuvres. When vessels apply uniform navigation rules, it can strengthen their trust in each other. One vessel believes that the other one also follows the same rule. The crew on board will not have suspicion and panic, and the procedures and algorithms of the unmanned vessel will not confuse. According to the navigation conditions at that time, it can make better predictions on the manoeuvring of the other vessel, and at the same time enable the other vessel to predict the manoeuvring behaviour and make corresponding responses according to the circumstance, the two encountering vessels can better predict the intention of each other and take the corresponding actions. If the unmanned vessel applies the different rules from the manned vessel, it can sharply increase the difficulty of predicting between vessels, the intensity of training and learning for ship navigators, and the complexity of the programming of the autonomous system.

Compared with the new collision avoidance rule, it is better to choose to comply with the existing COLREGs. Especially at present, since the unmanned vessel is in the primary developing stage, the research and construction should be carried out in accordance with the current COLREGs requirements, which is the best solution. Therefore, the unmanned vessel must meet the definition of “vessel” in COLREGs, follow its relevant regulations.

it is presumed that a large number of collisions can be effectively reduced by increasing the degree of automation of the ship, especially for collision avoidance in accordance with the COLREGs (Shen, 2019). There is little practical significance to research intelligent collision avoidance strategies and algorithms without COLREGs. COLREGs should be used as the fundamental basis for the design of intelligent collision avoidance strategies and algorithms.

Currently, maintaining the equivalent safety standard of conventional vessels is one of the problems and bottlenecks that is difficult to solve with existing artificial intelligence technology (Pietrzykowski & Malujda, 2018), especially for the collision situations where COLREGs do not apply and when they are applied (Zhao, 2008).

3.1.3 Amending COLREGs

The obsolete clauses in COLREGs need to be further clarified, expanded, or even amended. Only in this way can we solve the problems caused by the unmanned vessel - such a new thing for us. COLREGs can also guide the development of unmanned vessels and point out the healthy and orderly direction for them.

According to the degree of obstacles to the application, the clauses in COLREGs can be divided into three types: the first type applies to unmanned vessels without obstacles; the second type applies to unmanned vessels with obstacles that can be solved by advanced technology; the third type applies to unmanned vessels with obstacles that only can be solved by amended provisions.

In terms of the second type, the implementation of such clauses can be achieved through technological advancement. There is no need to amend the main body of the clauses, but some of them need to be clearly explained or declared. It includes Rule 6 “Safe speed”, Rule 7 “Risk of collision”, Rule 9 “Narrow channels”, Rule 19 “Conduct of Vessels in Restricted Visibility”, Part C “Lights and Shapes”, Part D “Sound and Light Signals”.

As for the third type, there are obstacles to applying unmanned vessels, which cannot be solved by relying only on technology, including Rule 2 “Responsibility”; Rule 3 “General Definitions”, “vessel not under command”, “vessel restricted in her ability to manoeuvre”, “in sight of one another”; Rule 5 “Lookout”; Rule 8 “Actions to Avoid Collision”, “Good seamanship”. COLREGs does not quantify the relevant concepts of these clauses. And there is no equivalent standard specified. In other words, the COLREGs cannot be described in quantified. It came from human thinking and experience. Therefore, under the COLREGs framework, automatic collision avoidance cannot be achieved. It should be optimized and modified.

IMO member states also put forward relevant proposals for the purpose of certainty and coordination. It is preferable to have a unified set of rules to be developed for observance by both MSS and MASS. It is anticipated, therefore, that the advent of MASS is necessitating amendment to the COLREGs 1972 for application to MASS (IMO, 2018b)

Since unmanned vessels are developed in accordance with COLREGs, COLREGs should give certain concessions on the relevant clauses that cannot be achieved in a short period, even after the technological advancement. The revised methods of amendments include but are not limited to clarify the explanation of some clauses and add the description about the unmanned vessel; Expand the particular scope of application to include unmanned vessels; Modify some clauses to make them applicable to unmanned vessels; Quantify the specific required standards, to ensure the application of unmanned vessels.

In summary, COLREGs were not formulated considering unmanned vessels. it was written to be interpreted by well-experienced sailors and imply the usage of their experience and common sense. There are gaps to be filled and subjective or ambiguous definitions to be addressed (Jurak, 2020).

3.2 Unmanned vessel belongs to “vessel” of COLREGs

At first, it needs to be discussed whether the unmanned vessel belongs to the “vessel” specified in the definition of COLREGs and whether the unmanned vessel fits the scope of application in the COLREGs. It determines whether the unmanned vessels are subject to the jurisdiction and constraints of COLREGs. If COLREGs is not scoping unmanned vessels, there is no significance in discussing other provisions in-depth because it is the prerequisite for discussing others.

3.2.1 Definition of “vessel” in COLREGs

Rule 1 of COLREGs stipulates that all vessels upon the high seas and in all waters connected there with navigable by seagoing vessels (IMO, 1972) should follow COLREGs. In other words, all ships sailing in waters outside the scope of national jurisdiction are required to comply with COLREGs. Within the scope of national jurisdiction, in addition to COLREGs, there may be local laws or rules. But they are basically the same. Most domestic laws on collision avoidance are all derived from COLREGs. It is therefore hard to argue against the fact that compliance to the COLREGs is a requirement even for vessels without a crew on board (Öhland & Stenman, 2017).

Rule 3 of COLREGs stipulates that “The word vessel; includes every description of water craft, including non-displacement craft, WIG craft and seaplanes, used or capable of being used as a means of transportation on water” (IMO, 1972). This is the definition of “vessel” clearly listed in COLREGs. From a literal analysis, the scope of “vessel” in COLREGs extends a vast range. It does not require the standards of type, tonnage, length, or drift, even the name or title. For example, the “seaplane” also belongs to “vessel”.

The definition puts more emphasis on the “transportation” function of a vessel. It includes both the vessel is used for transportation or can be used for transportation.

However, with the diversity of human activities at sea, the functions of vessels have also appeared diversified, such as scientific research ships, recreational ships, and other non-transport operation ships. Therefore, “transportation” is no longer the fundamental attribute of “vessel”. It is defining “vessel” with “transportation” as the fundamental attribute can make the connotation and extension of “vessel” too narrow. The clause is obsolete and needs to be amended.

It is also important to note that COLREGs does not specify that the ship must be staffed with seafarers or that the seafarers must be on board. The clause of COLREGs itself does not exclude unmanned ships from the scope of application. And hence do not seem to pose any particular issues for unmanned vessels (Fastvold, 2018).

