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Influences on navigational safety and environment of the application of new technologies onboard fishing vessels in China : AIS fishing net locator and smart terminal of Class B AIS

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INFLUENCES ON NAVIGATIONAL SAFETY AND ENVIRONMENT OF THE APPLICATION OF NEW TECHNOLOGIES ONBOARD FISHING VESSELS IN CHINA

AIS Fishing Net Locator and Smart Terminal of Class B AIS

By

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The People's Republic of China

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DECLARATION

I certify that all the materials in this dissertation that are not my own work have 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: **Influences on Navigational Safety and Environment of the Application of New Technologies onboard Fishing Vessels in China ---- AIS Fishing Net Locator and Smart Terminal of Class B AIS**

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Automatic Identification System (AIS) Fishing Net Locators (FNL) and the Smart Terminal of Class B AIS are two devices used widely onboard Chinese fishing vessels in recent years. This two equipment was firstly invented respectively to protect the property, i.e. the fishing net, of the fishers and to help avoid collision between the fishing vessel and the merchant ship. However, for merchant ships, the widespread application of these two devices has led to some unexpected challenges.

Chapter 1 contains literature review of the background and development of AIS FNLs and the Smart Terminal of Class B AIS. Chapter 2 is the legal regime in the International Convention for Safety of Life at Sea (SOLAS) and the International Telecommunication Union (ITU) Radio Regulations for AIS and VHF technology.

Chapter 3 discusses the work principles and application of AIS FNLs and after analysis, proposes three conclusions including, first, the misuse of symbols by AIS FNLs brings confusions to navigators when they are trying to identify a ship on the radar screen; second, the naming convention of AIS FNLs is now still inconsistent; third, the transmission from large numbers of AIS FNLs may clog the AIS channel and overload AIS receivers on board a merchant ship. Accordingly, we put up with three suggestions, including to assign reserved bits in AIS to FNLs, unify their naming convention and design AIS FNLs based on primary-secondary mode.

Chapter 4 introduces the development of the Smart Terminal of Class B AIS. One advantage of the use of this equipment is that fishing vessels may improve their safety level because the Smart Terminal will give early warnings automatically to merchant ships in the vicinity for collision prevention. Moreover, this device can broadcast voice messages both in English and in Chinese so that Chinese fishers who are not capable of speaking English can overcome the language barrier in a certain extent. However, in practice, the broadcast of the Smart Terminal is too frequent in dense fishing areas, occupying too many public resources on Very High Frequency (VHF) Channel 16. The prolonged voice message of high-frequency and low-quality can result in fatigue of officers on watch (OOW). Suggestions include the optimization of the smart terminal of class B AIS to balance the needs of all parties, inter-ministerial cooperation and the establishment of industry standards.

Our research in this paper, we believe, is helpful for the unified and standardized use of AIS FNLs and the Smart Terminal of Class B AIS. Only by reducing or even eliminating the interference to merchant ships, can these two devices give full play to their advantages and contribute to safer shipping.

KEY WORDS: Fishing net locator, The smart terminal of class B AIS, Navigational safety, Marine environment protection, Collision prevention between fishing vessels and merchant ships

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LIST OF ABBREVIATIONS

AIS	Automatic Identification System
AMRD	Autonomous Maritime Radio Device
AtoN	Aid-to-Navigation
CH	Channel
CPA	Closest Point of Approach
CSTDMA	Carrier-Sense Time Division Multiple Access
DSC	Digital Selective Call
ECDIS	Electronic Chart Display and Information System
EEZ	Exclusive Economic Zone
FNL	Fishing Net Locator
GISIS	Global Integrated Shipping Information System
GMDSS	Global Maritime Distress and Safety System
GT	Gross Tonnage
IDVD	Inverse Dynamics in the Virtual Domain
IMO	International Maritime Organization
IR	Infrared
ISWG	Intersessional Working Group
ITU	International Telecommunication Union
LIDAR	Light Detection and Ranging
MASS	Maritime Autonomous Surface Ship
MMSI	Maritime Mobile Service Identify

MOA	Ministry of Agriculture and Rural Affairs of the People's Republic of China
MOT	Ministry of Transport of the People's Republic of China
MSA	Maritime Safety Administration
MSC	Maritime Safety Committee
NAV	Sub-committee on Safety of Navigation
OOW	Officer on Watch
OR	Aeronautical Mobile
OSC	On-Scene Search and Rescue Commander
RSE	Regulatory Scoping Exercise
SAR	Search and Rescue
SART	Search and Rescue Radar Transponder
SG	Study Group
SOLAS	International Convention for Safety of Life at Sea
SOTDMA	Self-Organizing Time Division Multiple Access
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
TCPA	Time to Closest Point of Approach
USV	Unmanned Surface Vehicles
VHF	Very High Frequency
VLCC	Very Large Crude Carriers
VTS	Vessel Traffic Service
WP	Working Party
WRC	World Radiocommunication Conference

Chapter 1 INTRODUCTION

1.1 Background

China is one of the world's leading countries in fishing output. In 2018, the number of registered fishing vessels in China was more than 800,000. AIS Fishing Net Locators (hereinafter referred to as AIS FNL) and Smart Terminal of Class B AIS are two applications used widely onboard of Chinese fishing vessels which have attracted the attention from the shipping industry at home and abroad in recent years. AIS FNL was firstly invented to protect the property, e.g., the fishing nets, of the fishers whereas the Smart Terminal to help avoid collision between fishing vessels and merchant ships. However, in practice, the widespread application of these two devices has led to some unexpected challenges for merchant ships. The author is an officer working onboard "HAIXUN 01", the largest patrol ship of China Maritime Safety Administration (MSA). During the past three years, when conducting patrol mission in coastal waters off Shanghai, Jiangsu, Zhejiang and Fujian Province, the author and her colleagues noticed an extensive use of AIS FNLs at sea and heard frequently on VHF Channel 16 the automatic calling from fishing vessels with their Smart Terminal of Class B AIS especially in Zhoushan Fishing Ground and coastal waters off Fujian Province.

AIS FNL

Most fishing vessels nowadays install their fishing nets a locating device using AIS technology. There are two main purposes to fit such an AIS FNL: one is to track fishing nets for recovery, and the other one is to remind OOWs onboard merchant ships of the location of fishing nets in case of entanglement of fishing nets with propellers.

However, the waters where fishing vessels and fishing nets are of high density, since the FNL uses AIS technology, the information transmitted by such a large number of fishing nets will clog AIS channel and occupy the merchant ships' AIS receiver. Meanwhile, AIS signals of FNLs will be displayed on the radar screen of merchant ships, showing the same symbol, a green triangle, as ships. This will disturb OOWs to identify other merchant ships or fishing vessels on the radar screen. And when the volume of AIS receiver is fully occupied by FNLs, AIS signals from ships will be lost which will have a negative impact on collision avoidance between ships.

Moreover, on the one hand, noticing the ongoing discussion of International Maritime Organization (IMO) about follow-up work emanating from *Action Plan* to address marine plastic litter from ships, AIS FNL can be a plastic litter generated from fishing vessels if it is abandoned at sea. On the other hand, it can also facilitate the recycling of fishing nets by reducing plastic garbage such as lost fishing nets.