3.2.2 Extension of the definition

For confirming that the unmanned vessel is a “vessel” of COLREGs, the argument is focused on whether the master and crew working on board are recognized as a necessary factor for being a “vessel”. When legislators defined vessel, they did not foresee the occurrence of unmanned vessels, and nor is it stated in COLREGs that “carrying crew” is a precondition for the vessel. Regarding the legal determination of whether an unmanned vessel is a “vessel”, the most critical element is whether the “no crew onboard” violates the legal requirements. It is the primary issue when discussing unmanned vessels and COLREGs.

Some scholars believe that “vessel” is a “generic term” (Veal & Tsimplis, 2017). The generic term used in treaty law is permanent or continuously effective. It can be understood as the meaning of making the treaty applicable in different situations, regardless of the original meaning when the treaty was concluded.

So, the definition of “vessel” in COLREGs is a generic term or not? First, the term “vessel” is universal because of its abstract nature. Its primary connotation is a watercraft sailing on the water, and it has different types and classifications according to different forms. For example, according to the functions, vessels can be classified into oil tankers, cruise ships, bulk carriers, fishing boats, etc. According to other classification methods, it can also be classified into civil ships, military ships, power-driven vessels, sailing boats, rowing boats, and even large ships, small crafts, and so on. Therefore, to a certain extent, the unmanned vessel is a new type of vessel based on intelligent technology. It is the concretized concept of “vessel”, and it should belong within the meaning of “vessel”. Secondly, the current legal framework is intended to permanently address the matters involved, especially on marine safety issues. In the upcoming mixed navigation era, when unmanned vessels and manned vessels coexist, it is an inevitable trend for unmanned vessels to apply the current shipping legal framework. “Vessel” should be interpreted as including unmanned vessel.

Furthermore, according to Article 31(1) of the Vienna Convention on the Law of Treaties (1969), the treaty “shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose”. Incorporating unmanned vessels into the regulatory scope of COLREGs is entirely in line with its goals. In this way, it can be clarified that the unmanned vessel will perform related operations in accordance with the provisions of COLREGs when sailing at sea. It can not only enhance the safety of unmanned vessels and manned vessels navigating in the same waters but also determine the responsibilities of related parties after an accident.

To shape the complete scope of the “vessel” according to what the drafters thought at the original time was a primary and secondary reversal. The term “vessel” is sufficiently versatile and inclusive. Unmanned vessels equipped with new intelligent technologies have not changed the fundamental characteristics of vessels. Therefore, unmanned vessels have the legal status of a “vessel”. As a result, “vessel” has the attributes of a generic term. In the abstract sense, the “vessel” represents the connotation, while the unmanned vessel belongs to the extension of “vessel”.

3.2.3 Amend the definition

The above analysis has shown that unmanned vessels can fit the requirement of COLREGs. But it needs a deep understanding to prove it, and there is no clear legal statement. Thus, Rule 3 of COLREGs needs to be amended. Add unmanned vessel into the definition of “vessel”, and a separate definition for fully unmanned or remote-controlled vessels also need to be considered to guarantee that they are both included.

It is just like Wing-In-Ground (WIG) craft, which was clarified as a “vessel” in the 2001 amendment of COLREGs. And the definition of WIG was also added to Rule 3. The Wing-In-Ground craft means “a multimodal craft which, in its main operational mode, flies in close proximity to the surface by utilizing surface-effect action” (IMO, 1972). It is a product of the development of science and technology, the same as unmanned vessels. It shows that unmanned vessels can also be specially specified in the definition of “vessel” in COLREGs, just like WIG craft.

3.2.4 Confirm the legal status

In COLREGs Rule 2 responsibility Paragraph (a), the seafarers have been mentioned. It stipulates that “Nothing in these Rules shall exonerate any vessel, or the owner, master or crew thereof, from the consequences of any neglect to comply with these Rules or of the neglect of any precaution which may be required by the “ordinary practice of seamen”, or by the special circumstances of the case” (IMO, 1972). It is known that COLREGs is not only a technical specification for guiding vessels but also the legal basis for determining liability when a vessel is involved in a collision. And this clause declares the relevant responsibilities of the master or crew. But if there is no master or crew on the unmanned vessel, no clear responsible person when the vessel collides.

The difference between MASS at L3 and traditional ships in terms of subject responsibility is the location of the controller. MSC 99/INF.3 submits that the core element of COLREGs is that vessels are controlled by humans through seamanlike assessment. It is decisive “who” is controlling the ship, not from “where”. Remotely controlled vessels will fulfill the requirements of COLREGs to the extent that the technology provides sufficient situational awareness (IMO, 2018c). For L3 unmanned vessels, it should be clear that the remote controller can be recognized as a master or crew member and has fairly “good seamanship”, capable of handling urgent situations.

The MASS at L4 should be retained final responsibility of the owners, actual managers, and direct controllers should be to deal with special circumstances and specific scenarios. It should also include actual managers and direct controllers or other relevant persons.

3.3 Unmanned vessels and "priority"

The unmanned vessel is a special kind of vessel. It is different from traditional ships in terms of hull, structure, equipment, especially manning. So, can COLREGs give the unmanned vessels the "priority"? The unmanned vessel is deemed as a "vessel not under command" or "vessel restricted in her ability to manoeuvre" e.g. some scholars proposed that COLREGs could be amended to include autonomous ships within the class of vessels restricted in their ability to manoeuvre (Carey, 2017). So that the unmanned vessels can achieve specific navigational priority.

3.3.1 "Priority" in COLREGs

Rule 3 Paragraph (f) stipulate the definition of "vessel not under command" as "a vessel which through some exceptional circumstance is unable to manoeuvre as required by these Rules and is, therefore, unable to keep out of the way of another vessel" (IMO, 1972). From the definition, it can be seen that the main reason that causes the vessel to lose control is "exceptional circumstance". "Vessel not under command" is caused by circumstance factors, not because of its own characteristics. Any type of vessel in COLREGs can become a "vessel not under command" during a period. It is a special situation, not a particular kind of vessel. Becoming a "vessel not under command" is just holding for a certain period, not all the time. When the "exceptional circumstance" recovered to normal condition, the vessel would return to a common vessel again, no longer a "vessel not under command."

Rule 3 Paragraph (g) of COLREGs defines the "vessel restricted in her ability to manoeuvre" as "a vessel which from the nature of her work is restricted in her ability to manoeuvre as required by these Rules and is, therefore, unable to keep out of the way of another vessel"(IMO, 1972). Some typical situations are also listed in the rule, such as a vessel engaged in dredging, launching, or recovery of aircraft, underwater operations, or mine clearance operations. It can be seen from the definition that the main element that becomes "vessel restricted in her ability to manoeuvre" is the "nature of work". Because the work which the ship is doing affects its ability to manoeuvre, it cannot give way to the other ship if there is a danger of collision between them. But when the work is stopped or finished, it no longer has the identity of "vessel restricted in her ability to manoeuvre" nor the "priority". So, "vessel restricted in her ability to manoeuvre" doesn't specifically refer to a certain kind of ship. It is a special working status. This status will last until the maneuvrability is recovered.