Smart Terminal of Class B AIS.

"HAIXUN 01" noticed as well the use of Smart Terminal of Class B AIS on board Chinese fishing vessels in coastal waters of China. Some fishing vessels have this terminal to broadcast automatically on VHF channel 16 to remind vessels approaching. The broadcast contains information such as ship's name, call sign, MMSI, relative bearing and distance for calling. The voice of machine can be male or female in Chinese or English. Every broadcast takes about 15 to 20 seconds and the frequency of broadcast can be high in waters with many fishing vessels. This is a way for fishing vessels to avoid collision with merchant ships by automatically sending alert on VHF CH16. It is also helpful to resolve the language barriers between fishing vessels and foreign ships.

With a large amount of fishing vessels in waters, the auto broadcast from fishing vessels will significantly occupy VHF CH16. During a four-hour shift, this kind of alert can be broadcasted for about two and a half hours in total. Channel 16 VHF is a radio frequency designated for distress, urgency and safety priority calls. OOWs have to standby on this channel and the frequency may also carry routine calls used to establish communication. The broadcasts from the Smart Terminal of Class B AIS occupy too many resources on VHF CH16 and OOWs can get fatigued more easily after listening to long-lasting broadcasts not related to their own ships.

1.2 Objectives of research

This dissertation is intended to conduct research on the background, working principles and current situation of application of these two devices. Meanwhile, the author will try to find some suggestions on the technological improvement of these two devices and how the competent authorities can manage and supervise the use of such devices.

1.3 Review of previous researches

1.3.1General application of AIS FNLs

AIS is a technology based on transponders installed on ships and located in other places that transmit and receive information on dedicated VHF frequencies. The development of AIS enables identification of ships fitted with such equipment, facilitates vessel traffic service (VTS) to automatically identify ships within surveillance area and provides useful tracking data for security services and commercial business (Bole et al, 2014). IMO attaches great importance to the role of this technology in navigational safety. On 29 November 1995, the Meeting of States Parties to the 1974 SOLAS Convention passed Resolution 9 about automatic ship identification transponder / transceiver system in which the device was affirmed to greatly improve the safety of navigation. In 1996, the Forty-second Meeting of Sub-committee on Safety of Navigation (NAV sub-committee) of IMO discussed the draft performance standard for the shipborne automatic identification system device using VHF DSC technology and referred it as AIS (Zhang, 2003). Two years later, on 12 May 1998, the Maritime Safety Committee (MSC) of IMO adopted Recommendation on Performance Standards for Universal Automatic Identification System (AIS) in Resolution MSC.74(69) and listed three functional requirements for AIS including "a ship-to-ship mode for collision avoidance", "a means for littoral States to obtain information about a ship and its cargo" and "a VTS tool, e.g., ship-to-shore (traffic management)" (IMO, 1998). In 1999, the Forty-fifth Session of NAV Sub-committee agreed to include carriage requirements for AIS in Regulation 19 in Chapter V of the revised SOLAS (IMO,1999) and the revised Chapter V was approved by MSC 72 and confirmed by MSC 73 in 2000(IMO, 2000). AIS then became a requirement for ships covered by SOLAS Convention in 2004 and now defined as Class A vessels. This date has been brought forward from 2007 due to international pressure (Bole et al, 2014).

In addition to ships, it is worth noting other types of AIS 'user', for instance, AIS SARTs (search and rescue transponders), aids to navigation (e.g., buoys), SAR (search and rescue) aircraft and AIS base stations can send transmissions as well. IMO adopted Performance Standards for Survival Craft AIS Search and Rescue Transmitters (AIS-SART) for Use in Search and Rescue Operations in 2007 in Resolution MSC.246(83). And the Ninety-third Session of MSC of IMO approved MSC.1/Circ.1473 on Policy on the use of AIS aids to navigation and SN.1/Circ.243/Rev.1 on Amendment to guidelines for the presentation of navigation-related symbols, terms and abbreviations in 2014.

Moreover, Bole et al (2014) stated that in 2007, IMO introduced specified minimum standards for non-SOLAS (now defined as Class B) vessels which are generally small vessels but can also be larger vessels that only operate in national waters of one state. In case of potential AIS congestion and interference caused by the considerable number of potential Class B users, Class B equipment was designed to prevent such problems in several ways. First, the amount of data transmitted per vessel is limited and the intervals between message transmissions increased. Second, Class B transmitters only operate in low power (2 W) (which limits their range to less than 10 miles).Third, they do not use SOTDMA but CSTDMA carrier with time-sensitive division multiple access which means the Class B transmitters are designed to work within AIS time slots but defer to Class A and other AIS transmissions.

1.3.2 The development of AIS FNLs

The Chinese maritime science and technology community has always paid close attention to the development of AIS. In 2000, a group of experts and scholars were specially organized to discuss AIS issues and a journal called International Navigational Information published a special column of AIS technology. In August 2000, Swedish manufacturers were invited to demonstrate the function of AIS equipment at Shanghai Maritime Safety Administration (Shanghai MSA). In November 2000, Lockheed Martin Corporation came to Shanghai to introduce AIS network project undertaken by the company in both the United States and Turkey. In April 2001, a symposium on application of AIS technology onboard ships engaged in coastal operations was held in Dalian, China. In order to promote the implementation of IMO's new regulations on AIS contained in SOLAS Convention, namely Chapter V Regulation 19 Carriage requirements for shipborne navigational systems and equipment, Dalian NavTech Information Technology Co., Ltd. (formerly known as Dalian Maritime University Navigation and Technology Co., Ltd.) developed a new generation of "Shipborne AIS Navigation System" with independent intellectual property rights by integrating a self-developed ECS-ECDIS as its core, a C-map digital chart as its basis (which supports electronic chart display conforming to international standard S-57) and AIS equipment produced by the Swedish company Saab (Gao, 2006).

Besides the exploration of the use of AIS equipment onboard merchant ships, China also tries to give full play to the role of AIS for the safety of fishing vessels. At present, a great majority of AIS equipment used on fishing vessels is Class B AIS. Such device is less expensive compared with Class A AIS but can basically meet the needs of fishery management (Hu, 2013). Early when the standard for Class B AIS ship station was released, AIS manufacturers at home and abroad have already started to actively participate in researching and developing low-cost AIS products (Class B) suitable for small vessels, thereby making it possible for non-SOLAS fishing vessels and small vessels to install AIS equipment. Several fisheries bureaus of the Ministry of Agriculture of China have also proposed plans and pilot project for installing AIS on fishing vessels. Such trials on fishing vessels are also at the forefront among international peers (Han, 2008). With the aim to prevent the occurrence of collision accidents, especially between merchant ships and fishing vessels, fishery departments require fishing vessels to be equipped with AIS equipment. Taking Zhoushan, a sole city of archipelago in China which located in Zhejiang Province, as an example, through government financial support and other means, in 2013, about 6,300 fishing boats was installed with AIS equipment. Zhoushan Ocean and Fisheries Bureau fully draws on the maritime department ’s experience in applying AIS on merchant ships and is committed to the research and development of collision avoidance systems for fishing vessels. Encouraged by government, on the basis of the original technical specifications of Class B AIS ship station, manufacturers further improved Class B AIS equipment and adapted it to practical needs of fishing vessels by adding a DSC alarm function in order to send distress or emergency information on VHF channels and establish a monitoring platform, which can send alarms to fishers on the bridge when ships (excluding fishing vessels) approach into a pre-set 3 nautical miles (nm) alarm ring (Jiang, 2008). Wang et al (2019) was of the view that the use of AIS has greatly improved the safety of fisheries. According to statistics, from 2000 to 2011, there were 5,875 marine accidents happened in China, with 5,588 lives lost or missing. The direct economic loss was nearly 1 billion yuan. But since China MSA issued regulations requiring the installment of AIS equipment onboard, Chinese power-driven ships engaged in coastal and inland work (except for fishing vessels, official ships, sports boats and military ships) in 2010, taking Zhejiang Province as an example, within one year, the collision between fishing vessels and merchant ships dropped by 39.6% year-on-year, achieving significant social and economic benefits.