The reason for clearly defining "vessel not under command" and "vessel restricted in her ability to manoeuvre" is to declare and confirm the status that they have poor manoeuvrability. They are unable to take the collision avoidance actions due to the exceptional circumstance or the nature of their work and can not give way to other vessels. Hence, COLREGs gives them particular "priority" to achieve the "right of way". In addition to listing "vessel not under command" and "vessel restricted in her ability to manoeuvre", the rules also list other vessels with poor manoeuvrability, such as "a vessel engaged in fishing" and a sailing vessel.

Furthermore, Rule 18 of COLREGs, "Responsibilities between Vessels", stipulates the hierarchy of collision avoidance responsibility between these vessels. The "priority" of "giving way" from high to low, equivalent to manoeuvrability from low to high, is a vessel not under command or a vessel restricted in her ability to manoeuvre; a vessel engaged in fishing; a sailing vessel; a power-driven vessel.

According to the manoeuvrability, the nature of the work, different types of vessels is required to perform different collision avoidance obligations and bear different responsibilities. Based on the quality of manoeuvrability to determine the distribution of priority, the COLREGs can form a responsibility hierarchy which is the essential "giving way system" of maritime traffic. "Vessel not under command" and "vessel restricted in her ability to manoeuvre" have the highest-level priority of "right of way".

3.3.2 No "Priority" for unmanned vessels

Some scholars believe that we can start with the responsibility hierarchy system of COLREGs to clarify the collision avoidance responsibility levels of unmanned vessels and other vessels. For instance, give unmanned vessels a higher level of priority of "right of way" and formulate regulations on the reduction and exemption of unmanned vessels to a certain extent. If an unmanned vessel were labelled as "not under command" or "restricted in ability to manoeuvre", other vessels would be obligated to keep out of their way (Norris, 2013b).

It can appropriately simplify the requirements for collision avoidance operation of unmanned vessels, reduce the difficulty of the research, and promote its development and progress. In addition, for COLREGs, there is no need to make a lot of amendments or clarifications, and avoids disputes over the quantification of some definition such as "good seamanship". This system looks more stable and economic, may be more readily accepted by the state members of IMO.

The main theoretical basis of this view is that the MASS at L4 uses an artificial intelligence (AI) system through a special algorithm to collect information and make corresponding action decisions. Such behaviour is not under the command of “human”. And for MASS at L3, the vessel is under the control of the shore-based operator who does not work onboard. It is actually under the control of “crew onshore”, and it is an argument whether this type of control can be regarded as under the control of “crew onboard”.

The main theoretical basis for treating an unmanned vessel as a “vessel restricted in ability to manoeuvre” is that the delay and interference of communication cause its manoeuvrability to be restricted. Especially for MASS at L3, there must be a communication delay between the unmanned vessel and the shore-based control centre. If the weather conditions are not good, there is likely to be a considerable delay or interference, which can cause great hidden dangers to safety. In addition, there are other effects such as the reaction time of the operator, the time of data procession, and the reaction time of the vessel executing the order itself, etc.

However, there are obvious shortcomings in treating unmanned vessels as a “vessel not under command” or a “vessel restricted in ability to manoeuvre”. Firstly, there are moral hazard issues. If the status of an unmanned vessel is legally determined, almost all other vessels must give way for it. This means that researchers of an autonomous control system, ship owners, and shore-based operators can hardly consider the issues of unmanned vessels giving way to others. Therefore, some related personnel may deliberately cause a collision risk or an urgent situation between the unmanned vessel and the giving way vessel in order to gain some specific benefits by taking advantage of the unmanned vessel's higher priority of “right of way”. Secondly, there is a risk of encountering an unfamiliar situation. When there is a danger of collision between an unmanned vessel and an actual “vessel not under command” or “vessel restricted in ability to manoeuvre”, the unmanned vessel can no longer disguise. It should immediately take action to avoid collisions.

In addition, according to the definition, determining whether a ship is “not under command” is not due to its own characteristics, but the “exceptional circumstance”. The vessel is supposed to be unmanned all the time, so this cannot be considered an “exceptional circumstance”. Therefore, we do not see any reason for an unmanned cargo vessel to be labelled “not under command” (Van Dokkum, 2012). Furthermore, based on the actual cases, courts have interpreted the words ‘not under command’ as an exceptional circumstance caused by failure or damage and not as a normal mode of operation, such as the mode of an unmanned vessel. “The term exceptional circumstances clearly refers to circumstances other than a vessel’s ordinary operational arrangements” (Veal & Henrik, 2017).

Under the mixed navigation mode, unmanned vessels and manned vessels should have the same navigation legal status. “There is not much justification for this since unmanned vessels are designed to work and behave like manned vessels at sea.” (Norris, 2013a). Although there are significant differences between unmanned vessels and manned vessels in the navigation system, and the unmanned vessels do not have any crew on board, it does not mean that unmanned vessels should have priority navigation rights and higher navigation legal status. When unmanned vessels and manned vessels sail together, they should equally bear the navigation risks, follow the same conventions and regulations, and jointly undertake maritime cargo transportation tasks. Therefore, an unmanned vessel cannot be simply classified as a “vessel not under command” or a “vessel restricted in ability to manoeuvre”.

3.3.3 The right of “not under command”

An unmanned vessel is not a “vessel not under command”, nor a “vessel restricted in ability to manoeuvre", but it is not always controllable. It should also have the right of "not under command".

Under normal working conditions, it should not be regarded as a vessel not under command, but under "exceptional circumstances", such as power loss, failure of the engine and (or) steering gear, and interruption of the communication between the SBO and unmanned vessel, it may also become a "vessel not under command". It should be noted that this kind of "not under command" should exclude the behaviour of the controller deliberately giving up the right of control in order to obtain the priority of navigation.

It just like a sailing vessel, which not only has a high level of "priority" but also has the right of "not under command". When a sailing vessel encounters rapids current with no wind, it is equivalent to losing power and considered to be "not under command". Unmanned vessels have similar situations and should be clearly listed as "not under command" status. Even some "more special circumstances" only for the unmanned vessel, such as, in strong winds, heavy rains, blizzards, or other extreme weather, the various sensors of the unmanned vessel may be strongly affected by the weather and cannot effectively receive surrounding information, which leads to that autonomous control system can not make the correct decision.