In the meantime, from 2013, manufacturers in China have begun to try to apply AIS technology to fishing nets with the aim of facilitating fishing nets retrieval and reducing fishing nets loss caused by merchant ships' propeller twisting. Manufactures then invented AIS fishing net locators (AIS FNL) using either Class B AIS technology or AIS-SART technology. These two types of AIS FNL, according to one of the main manufacturers whose company located in Fujian Province, have different technical specifications. AIS FNL using Class B technology follows the rules to listen, at the start of the time slot, to see if they can detect the transmission of other station in that slot, while those designed with AIS-SART technology transmitting information 6 times per minute without detecting. The former one is of relatively higher expense because it has to be equipped with a receiver. And AIS FNL using AIS-SART technology, as a result, "wins out" in the market and is now being widely used at sea due to its comparatively low cost.

Moreover, fishing net locators based on Beidou technology were designed by Liu, et al (2017). They stated that in the process of fishing, fishers lost easily those fishing nets drifting with current, wind and waves which can therefore hinder navigation. The traditional tracking method for fishing nets is visual observation, but its drawbacks include high labor intensity and poor tracking reliability. Aiming at fishing nets tracking and locating, a fishing net locater based on Beidou navigation system has been designed. The locater could broadcast their location information by Beidou satellite positioning and VHF and could connect with the ship borne AIS system to realize fishing nets tracking and avoid risks of merchant ships, with high accuracy, low power consumption, and wide coverage. Meanwhile, fishing net locaters can be used in remote and real-time monitoring and management platform for fishery production. The application can enhance the practicability and expansibility of fishing net locaters and finally improve fishery production and reinforce the ability of rescuing of fishing boats.

Meanwhile, AIS FNL has been discussed in International Telecommunication Union (ITU) as an autonomous maritime radio device (AMRD). In 2015, the ITU Radiocommunication Sector (ITU-R) determined the studies programme in the Fifteenth Session of World Radiocommunication Conference (WRC-15), for the next four years from 2015 to 2019. Working Party 5B (WP 5B) under Study Group 5 (SG 5) was responsible for conducting the study on maritime mobile service. China's proposal to carry out research on AMRD was adopted, officially established and listed as item 1.9.1. The content of this item is as follows: regulatory actions within the frequency band 156-162.05 MHz for autonomous maritime radio devices to protect the Global Maritime Distress and Safety System (GMDSS) and automatic identifications system (AIS), in accordance with Resolution 362 (WRC-15) (Liu, 2018). ITU defines AMRD as a mobile station operating at sea and transmitting independently of a ship station or a coast station. There are two groups of AMRD identified: Group A AMRD which enhance the safety of navigation and Group B AMRD that do not enhance the safety of navigation. It is worth noting that the term "enhance safety of navigation" is derived from the International Convention for the Safety of Life at Sea (SOLAS)as amended. In SOLAS, Chapter V is titled as "Safety of Navigation" and contains the relevant IMO regulations. Consequently, the criterion for distinguishing Group A AMRD from Group B AMRD is their influence on the safety of navigation. However, although the term "safety of navigation" is used in SOLAS and other IMO documents, there is no existing definition. Since the regulations listed in SOLAS Chapter V are relevant to achieving safety of navigation, consequently, in distinguishing the two groups of AMRD the question has to be answered: is safety of navigation enhanced or rather degraded (ITU, 2017)? Lei & Chang (2019) was of the view that AIS FNLs, one of the most widely used AMRD in China, are helpful for ships to avoid fishing nets, especially those with relatively standard name such as "NET MARK-XXX". The ships underway can recognize the location of a fishing net as early as possible, and take actions to pass the fishing nets clear, avoiding strangling fishing nets or colliding with the fishing gear. But they also agreed that in the meanwhile, it is undeniable that the wide use of a large number of AIS FNLs without well-established management systems and equipment standards has inevitably posed a great negative impact on the safety of navigation. Firstly, the disorderly displayed AIS symbol interferes VTS officers with target identification and traffic situation judgment, affecting ship traffic organization and key ship monitoring conducted by VTS. Secondly, unrestricted and wide use of AIS FNLs is most likely to lead to time slot collision and AIS congestion. Thirdly, during maritime SAR, dense AIS FNLs symbols displayed on the radar or ECDIS screen make it difficult for SAR units to identify the target and judge the situation, select the optimal search and rescue routes as well as to locate the person or ships in distress with AIS-SART. Liu (2018) discussed the influences of AIS FNLs as well and proposed directions of future researches and discussions in ITU to determine the frequency band, numbering scheme and operational specifications for AMRD.

1.3.3 Channel disturbance caused by AIS FNLs

The wide use of AIS FNLs mainly in China has caused some problems. On the one hand, displaying the same green triangle symbol as a ship, a large amount of AIS FNLs signals showed on the radar screen may confuse a deck officer onboard merchant ships when he or she is trying to pick out a real ship and determine whether there exists a risk of collision between the two ships. On the other hand, the overwhelming number of AIS FNLs in busy fishing areas raised a reasonable concern about AIS congestion and interference. There are warnings and complaints coming from mariners. Captain Mike Jessner, a captain for American President Lines, "is working to shed light on this issue and to solicit international support in order to change the status quo and outlaw the use of vessels units on fishing nets" (2018). The Federal Communications Commission of the United States launched Enforcement Advisory No. 2018-04 prohibiting marketing, sale, or use of fishing net buoys that use radio frequencies reserved for marine navigation safety communication by stating that AIS radio frequencies are authorized exclusively for marine navigation safety communications and the use of noncompliant AIS devices is illegal and has the potential to disrupt important maritime communications, increasing the risk of accidents by creating confusion about whether an AIS signal represents a vessel that must be avoided. Violators of the Commission's marketing and operating rules may be subject to the penalties authorized by the Communications Act, including, but not limited to, substantial monetary fines (up to $19,639 per day for marketing violations and up to $147,290 for an ongoing violation) (2018).

1.3.4 Channel disturbance caused by the smart terminal of Class B AIS

To protect the life and property of fishers at sea and to reduce the collision between fishing vessels and merchant ships, a research group from Zhoushan Municipal Oceanic and Fishery Bureau, collaborating with Tianjin 712 Communication and Broadcasting Co., Ltd., developed a collision avoidance system (AIS-B system), which can display an alarm ring on the screen of ECDIS and provides alarm alert to fishers with voice notification when a merchant ship enters the alarm ring set (Gong & Tang, 2015). This system is called Smart Terminal of Class B AIS. With an aim to enhance the safety of fishing vessels by giving early alarm to fishers on board one's own ship and navigators from merchant ships, the wide application of the system's voice message broadcast has caused problems such as occupying too much public resources on VHF Channel 16 (Yang et al., 2020) .

1.4 Methodology

The author widely reviewed related literature ranging from international conventions, IMO documents, ITU recommendations to articles from periodicals. In addition, related news and information was obtained from government and other types of websites. The author, together with her colleagues, also visited major manufactures in Jiangsu, Zhejiang and Fujian Provinces. These areas witnessed the large-scale application of AIS FNLs and Smart Terminal of Class B AIS in their coastal waters. Opinions were exchanged among the maritime authority, the fishery department and major manufactures. Possible solutions were discussed during visits and advice was taken from field-study trips.

1.5 Structure of dissertation

This dissertation consists of five chapters. Chapter two explores into legal regime of AIS and VHF based mainly on the SOLAS Convention and Radio Regulations. Chapter three provides detail information about technical principles and application at sea of AIS FNLs. Challenges posed and corresponding suggestions are also given. Chapter four shares a similar structure with Chapter three. An introduction, advantages and drawbacks of application as well as recommendations to improve Smart Terminal of Class B AIS are presented in this chapter. Last but not the least, the final chapter discourses overall summaries and conclusions.

Chapter 2 LEGAL REGIME OF AIS AND VHF

2.1 Legal regime of maritime mobile service

According to the definition of the Radio Regulations (2016), maritime mobile service is a radiocommunication service which involves the transmission, emission and/or reception of radio waves between coast stations and ship stations, or among ship stations or associated on-board communication stations; survival craft stations and emergency position-indicating radiobeacon stations may also participate in this service.

2.2 Legal regime of AIS

2.2.1 SOLAS Convention

Currently, according to Regulation 19 of Chapter V of the SOLAS Convention, all ships of 300 gross tonnage (GT) and upwards engaged on international voyages and cargo ships of 500 GT and upwards not engaged on international voyages and passenger ships irrespective of size shall be fitted with AIS. Such equipment shall conform to performance standard not inferior to those established in Resolution

74(69), annex 3 and MSC.1/Circ.1252, i.e. Guidelines on Annual Testing of the Automatic Identification System (AIS) (IMO, 2007). What's more, AIS shall be operated taking into account the revised guidelines for the onboard operational use of Shipborne Automatic Identification Systems (AIS) (A.1106 (29)) (IMO, 2015) adopted by the Organization.

2.2.2 Radio Regulations

Frequency bands 161.9625-161.9875 MHz and 162.0125-162.0375 MHz are assigned, in Article 5.228C, to be used by AIS only. The aeronautical mobile (OR) service can use these frequency bands for SAR aircraft operations.

Appendix 15 of the ITU Radio Regulations stipulates that AIS frequencies, namely 161.975 MHz and 162.025 MHz, shall be used by AIS operated in accordance with the latest version of Recommendation ITU-R M.1371. Its latest version ITU-R M.1371-5 (2012) clarifies that AIS use for other categories of maritime safety related communications, aside from ship to ship use and VTS applications, is allowed, if the primary functions are not impaired. And this system is capable of expansion to accommodate future expansion in the number of users and diversification of applications, including vessels which are not subject to IMO AIS carriage requirements, aids to navigation and search and rescue.

Appendix 18 states that AMRD Group A may use AIS 1 and AIS 2, together with channel 70, in accordance with Recommendation ITU-R M.2135 while 160.9 MHz (channel 2006) is designated to AMRD Group B. AMRD Group B can transmit with a power less than 100 mW and its antenna height is limited to 1m above the surface of the sea. Channel 2006 may also be used for experimental use for future applications or systems (e.g., new AIS applications, man overboard systems, etc.). If authorized by administrations for experimental use, the operation shall not cause harmful interference to, or claim protection from, stations operating in the fixed and mobile services, including the use of autonomous maritime radio devices Group B.

2.3 Legal regime of VHF

VHF, according to Radio Regulations developed by ITU, is a frequency band ranging from 30 to 300 MHz. Chapter IV of the SOLAS Convention, Resolution A.954(23) (Proper use of VHF channels at sea) as well as article 5 and 30 of the Radio Regulations contain regulations related to VHF channel discussed in this essay.

2.3.1 SOLAS Convention

Chapter IV (Radiocommunications) of the SOLAS Convention

Part A: Requirements on continuous DSC watch on VHF channel 70

Regulation 7 (Radio equipment) stipulates that every vessel shall be provided with a VHF radio installation capable of transmitting and receiving: DSC on the frequency 156.525 MHz (channel 70) and radiotelephony on the frequencies 156.300 MHz (channel 6), 156.650 MHz (channel 13) and 156.800 MHz (channel 16). Each ship shall also be equipped with a radio installation capable of maintaining a continuous DSC watch on VHF channel 70 which may be separate from, or combined with, that required by subparagraph 7.1.1.1. Ships constructed before 1 February 1997, which are engaged exclusively on voyages within sea area A2, may be exempted by the administration from the requirements of Regulations 7.1.1.1 and 7.1.2, if such ships maintain, when practicable, a continuous listening watch on VHF channel 16.

According to Regulation 12.1 (Watches), every ship, while at sea, shall maintain a continuous watch: on VHF DSC channel 70, if the ship is fitted with a VHF radio installation.

Part B: A continuous listening watch on VHF channel 16

Meanwhile, Regulation 12.3 states that until 1 February 1999 or until such other date as may be determined by the Maritime Safety Committee, every ship while at sea shall maintain, when practicable, a continuous listening watch on VHF channel 16. The note of Regulation 12.3 refers to Resolution MSC.131(75) in which all GMDSS ships, while at sea, are required to continue to maintain, when practicable, continuous listening watch on VHF channel 16. The main reason for this requirement is that there are many non-SOLAS ships not to be fitted with neither VHF DSC facilities nor GMDSS equipment. These ships still use VHF channel 16 for distress and safety calls. In the meantime, there are parts of the world not being covered by VHF coast stations. In these places, distress alerts transmitted by ships in distress can only be received by ships in the vicinity. Ships need an open "short distance frequency" in order to reach each other for immediate voice inter-ship calling for distress, urgency and safety communications until both SOLAS and non-SOLAS ships have the common capability to use DSC on VHF channel 70. And GMDSS-fitted ships are recognized being able to simultaneously maintain continuous listening watch on VHF channel 16 and for DSC on VHF channel 70. As a result, keeping a continuous listening watch on VHF channel 16 is still a mandatory requirement for OOWs onboard all GMDSS ships.