A noteworthy situation should be paid attention to the perception, decision-making, and control system of the MASS at the L4, which is composed of a series of algorithms. Any system may fail under specific conditions, so there is a certain probability that the MASS at the L4 can be incomprehensible to humans. In this case, whether an unmanned vessel can be recognized as a "vessel not under command" is an argument. Because it depends on the Legal status of an unmanned vessel; the difference between machine failures and design errors, etc (LYU et al., 2020).

Furthermore, for specific amendments to the provisions of COLREGs, Rule 3 Paragraph(f) can be supplemented. It should point out that for unmanned vessels, it cannot be directly identified as a vessel not under command because of its unmanned nature. It also stated that the conditions for the unmanned vessel to be “not under command” do not include deliberately giving up the right of control.

3.4 Electronic lookout: A better way for lookout

“Proper lookout” is fundamental to ship collision avoidance. It is the paramount clause of COLREGs. Lookout is the cornerstone of navigation safety. Only when a ship always maintains a proper lookout can it have sufficient information and make reasonable estimates of the surrounding circumstance to take corrective actions. The unmanned vessel is no exception. It relies on various equipment and sensors installed on the ship to collect necessary information, including image, sound, echo, etc. They provide enough information for the autonomous control system, and through algorithm calculation, give the best action command. This type of “lookout” obtains information without relying on human senses, but on electronic devices, referred to as “electronic lookout”.

3.4.1 Lookout clause

Rule 5 of COLREGs stipulates that “Every vessel shall at all times maintain a proper lookout by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so to make a full appraisal of the situation and of the risk of collision.” (IMO, 1972)

It is called the “Lookout Clause” and is one of the most important clauses of

COLREGs. In 1960, the “lookout” was only mentioned in Rule 2 responsibility in COLREGs. When the rules were demanded in 1972, the “lookout clause” was set as a separate clause in the first place of Part B, steering and sailing rules. From this, it can be seen that the importance of the “lookout” clause in COLREGs.

Any vessel must perform a “proper lookout”, that is, as long as it is a vessel specified in Rule 3 of the “COLREGs”, it is obligated to maintain a “proper lookout at all times, regardless of the weather, sea conditions, type, size and whether the vessel is a “vessel not under command” or a “vessel restricted in her ability to manoeuvre”.

Ships must fulfill the obligation of proper lookout “at all time”. Maritime risks may occur at any time and are quite complicated. No matter when the vessel is underway, anchoring, berthing or unberthing, the lookout should be comprehensive and continuous. The judiciary considers “lookout” to be persistent attention and endless vigilance. Besides, it warns that seafarers who have the duty of watching should bear the responsibility for the severe consequences caused by neglect of watching.

“Proper lookout” must use “sight” and “hearing” sense and “all available means appropriate in the prevailing circumstances and conditions”. Among them, “sight” and “hearing” are the traditional ways of the lookout. It mainly depends on “human factors”, the vision and audition, as the main lookout means clearly listed in the clause. Both have the natural attributes of human beings. “Sight lookout” is the most fundamental routine way to maintain a proper lookout. The advantage of “sight” lookout is that it is simple, convenient, intuitive, and can quickly obtain accurate information in different aspects simultaneously. “Hearing lookout” is the primary way to maintain a proper lookout when visibility is poor. The information obtained by traditional lookout ways is also the most direct and credible. In addition, the lookout clause generalizes the means of the lookout. It refers to “all available means appropriate in the prevailing circumstances and conditions”, including the use of binoculars, radar, GPS, AIS, and other electronic navigational instruments. They do this “lookout” task together.

For instance, when the vessel is equipped with radar, objects on the radar screen have to be compared with visually obtained information and vice versa. A visual lookout has to be conducted with the naked eye, with sunglasses or with the use of binoculars. (Van Dokkum, 2012). Proper lookout is a combination of “direct lookout” performed by human senses and “indirect lookout” by using navigation devices.

In addition, the lookout should be “proper”. It aims to make a full assessment of the situation and the risk of collision to ensure maritime safety; Lookout is the process of ships continuously collecting and identifying and “appraisal” the information of the circumstance. It is an act of assessing something. Thus, referring to human judgment. The watchkeeping duty in STCW arguably contains this element as well. It means that sight and hearing are of no use unless the information is interpreted to avoid the risk of collision (Fastvold, 2018).

Therefore, the “proper lookout” is a prerequisite for “good seamanship”. In addition to looking out to collect information, it is necessary to use “good seamanship” to analyze the information obtained from the lookout, to make a full appraisal of the situation and the risk of collision.

3.4.2 Electronic lookout

The so-called “electronic lookout” can be classified into two situations: For MASS at L3, the vessel operator of the unmanned vessel is transferred from the vessel to the shore-based control centre where the SBO does not directly use the “sight” and “hearing” senses to achieve lookout on the vessel. And “sight” and “hearing” information can only be achieved through electronic equipment such as cameras and sonar installed on the vessel. For MASS at L4, the fully automatic mode has no crew and no SBO. There is no human auditory and visual information. Only the relevant information collected by electronic navigation aids is transmitted to the intelligent control system for analysis and processing.

The purpose of the lookout is to collect information around the vessel and make assessments and decisions accordingly. It is related to several factors, including adequate crew on watch to do this job; the position of the crew on watch is optimal; the means of “lookout” is enough; the crew on watch should be severe, cautious, and conscientious during the “lookout” process. And it is necessary to consider the moment when a vessel detects the encounter vessel and the distance between the two vessels in the meantime.

But The lookout clause does not limit the location of the crew on watch. The definition does not clearly state that the lookout must be on board. It means that the watchman is not necessarily a seaman on board. Therefore, it can be interpreted that the SBO of the MASS at L3 can also complete the duty of watching.

In addition, the technology of “lookout” is developing rapidly. For example, the US Navy has established a system for detecting objects at sea that uses electronic sensors to detect distant objects and record their position, in order to provide a reference for its navigation program, when determining a navigation route (Pritchett, 2015).

For MASS at L4, the autonomous collision avoidance algorithm is continuously optimized. The accuracy of measurement and perception of electronic navigational instruments such as GPS, AIS, radar, cameras, and various sensors continues to develop significantly. It is becoming possible for computers to replace human eyes to identify, track and measure a target (Zhou et al., 2020). The autonomous sensing and response capabilities of the unmanned vessel can surpass the human's ability to the “lookout”.