And among performance standards of Regulation 14.1, Resolution A.803(19), as amended by Resolution MSC.68(68), annex 1, was developed for shipborne VHF radio installations capable of voice communication and digital selective calling. The equipment is required to transmit three categories of calls, including distress, urgency and safety, ship operational requirements and public correspondence, via both voice and DSC. It should also provide for these three categories of communications using voice.

Proper use of VHF channels at sea (Resolution A.954(23))

This resolution was developed to ensure that all persons on board can use VHF channels at sea properly. The establishment of such an instrument is of obvious necessity. Proper use of VHF radiocommunication channels can contribute to safety of life at sea and efficiency of shipping, while misuse of those channels may result in severe interference in important communications and might pose threats to safety at sea.

But this document was developed on the basic consumption that all communications on VHF are conducted by people on board. Therefore, it aims to control the use of VHF channels by offering guidelines to persons on board. It recalled that the Radio Regulations required an operator holding a certificate issued or recognized by the Government to control the service of every ship radio-telephone station. It also recalled that the STCW Convention had regulations on the certification of masters, chief mates and officers in charge of a navigational watch and these persons were required to have knowledge about the procedures used in radiotelephone communications and the ability to use radiotelephones, in particular with respect to distress, urgency, safety and navigational messages. It invited member States to ensure that all persons on board controlling the operation of VHF equipment have the knowledge mentioned above. And the guidelines in the annex contains VHF communication technique and procedures needed to be followed by navigators. For example, operators should prepare well before transmitting by thinking about the information to be exchanged and, if necessary, write down some notes to avoid unnecessary interruptions and ensure that no valuable time is wasted on a busy channel. Moreover, navigators should listen before starting to talk on VHF channels to avoid unnecessary and irritating interference.

It is worth noting that subparagraph 1 in paragraph 1.3 (Discipline) states that calling on channel 16 for purposes other than distress, urgency and very brief safety communications should be avoided when another channel is available. And paragraph 1.10.1 mentions that in accordance with the Radio Regulations, channel 16 may only be used for distress, urgency and very brief safety communications and for calling to establish other communications which should then be conducted on a suitable working channel.

2.3.2 Radio Regulations

The author extracted the following regulations related to VHF channel 16 (156.8 MHz) and VHF channel 70 (156.525 MHz) from the ITU Radio Regulations and organized them.

For both VHF channel 16 and 70

These two frequencies are listed in Appendix 15 of Radio Regulations and used for the transmission of distress and safety information under the GMDSS. Any emission causing harmful interference to these channels is prohibited. Before transmitting for other than distress purposes on VHF channel 16 and 70, a station shall, where practicable, listen on the frequency concerned to make sure that no distress transmission is being sent.

VHF channel 16

The frequency 156.8 MHz is the international distress, safety and calling frequency for the maritime mobile VHF radiotelephone service (ITU, 2020). In addition, this frequency may be used by aircraft stations for safety purposes only. According to Article 31 of the ITU Radio Regulations, ship stations should maintain a watch on VHF channel 16.

VHF channel 70

The frequency 156.525 MHz is the international distress, safety and calling frequency for the maritime mobile VHF radiotelephone service using digital selective calling (DSC). This channel is to be used exclusively for digital selective calling for distress, safety and calling, and ship stations shall maintain an automatic watch on this frequency.

Chapter 3 INTRODUCTION OF AIS FNL AND CORRESPONDING SUGGESTIONS

3.1 Introduction of FNL

AIS FNL is also known as AIS indicator, fishing net locator and so on. It is fitted usually on marine drift nets and gill nets. Each fishing vessel operating with these two types of nets generally carries 5 to 8 large scale fishing nets of which is equipped with dozens of AIS FNL. Based on the statistics above, the quantity of AIS FNL used at sea can reach millions.

At present, there are two types AIS FNL available in the market. The first one is a class B AIS. It has a CSMA and transmits signals only when AIS channel is idle. This type of AIS FNL does not interrupt the transmission of AIS signals from other devices. But it costs more because a receiver is required to be integrated in the device.

The second type of AIS FNL uses AIS transponder technology. It forcibly transmits signals at fixed time intervals on the channel without listening. Figure 1 shows AIS FNL using AIS transponder technology. This type of FNL has dual-mode positioning system with both Beidou and GPS, and it periodically transmits its static and dynamic information to the AIS nearby. Its working distance ranges from 8 to 15 nautical miles. It can be used for about 15 days after being fully charged. The average service life of this device is one year to one and a half years. The power of the equipment is generally 4W-4.5W with a maximum of 10W. In general, the transmitting distance is in proportion to the transmitting power. This type of AIS FNL occupies AIS channels more, but its circuit is simple, the power consumption is low, and the cost is low.

After consultation with manufacturers, the latter product is currently dominating the market since there is an easy access to the core components of the AIS FNL in the market and the threshold for research and development and manufacturing of AIS FNLs is relatively low. The selling price of an AIS FNL using AIS transponder technology is usually less than 400 yuan, which is much cheaper than a fishing net. After the installation of AIS FNLs on fishing nets, it is easier for merchant ships to detect fishing nets displayed on radar screen, which effectively reduces the probability of ships navigating into the fishing nets. This also explains why AIS FNLs are widely applied in recent years.

Figure 1 – Photos of AIS FNL
Source: Dalian: Author.

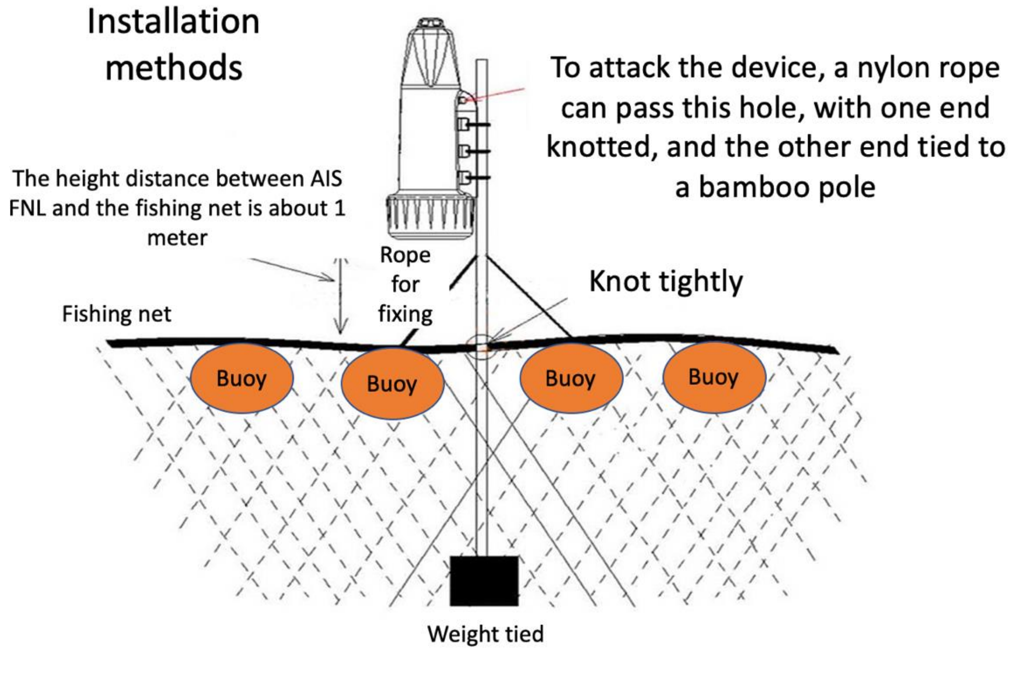

Figure 2 – Installation method of AIS FNL
Source: Dalian: Author.