The “electronic lookout” means of unmanned vessels can be identified as “all available means” of lookout definition. Arguably the look-out requirement might not need any amendment and is articulated in a manner that allows for expansive interpretation without jeopardizing the predictability or stability and opens for weighting the intention. (Fastvold, 2018)

Furthermore, an “Electronic lookout” has other advantages. For MASS at L4, it does not rely on humans, does not involve fatigue factors, distracted attention, and other issues. Thus, it eliminates the hidden dangers that fatigue brings to the lookout. Automated eyes and ears could prevent us from human errors arising when we are tired, sick, or fatigue. The further technology advances, the more likely it is that the systems could meet the current standards (Kaminski, 2016). There are views that the look-out system can compete with a crew with relevant experience, in fulfilling the responsibility (Chang et al., 2020). Hance, “electronic look-out” can do the same, or even better.

Based on some practical navigation experience, it can be concluded that electronic instruments onboard are trustworthy. These electronic navigation aids are becoming more advanced and reliable, with higher precision and fewer errors. Crew members use them daily as a basic lookout means. They can collect more information that even cannot be seen or heard. And the information collected by them can be more timely, accurate, and comprehensive than “sight and hearing”.

Especially in heavy fog, heavy rain, and other extreme weather that causes poor visibility, “electronic lookout” is the most effective way of the lookout. The “sight and hearing lookout” is only auxiliary. Hearing is the basic means of maintaining a proper lookout when visibility is poor, but it is not the most effective one. In fact, few crew members will comply with the regulations on the sound signal in poor visibility, particularly in open waters. It is determined by the characteristics of modern large-scale merchant vessels. When you hear the other one's sound signal, the distance between the two vessels may not be enough to avoid a collision. At this time, we can rely more on electronic navigation equipment, such as radar, AIS, ECDIS, VHF, etc. The practice has proved that these devices are effective, and they can clearly and timely discover the conditions of surrounding circumstances. If unmanned vessels can fully use these devices for “electronic lookout” or even adopt more advanced technologies, they are fully meet the “lookout” requirements.

3.4.3 Amendment of lookout clause

In Rule 5, the requirement of a master, a physical presence of the OOW, and a safe ‘manning’ is not vague. (Fastvold, 2018). Whether it is transferring control to the shore-based control centre in MASS at L3 mode or completely excluding the existence of crew in MASS at L4 mode, under the current rules, unmanned vessels without crews both lack specified implementers of the lookout.

Therefore, COLREGs should clarify that the implementers of the lookout are not necessarily human beings on board. The current “proper lookout” can be implemented by the crew on board, but the advanced technology and equipment and the advent of unmanned vessels can bring a massive challenge. Development requires extensive changes in traditional navigation activities, including requirements of crew.

MASS at L3 can rely on intelligent devices to collect, analyze, and process information. The SBO can complete the entire process of the lookout. The implementer of this kind of lookout is still human. The biggest shortcoming is that the transmission of information may be delayed or interfered. However, with the support of sufficient and appropriate technical means, this kind can replace traditional lookout.

For MASS at L4, AI will replace traditional crews and SBO for lookout. Therefore, it is necessary to expand the interpretation of the terms of the lookout and clarify the status of the electronic lookout. It can meet the technical conditions of the lookout, but corresponding standards need to be supplemented. Standards should include requirements for real-time accuracy, redundancy, and emergency preparedness of electronic lookout.

Therefore, the supplement on the electronic lookout can be formally added to Rule 5 of COLREGs. Such as, every vessel shall continuously maintain a proper look-out by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision, including sight, hearing, and an electronic lookout which meet standards.

3.5 Performing “good seamanship” without seaman on the ship

“Good seamanship” means that the navigators of vessels take the most suitable collision avoidance actions based on long-term practice and accumulated navigation experience. And do their utmost to manage vessels with due care and reasonable obligations to avoid hindering the other vessels. “Good seamanship” is a necessary criterion for COLREGs, and the navigation and collision avoidance operation should follow the requirements of the “good seamanship” clause.

The essence of good seamanship is the summary of the long-term experience accumulated by the master and crew members, and it is an absolute subjective concept.

3.5.1 Good seamanship

The Rule 8 of COLREGs has mentioned “good seamanship” that “any action to avoid collision shall, if the circumstances of the case admit, be positive, made in ample time and with due regard to the observance of good seamanship” (IMO 1972).

There are many similarities in other clauses of COLREGs, and the requirements can be equivalent to good seamanship, although there is no explicit reference to it, e.g., The Rule 17, “Action by stand-on vessel” use qualitative definitions like “as soon as it becomes apparent” “finds herself so close that collision cannot be avoided by the action of the give-way vessel alone,” “action as will best aid to avoid collision” and “if the circumstances at the case admit” (IMO,1972).

The “Good seamanship” clause is the first principle of maritime navigation. It is also the first principle to follow the COLREGs. In fact, COLREGs does not clearly specify the definition of “good seamanship”, nor does it clearly determine the standard for “good seamanship”. It only stipulates the requirements for adopting “good seamanship” and the responsibility of violations of “good seamanship”. Inferred from other clauses of COLREGs, “good seamanship” is formed during the process of accumulation of practical experience in sailing by seafarers. It is an ability to make the most suitable decision of collision avoidance based on navigation conditions, weather, information, equipment, and all other relevant resources. And then, take the best action to avoid a collision even if this action is not stipulated in the rules or even contrary to the other provisions.

The requirements for “good seamanship” are various. To be sure, the implementer of “good seamanship” in the rules is “human”. The vessel should be equipped with enough crew members to ensure enough implementers of “good seamanship”. The crew members should be knowledgeable, experienced, and competent to satisfy the requirements. It is a summary of the navigation experience of the “seaman”, which is formulated to regulate the behaviour of the master and crew, requiring them to do their best to control, supervise and manage the vessel.

According to the explanation of “good seamanship” above, the vessel should be equipped with sufficient crew. However, it is not to force vessels to carry seaman. The essential purpose is to control the number of seamen to ensure that the seaman’s navigation experience is effective, thereby achieving maritime safety. No crew member on board will not lead to an unmanned vessel that does not meet this essential purpose. When an unmanned vessel can take equivalent actions through the autonomous navigation and collision avoidance system without any crew to reach or exceed the safety level of “human” navigating with “good seamanship”, it should be considered meeting the requirements of “good seamanship”. There is no apparent reason to believe that no seaman on board does not necessarily mean a violation of “good seamanship”.

The CMI IWG's questionnaire on unmanned vessels also has related questions about “good seamanship”. According to the recovered questionnaire, there are three main views. One is the view represented by Japan that unmanned vessels do not violate “good seamanship”. If SBO are trained and certified to operate the vessel remotely, or MASS uses intelligent operating procedures to steer the ship by itself, it is entirely in line with the substantive requirements of “good seamanship”; The United States and several countries said that before the occurrence of MASS-related cases, it was impossible to judge whether MASS violated “good seamanship”; Italy and other countries advocate that MASS at L3 and MASS at L4 should be treated differently, and only MASS at L3 can meet the requirements of “good seamanship”.