The traffic in coastal waters of China is well-known to be dense and complicated. Numerous merchant ships and fishing vessels are navigating here with their routes interweaved. In the East China Sea in particular, there locates the largest fishing ground of China, namely, the Zhoushan Fishing Ground. Meanwhile, ships heading for and leaving from the world's largest and second largest ports, Ningbo-Zhoushan port and Shanghai port, are transiting through this area which increases further the traffic density. As a result, collisions between merchant ships and fishing vessels happen from time to time and more frequently, disputes over tangled and damaged fishing nets arise. On the one hand, for OOWs onboard merchant ships, it is difficult to observe and avoid fishing nets because they are small objects of large numbers. On the other hand, for fishing vessels, fishing nets cost tens of thousands of yuan to protect their property at high price, fishers will take dangerous actions such as crossing the bow of merchant ships to force the coming big vessel to change the course. In such a context, a series of AIS system-based equipment was invented to alert OOWs onboard merchant ships to fishing nets. AIS Fishing Net Locator (hereinafter referred to as the AIS FNL) is one of the most widely used devices.

However, the wide use of AIS FNLs has caused some problems as well. On the one hand, displaying the same green triangle symbol as a ship, a large amount of AIS FNL signals showed on the radar screen may confuse a deck officer onboard merchant ships when he or she is trying to pick out a real ship and determine whether there exists a risk of collision between the two ships. On the other hand, the overwhelming number of AIS FNLs in busy fishing areas raised a reasonable concern about AIS congestion and interference. There are warnings and complaints coming from mariners. Captain Mike Jessner, a captain for American President Lines, "is working to shed light on this issue and to solicit international support in order to change the status quo and outlaw the use of vessels units on fishing nets" (2018). The Federal Communications Commission of the United States launched Enforcement Advisory No. 2018-04 prohibiting marketing, sale, or use of fishing net buoys that use radio frequencies reserved for marine navigation safety communication by stating that AIS radio frequencies are authorized exclusively for marine navigation safety communications and the use of noncompliant AIS devices is illegal and has the potential to disrupt important maritime communications, increasing the risk of accidents by creating confusion about whether an AIS signal represents a vessel that must be avoided. Violators of the Commission's marketing and operating rules may be subject to the penalties authorized by the Communications Act, including, but not limited to, substantial monetary fines (up to $19,639 per day for marketing violations and up to $147,290 for an ongoing violation) (2018).

3.2 Application of AIS FNLs at sea and its influences

Nowadays, maritime transport accounts for more than 90% of China's foreign trade cargo transportation volume. The rapid development of maritime transport has brought about an increase in the navigation density of ships. With the deepening of the marine power strategy and the outline of the construction of a transport power country, 7 of the top 10 ports around the world in 2019 are in China. Various sea-related activities, such as offshore wind power, marine engineering, and fishing, are becoming increasingly active. Contradictions between various types of sea use, such as merchant shipping and fishery production, are increasing. The navigational environment along China's coast is becoming increasingly complex.

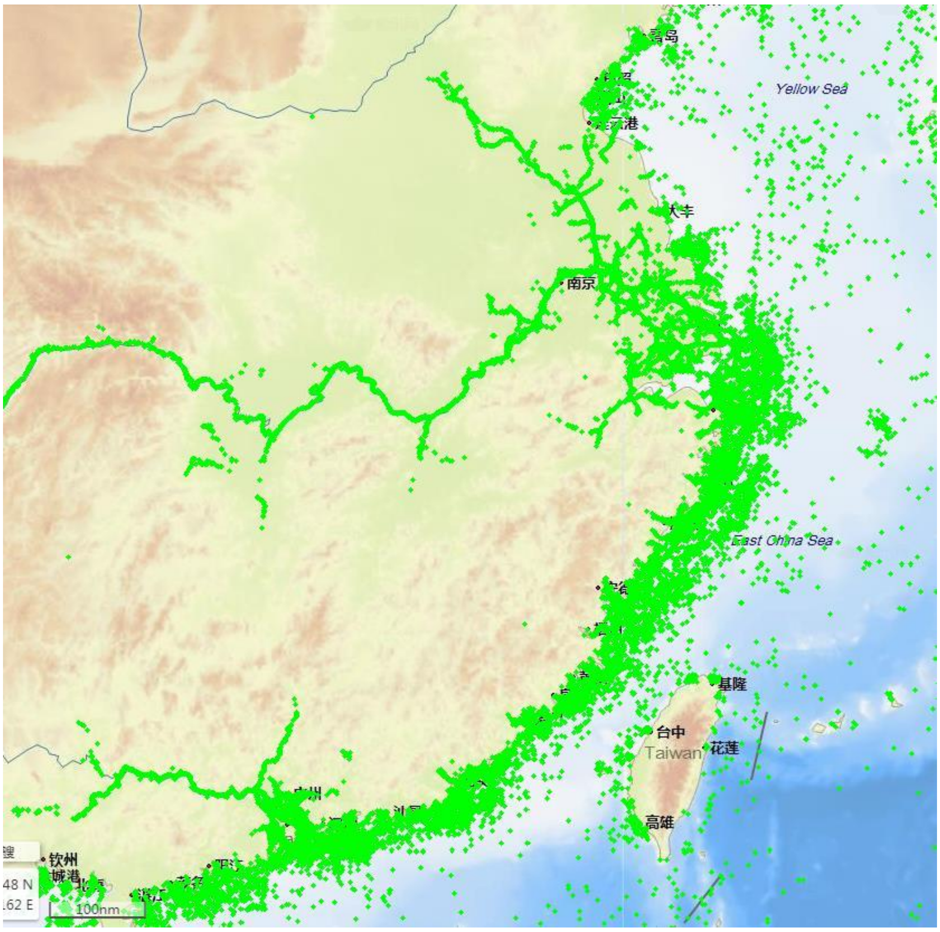

Figure 3 – AIS signals along coastal waters of China
Source: http://www.shipxy.com/

The green spots in figure 3 are signals transmitted by Class A AIS onboard merchant ships, Class B AIS of fishing vessels and FNLs. Zooming in the screen randomly in an area in the East China Sea, the triangle symbols displayed in the red circle in figure 4 are signals transmitted by AIS FNLs.

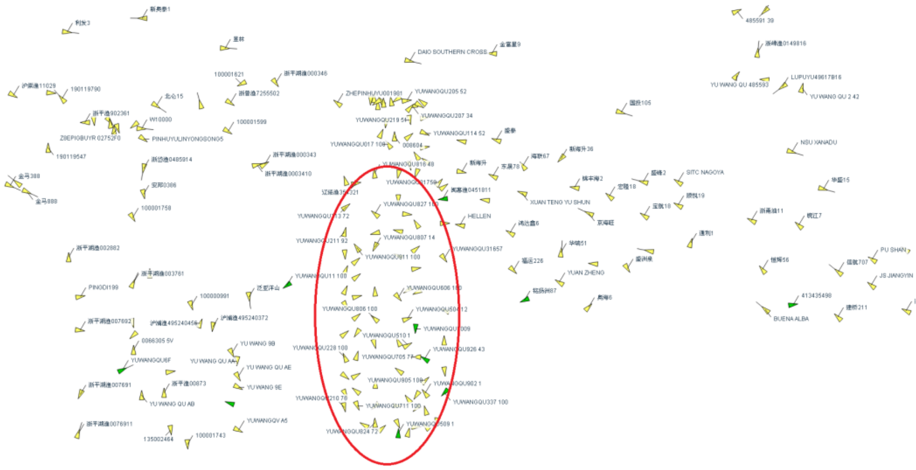

Figure 4 – A magnification of part of the East China Sea
Source: http://www.shipxy.com/

The impact of AIS FNL on the navigational safety of merchant ships is that a large number of AIS FNL covers customary routes of coastal trunk lines. The original intention of AIS FNL is to protect fishing nets and reduce disputes between merchant ships and fishing vessels. However, due to its huge number, the impact of AIS FNL on the marine navigation environment is increasingly apparent.

Fishers in the East China Sea lay their fishing nets in a direction from north to south and the length of a fishing net could reach a dozen nautical miles. The shape of the fishing nets changes with waves and tides and AIS FNLs are fitted on the fishing net every 0.2 to 1.5 nm. Normally, radars onboard cannot detect an echo of an FNL. But AIS symbol of an FNL will be displayed on the radar screen with a green triangle symbol the same as a AIS signal of a ship.

3.2.1 Rules of distribution of AIS FNL in coastal waters of China and its influences to navigators onboard merchant ships

M/V HAIXUN 01 noticed in her voyage that from Lianyungang port in Jiangsu Province to Minjiangkou in Fujian province and even in South China Sea, AIS FNLs are used in waters from offshore to the outer boundary of the Exclusive Economic Zone. These devices are used most densely in waters from the Yangtze River Estuary to Yushan Islands， and waters offshore along Taizhou and Wenzhou.

Figure 5 shows a large number of AIS FNLs displayed on the radar screen of M/V HAIXUN who is in her patrol mission in the first quarter of 2018 in the EEZ of East China Sea. Areas between Longitude 123°E to 123°30′E are covered by customary routes of merchant ships to navigate from south to north and vice versa.

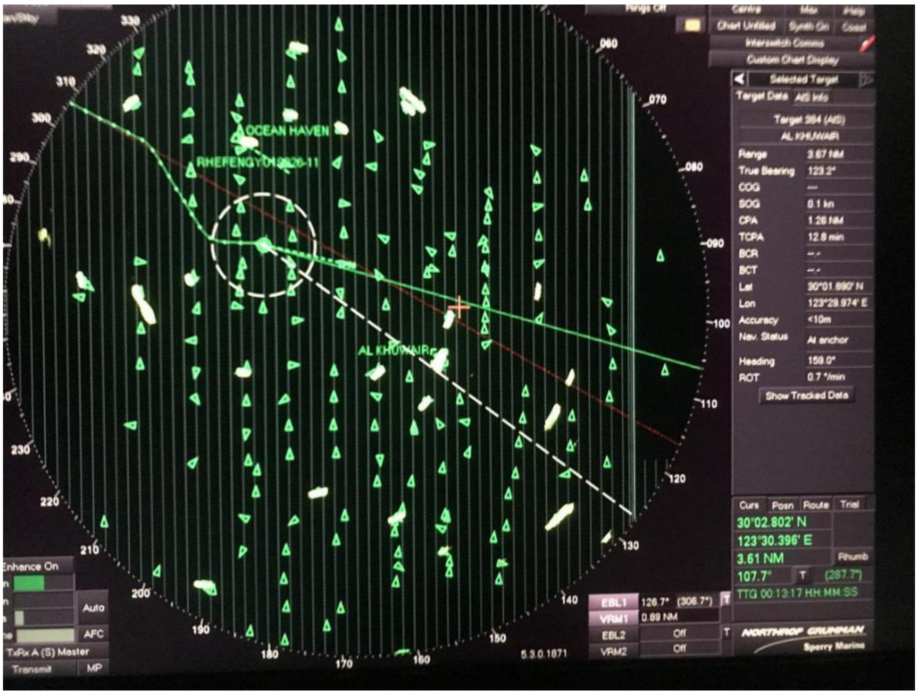

Figure 5 – A screenshot of radar onboard M/V HAIXUN
Source: Dalian: Author.

In the third quarter of 2018, M/V HAIXUN 01 found a large number of fishing nets in waters south of the Langgangshan Islands and these fishing nets extended into the Majishan channel. This area is where traditional near shore routes locate for small ships to sail between the north and the south and for large merchant ships to enter and leave Yangshan Port and Zhoushan Port.

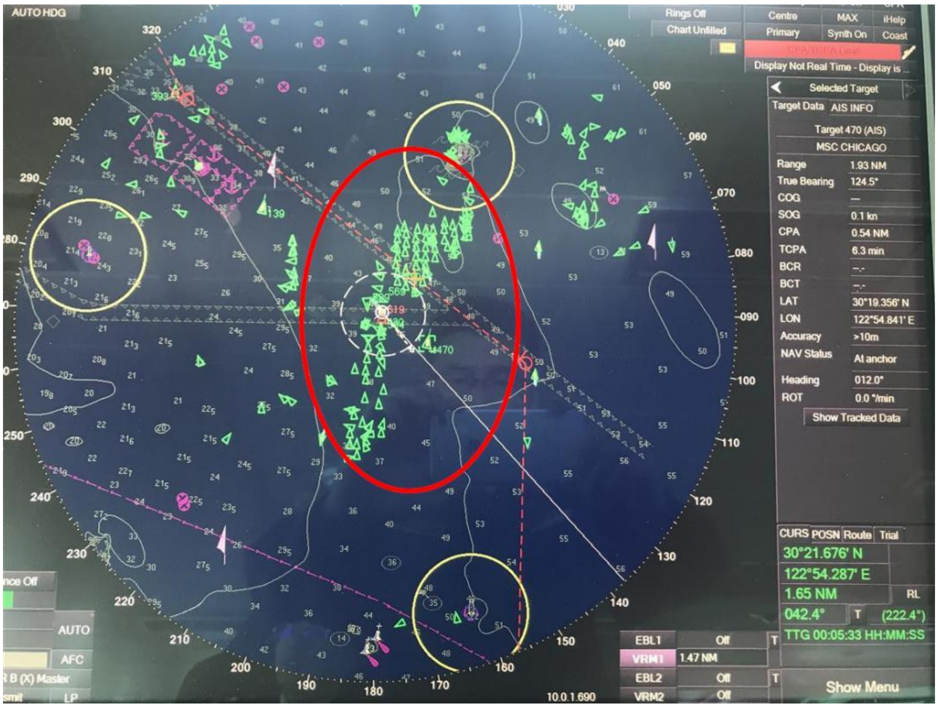

Figure 6 – A screenshot of radar onboard M/V HAIXUN
Source: Dalian: Author.