3.5.2 Early and substantial

When describing collision avoidance actions, COLREGs uses some words describing “good seamanship”, such as “positive”, “clear”, “ample time”, “in good time”, “early” and “substantial”. These words mostly appear in the relevant clauses about actions or operations, guiding the vessel when to take actions and how much needs to be done. Including but not limited to the following clauses:

Rule 16, “Action by give-way vessel”, of COLREGs stipulates “......, so far as possible, take **early and substantial** action to keep well clear.” (IMO, 1972)

Rule 8 “Action to avoid collision” Paragraph(a). “...... if the circumstances of the case admit, be **positive**, made in **ample time** and with due regard to the observance of good seamanship.” (IMO, 1972); Paragraph(c). “...... to avoid a close-quarters situation provided that it is made in good time, is **substantial** and does not result in another close-quarters situation.” (IMO. 1972); Paragraph(d). “......The effectiveness of the action shall be carefully checked until the other vessel is **finally past and clear**” (IMO. 1972).

It can be seen from these clauses that the opportune moment of the vessel’s action is required to be “early”, “ample time”, “in good time” in accordance with “good seamanship”. The level of action required to be “substantial” and “clear”. “ There is no suggestion in miles or minutes what constitutes early, neither how large course change or speed change constitutes substantial.” (Porathe, 2019) These action standards are not quantified and seem ambiguous. For unmanned ships, of course, it is a considerable challenge. It is one of the biggest obstacles to the application of COLREGs; and one of the essential difficulties in exploring algorithms.

For the opportune moment of action, these words ("positive", "ample time", "in good time", "early") are requirements for determination and subjective initiative. The collision avoidance actions should be carried out "positive and early". "Positive" refers to proactive and decisive actions. As a "person", marine navigators must exert their subjective enthusiasm at the level of psychological activities. SBO of MASS L3 can remotely determine collision avoidance measures. With the technology guaranteed, there is no significant obstacle to the "early" realization. For MASS at L4, there is no standard for whether the time to take action is in line with "good seamanship."

Secondly, in terms of the extent of action to be taken, "substantial" requires the action to be large enough to clear the other vessel. The actions can be quantified through the AI system. Hence, the difficulty of solving this issue through algorithms is relatively low compared to "early". But it should be noted that "substantial" is not the larger, the better. If the extent of action exceeds a certain threshold, the opposite effect may be achieved, upgrading the urgency level.

Thirdly, in order to ensure the effectiveness of collision avoidance actions, the level of action taken must be such that the two vessels can "finally past and clear" at a safe distance. At the same time, this is also a sign that the action has ceased or been completed. It also requires "human thought" to evaluate and judge. It should be continuously evaluated during the entire period of the action, not what can be achieved by calculation before taking action. For unmanned vessels, there are obstacles to implementation.

The “early” and “substantial” both require master and crew to use rich navigation experience, take all effective means to conduct a “proper lookout”, consider the environment, navigation conditions, and manoeuvrability to make the proper decisions. Start or end the actions at an appropriate moment. Take correct corresponding actions and ensure the actions reasonable during the whole process. It involves massive subjective cognition and judgment. Therefore, it is difficult to achieve by technology alone. Thus, COLREGs needs to make concessions.

Furthermore, this is also one of the difficulties that need to be overcome in researching the technology of unmanned vessels. “A possible strategy for programmers trying to catch “early and substantial” as well as “the ordinary practice of seamen” could be to study large amounts of AIS data for the specific area in questions and from that data deduce typical behaviour and numerical attributes of “early” and “substantial action. Using such AIS studies, the establishment of a zone outside which an action can be considered “early” could be attempted. But the context is important, not only the static geographical context but also the time dependent traffic density context” (Porathe, 2019).

3.5.3 Departure principle

According to COLREGs Rule 2 Responsibility (b). “In construing and complying with these Rules due regard shall be had to all dangers of navigation and collision and to any special circumstances, including the limitations of the vessels involved, which may make a **departure from** these Rules necessary to avoid immediate danger” (IMO, 1972). The “departure principle” in this clause is the best embodiment of “good seamanship”.

The “departure principle” does not violate “good seamanship”. It is more important to make “departure actions” in danger or special situations based on “good seamanship” than to comply with COLREGs rotely. The sailing conditions encountered by vessels are complex and diverse, and legal regulations are circumscribed and restricted. Therefore, the scope of “good seamanship” should be broader than the specific rules in COLREGs. Under the circumstances not stipulated in COLREGs, based on “good seamanship”, actions need to be taken to avoid collisions of vessels in accordance with the legislative purpose of COLREGs. Thus, Take actions following COLREGs under normal situations, and take actions departure from COLREGs in dangerous and special circumstances. They are both typical styles of “good seamanship”.

The “departure principle” makes “good seamanship” become the highest principle for collision avoidance. And the result of whether the vessel has collided becomes the highest standard for evaluating the effectiveness of COLREGs implementation. When the vessel is in danger, as long as no collisions occur, the avoidance actions can be considered to take with “good seamanship”, even if the vessel “violates” the specific rules in COLREGs. Because in an emergency, the vessel can take action “depart from” the rules. It means the navigator decisively took the “best” decision, regardless of whether the decision met the requirements of COLREGs.

On the contrary, even if the vessel was operated strictly in accordance with the requirements of COLREGs from beginning to end, but a collision occurred, it was considered that the vessel did not have “good seamanship”. Because in special circumstances, ships should adopt the “best” way of operation to avoid collisions, including “departure” operations. The vessel still adheres to the principle of non-emergency situations, which actually violates the principle of “good seamanship”. It is not the “best” decision; if it is the “best”, there is no collision.

“Departure principle” is highly dependent on sailing experience, so there are obstacles for unmanned ships to take “departure” operation. “Good seamanship” requires actions that depart from the rules when reasonable, but it is challenging to set the “departure principle” through the program for the unmanned vessel. The “departure principle” requires a departure behaviour base on crew members with rich practical experience and professional skills to conduct complex analysis and cognition. At present, the development of algorithms is mainly on the camera and sonar to recognize objects. Even the most elaborate preset program cannot cover all navigation situations. The program only can do the analysis work and can not make a “departure” decision at the moment when a dangerous situation occurs.

Hence, the fully autonomous unmanned vessels cannot achieve the high-level “human judgment” in the decision-making process, such as the “departure principle” in the current COLREGs, because this is a highly complex cognitive process. Even with the most advanced intelligent control algorithm known so far, it cannot meet the requirements of COLREGs Rule 2, Paragraph (b) to depart from the rules under dangerous or special circumstances. The COLREGs should make some necessary amendments at this point.

3.5.4 Redefine the good seamanship

Based on the previous analysis, the author believed that the “good seamanship” clause should be redefined by adding the “Equivalent Results Principle”. Simultaneously, the navigation and management of vessels should comply with the “ordinary practice of seaman” under due diligence or the “equivalent results practices” through an autonomous control system. It is deemed to have performed “good seamanship”, regardless of the type of the vessel.

The redefined “good seamanship” should include the manned vessel navigator and also the shore-based operator. They can take appropriate actions with due navigation experience based on encounter situation, weather condition, aids, etc. Besides, the unmanned vessel in the shore-based remote mode and the fully autonomous mode are functionally equivalent to the manned vessel with an experienced seaman. They are all in accordance with “good seamanship”.

It also includes the following supplementary explanations. It is clear that the implementers include the crew and the autonomous system of the unmanned vessel. The “crew” includes the crew on board and SBO. The implementer of “good seamanship” is no longer only the crew on board. SBO can realize “good seamanship” through marine equipment and real-time information transmission technology. The fully autonomous mode unmanned vessel

“Good seamanship” should be identified under the guidance of the “Equivalent Results Principle”, The SBO should meet the requirements of an experienced crew member for vessel manoeuvring. The fully autonomous unmanned vessel can be deemed to meet the requirements of “good seamanship”, when the autonomous control system achieves the equivalent effect, just like an experienced seaman navigates the vessel. This situation can be imagined that the vessel is under the command of a virtual seaman with experience.

In addition, it is necessary to demonstrate whether the unmanned vessel can make the same decision and assess its emergency handling capabilities as the human control. It is recommended to provide clear and unified quantitative supplements and explanations for “positive”, “early”, “good seamanship”, and other aspects. It can solve the issues of obstacles to the application of “responsibility and departure clauses” and other provisions to unmanned vessels.

3.5.5 If possible, quantify standards

Some scholars have proposed that it is necessary to clearly define subjective words such as “substantial” and “early”, if possible, quantify them so that unmanned vessels can perform in accordance with these standards. “The Nautical Institute tries to set some quantitative figures on when “early” could be when they suggest the closest distance another ship should be let: As a general guideline, attempt to achieve a CPA (closest point of approach), of 2 nautical miles in the open sea and 1 mile in restricted waters” (Lee & Parker, 2007).

3.6 “vessel in electronic sight of one another”

Rule 3 paragraph (k) of COLREGs stipulates, “Vessels shall be deemed to be in sight of one another only when one can be observed visually from the other.” (IMO, 1972) When the vessel is in this situation, it should take actions according to Section II (conduct of vessels in sight of one another) of COLREGs to ensure navigation safety and avoid collision risks.

3.6.1 “Unilaterally” or “mutually”

Regarding “be in sight of one another”, there is a dispute in the academic fields. It is focused on whether the vessel “see the other one unilaterally” or they “see each other mutually”. Scholars holding the view of “unilaterally” believe that “be in sight of one another” should pay attention to practicality and require only one vessel to see the other. It is equivalent to the two vessels that can see each other. The persons who hold the view of “mutually” believe that “be in sight of one another” should concentrate on the legality, requiring the two vessels to see each other visually.

Based on different understandings, it causes different obstacles to the application of the “be in sight of one another” clause for unmanned vessels. Under the “unilaterally” view, the unmanned vessels can adopt the navigation rules under Section II as long as it successfully recognizes the other ship. If it is under “mutually” view, the unmanned vessel should not only identify the other vessel but also confirm that the other one can also see it visually.

This paper believes that “be in sight of one another” should be understood as see the other one unilaterally. COLREGs is based on long-term navigational practical experience, so practicality is the core of COLREGs. This view is more conducive to safety. As long as you see the other vessel, you can clarify the situation and take action “early”. You don't have to wait for the other vessel to confirm the situation; thus, it can miss the best avoidance opportunity. Based on the actual experience, almost no vessel confirms whether the other party has seen the own party while sailing at sea. Because there is no significance, only wasting precious time. It upgrades the difficulty of judging the situation and even takes actions with the opposite effect. The understanding of the rules should be consistent with the purpose of formulating the rules. And the primary goal of COLREGs is just to ensure the safety of navigation. When any vessel can see the other vessel visually, it should take the corresponding actions to prevent the risk of collision from further aggravating as “early” as possible instead of waiting for the other party's confirmation.

3.6.2 “observed visually”

According to the clause, “be in sight of one another” only rely on observation based on the form of human vision. However, can an unmanned vessel see other vessels with human vision instead of navigation aids? It is the same as in Rule 5, “lookout clause”. After the discussion on “electronic lookout” in section 3.3 of this chapter, the essence of this issue is whether the unmanned vessel can use navigation and communication equipment to see other vessels “visually” without any crew on board.

Although MASS at L3 does not carry crew members, SBO can remotely control aids to obtain images transmitted from the camera to “visually” judge whether they have seen the other vessels. Whether it is in accordance with “be in sight of one another” at this time depends on the “image” transmitted by the camera can be recognized as “visual observation”. SBO can make human judgments based on the “images” that enter into his eyes. It is another type of “observed virtually” It is consistent with the condition that the OOW used telescopes to enhance human vision in traditional manned vessels. It does not change the essence of “visual” observation. In fact, a similar situation has occurred on board, e.g., some ships have been equipped with night vision cameras to assist in the lookout. OOW treats the images from the camera the same as the images they see with naked eyes. Therefore, MASS at L3 can achieve “visual observation” through navigation aids. But before that, it is necessary to solve the issues of camera accuracy and transmission. It can bring a hidden danger if the camera is not up to standard. For example, in extreme weather such as heavy rain, blizzard, strong wind, and waves, if the resolution of the camera is not enough or the lens is blocked by the water fog, it may cause some small boats to be unable to observe visually.

For MASS at L4, without any human involvement in the operation of the ship, and to be sure, it has no human “vision”. There are essential obstacles to the implementation of this clause. Assuming that excluding unmanned vessels from this clause, the unmanned vessels are considered to be in the situation of “not be in sight of one another” all the time. “It means that every unmanned vessel should be treated as a vessel in restricted visibility and follow the rules in section III. Section III only consists of rule 19, the conduct of vessels in restricted visibility. The 19th rule applies to vessels not in sight of one another in an area of restricted visibility." (Öhland & Stenman, 2017) Thus, it does not meet the purpose of COLREGs, especially in the mixed mode. It can cause the encounter situation to be unclear and uncoordinated. Both parties may be unable to understand the action of each other.

The reason why "be in sight of one another" is based on "observed visually" is because that vision is more credible than other methods. Human beings believe more in what they see, and their judgment can also be more precise. Moreover, they can take action more confidently based on what they have seen. According to the conditions, COLREGs has formulated particular action guidance, Section II, "conduct of vessels in sight of one another". When visibility is poor, there is no distinct encounter situation between two vessels, nor the "stand-on vessel" and the "give-way ship". Because they cannot see each other, the issues need to be handled more carefully. It is the same reason that "electronic lookout" is equivalent to "sight lookout". COLREGs should recognize the "equivalent results" brought by advanced technology.

MASS at L4 uses advanced sensors to obtain surrounding information. In fact, this way is more effective in discovering the target. These aids are indeed very credible. Even in the current era, this way of obtaining information has been widely used by seafarers in navigation practice. According to the sailing experience that the crew becomes more and more reliant on navigation aids. Obtaining information through observing only by human eyes has gradually evolved through the combination of navigation aids and vision. It should be affirmed that the equipment plays a vital role in "be in sight of one another", and usually, navigation aids can detect incoming vessels earlier than "visual".

One additional point is that the advent of unmanned vessels requires the use of navigation aids to achieve “be in sight of one another”, but it does not mean the negation of “observed visually”. In the era of mixed navigation mode in the future, unmanned vessels still need to use “observed visually” to better detect the incoming vessel at sea. Vision is still an irreplaceable way to coordinate unmanned and manned ships.

3.6.3 Legal status of “electronic vision”

Introduce the concept of “electronic vision” in COLREGs. It means that the vessel obtains surrounding information by detecting high-precision cameras, radar, AIS, and other navigation aids; and comprehensively processes the information to determine the situation of the incoming vessel. The effect is equivalent or better than human “vision”. Using “electronic vision” can be worn to take collision avoidance actions earlier. It is one of the key elements to promoting the application of the COLREGs to unmanned vessels.

Based on the inherent shortcomings of “be in sight of one another”, it is no longer in line with the development of shipping practice to only agree with the “visual” way. The concept of “electronic vision” should be added to COLREGs to make unmanned vessels meet the requirement of relevant clauses. It is recommended to consider the advancement of technologies such as perception and communication to expand the means of “be in sight of one another”. In addition to the traditional visual means, it also includes other means that is equivalent or more sufficient to vision. The means of expanding the composition includes AIS, radar, infrared and visible light camera systems, and advanced communication equipment, Internet of Things, and others. The introduction of the “electronic vision” does not mean that “observed visually” is replaced. “Observed visually” still has practical significance for traditional manned vessels and shore-based manoeuvring unmanned vessels. Both of them should be included in the revised COLREGs.

Rule 3 Paragraph (k) can be amended. The rules of action can be simplified to reduce uncertainty under the condition of being in sight of one another. Vessels shall be deemed to be in sight of one another when one vessel can be observed visually from the other vessel, or one can be detected by means equivalent to or even more sufficient than a vision from the other.

CHAPTER 4 CONCLUSIONS

The emergence and development of unmanned vessels bring opportunities and challenges to the shipping industry. The large-scale commercial introduction of unmanned vessels is inevitable. It will be developed step by step in accordance with the technical level established by IMO, from the manned remote-control mode to the unmanned shore-based control mode, and finally to the fully autonomous mode. But manned ships will not be wholly replaced. The mixed navigation mode of manned and unmanned ships co-existing will continue for an extended period.

Collision avoidance is a critical task for all vessels, including unmanned vessels. The existing COLREGs should be used as the guidelines for algorithm research. At the same time, with aims to provide solutions to promote the tolerance of the rules, COLREGs should also revise specific provisions to a certain extent according to the characteristics of unmanned vessels which carry no crew on board.

Due to no crew on board, there are obstacles to the application of unmanned vessels regarding the provisions of COLREGs that involve “human sense” and “empirical judgments”, such as “good seamanship” clause, “responsibility” clause, “lookout clause”, “be in sight of one another” clause and “, “vessel not under command” clauses. It is therefore paramount that possible application barriers in the regulatory system should be interpreted and amended before the actual introduction of unmanned vessel (Zhou, 2019).

This paper discusses the reasons for the obstacles to the application of these clauses for different levels of unmanned vessels (MASS at L3 and L4). And try to give relevant countermeasures or suggestions against these obstacles.

First, it is clear that unmanned vessels must belong to the definition of “vessel”” in COLREGs. The unmanned vessel is an extension of the definition. And it is not a“vessel not under command” nor a “vessel restricted in her ability to manoeuvre”. It does not obtain the priority of navigation. Unmanned vessels should have the same legal status as manned vessels. It is recommended to redefine the “vessel” in COLREGs and to clarify the state of “not under command” of unmanned vessels.

Lookout is the first-class clause in COLREGs, and any vessel should maintain a proper lookout at all times, but the means of looking cannot be limited to human “sight” and “hearing”. “Electronic lookout” can reach the same level of effect as “proper lookout”, or even better. COLREGs should accept the “electronic lookout” of unmanned vessels as a particular means base on the “equivalent results principle “.

“Good seamanship” is the core clause of COLREGs. It is the essence of the Rule and the highest-level principle of the actions. Through the discussion of the specific issues on “good seamanship”, such as “early”, “substantial”, and “departure principle”, it is clear that “good seamanship” is the biggest obstacle to the application of COLREGs for unmanned vessels. It is necessary to develop more comprehensive and advanced algorithms to make the collision avoidance actions of unmanned vessels equivalent to the actions taken by seaman based on “good seamanship”. Clear and reasonable action decisions would be made by the AI system of the unmanned vessel with the continuous development of science and technology. Meantime, COLREGs should also make appropriate concessions and redefine the related clauses based on the “equivalent results principle”. If possible, quantify the particular standards, and it can be more conducive to the implementation of unmanned vessels.

At present, the “be in sight of one another” in the COLREGs only relies on the

“ observation visually”. With the development of navigation technology, it has gradually shown its disadvantage. MASS at L3 can use “visual” equipment to achieve “be in sight of one another” to a certain extent. But MASS at L4 can do nothing to meet the “visual” requirement. Hence, it is recommended to introduce the concept of “electronic vision” to achieve the equivalence of “be in visual sight of one another” and “be in electronic sight of one another”.

In short, the relationship between unmanned vessels and COLREGs is complex, and they interact with each other. Base on fully considering relevant factors, with navigation safety as the ultimate goal, it is possible to make appropriate amendments to COLREGs.

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