Navigating along the coastal waters of China is well-known to all navigators around the world to be of extreme difficulty due to the complexity of its navigation environment. Now, with countless symbols of AIS FNL displayed on the radar screen, it becomes even more complicated for OOWs onboard merchant ships, especially for those coming from abroad.

3.2.2 The influence of AIS FNL on navigational orders in waters covered by VTS

AIS FNLs locate clearly the position of fishing nets, which facilitates VTS officers to give early warnings to passing merchant ships to avoid accidental entry. But troubles follow.

Figure 7 – A screenshot of radar of Wusong VTS showing Yangtze River Estuary
Source: Dalian: Author.

Figure 7 shows dense signals displayed in the area between the South Channel and the South branch channel. These signals can be identified as AIS FNL from its arrangement and density. But for VTS officers, it is hard to distinguish such kind of AIS signals from those signals transmitted by low-speed ships using Class B AIS, because on the monitoring screen in the VTS system, AIS signals of small ships are also displayed as green triangle and the low speed of the movement of small ships is difficult to notice.

3.2.3 The influences of AIS FNL on on-scene SAR

It is now very common for SAR units to find a large number of AIS FNLs on site of SAR area.

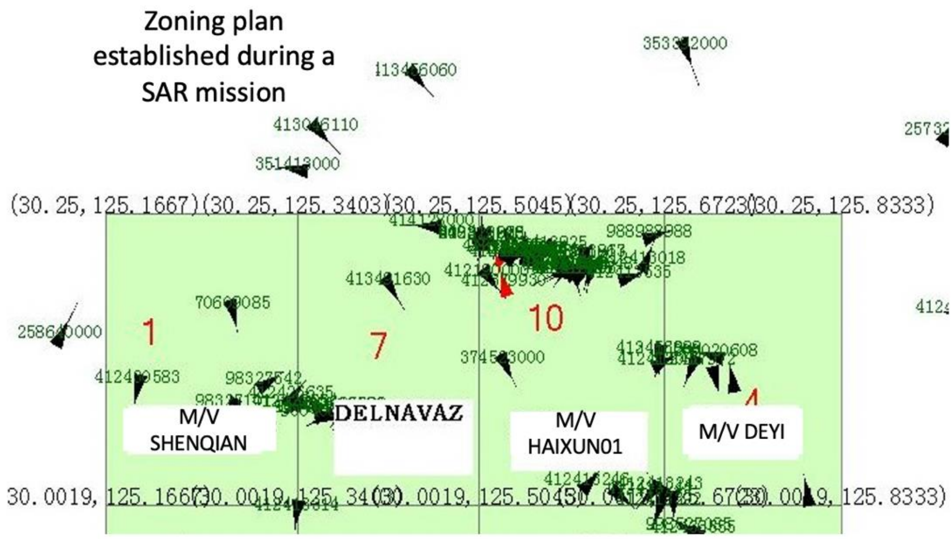

Figure 8 – The zoning plan established by M/V HAIXUN 01 for one SAR mission with a large number of AIS FNLs displayed on ECDIS
Source: Dalian: Author.

On the one hand, AIS FNLs provide a clear area of fishing nets so that the on-scene search and rescue commander (OSC) can coordinate fishing vessels to conduct SAR in areas covered by fishing nets and assign other SAR units to carry our SAR outside that area. But the negative influence of AIS FNLs on SAR is when checking suspicious floating objects, they may interfere the process and consume the time and energy of on-site SAR forces.

3.3 Challenges

Due to the above application status, AIS FNLs mainly lead to the following challenges:

3.3.1 AIS FNLs use different types of AIS messages, displaying various symbols on radar screen

The author and her colleagues noticed in practice that AIS FNLs are shown on the radar screen with different types of symbols and names. These symbols and names shown after activation may interfere with merchant ships' officer on watch to obtain information from radar and ECDIS. At present, there are mainly three types of AIS network position indicators and names on the display screens of commercial ship radar and electronic charts:

Type One: No. 18 message, a green triangle the same as a ship

The green triangle is a symbol used earliest and most widely by AIS FNLs. This type of AIS FNL broadcasts its location, name, MMSI code and other information with No. 18 message defined in the ITU-R M.1371 to nearby ships so that ships can get to know the position of fishing nets and take early action to avoid damaging them. No. 18 message is a dynamic message transmitted usually by Class B shipborne AIS, so transmitting this type of message of AIS FNLs are shown as the same symbols with ship (green triangle) on the radar screen and ECDIS.

Figure 9 – A screenshot of radar of green triangles shown by AIS FNLs
Source: Dalian: Author.

Figure 10 – A screenshot of radar of AIS FNLs in green triangles with their name “NET MARK”
Source: Dalian: Author.

Type Two: Type 21 Aid-to-Navigation Report, blue solid diamond

Figure 11 – A selected AIS FNL target displayed as a blue solid diamond in broken squares Source: Dalian: Author.

As shown in figure 11, AIS FNL uses the symbol of Physical AIS AtoN to indicate its position (the red cross is the cursor of radar). The string of characters and numbers showing next to the activated target is the name of AIS FNL.

Such AIS message is transmitted in Type 21 Aid-to-Navigation Report, emitting information including identification, location and MMSI code of the FNL.

Problems occur during the use of this type of mark by the FNL: firstly, the blue mark is relatively not so eye-catching on screens of radar and ECDIS compared with other symbols shown in green or yellow, so that it can be easily ignored by mariners onboard merchant ships; secondly, AIS FNL is not categorized as an AIS AtoN; thirdly, AtoNs are set up with sovereign attribute and if FNLs, displaying as an AtoN, were laid in sensitive waters, they would bring about disputes between countries.

Type Three: Type 21 Off Position Aid-to-Navigation Report, yellow solid diamond

According to GUIDELINES FOR THE PRESENTATION OF NAVIGATION-RELATED SYMBOLS, TERMS AND ABBREVIATIONS, for an AIS AtoN in Off Position, such failure will be indicated using yellow caution colour for the basic diamond part of a symbol with cross hair centred at reported position and for text "Off Posn" in top of the Physical AIS AtoN.

A part of AIS FNLs use this yellow solid diamond to show themselves. They transmit their position, identification and MMSI code by Type 21 Report as well. But the Off-Position Indicator, which is for floating Aids-to-Navigation only, is set as 1 rather than 0, indicating AtoN is off position. So, these FNLs will be shown in yellow caution colour with text "Off Posn " on top. Some fishers prefer such setting mainly because the yellow symbols are more clearly displayed on the radar and ECDIS screens of merchant ships. At the same time, the state of charge of batteries in AIS FNL will be shown in the “name” part, which is convenient for fishers to monitor the working status of the devices and recycle and charge them before they run out of power.

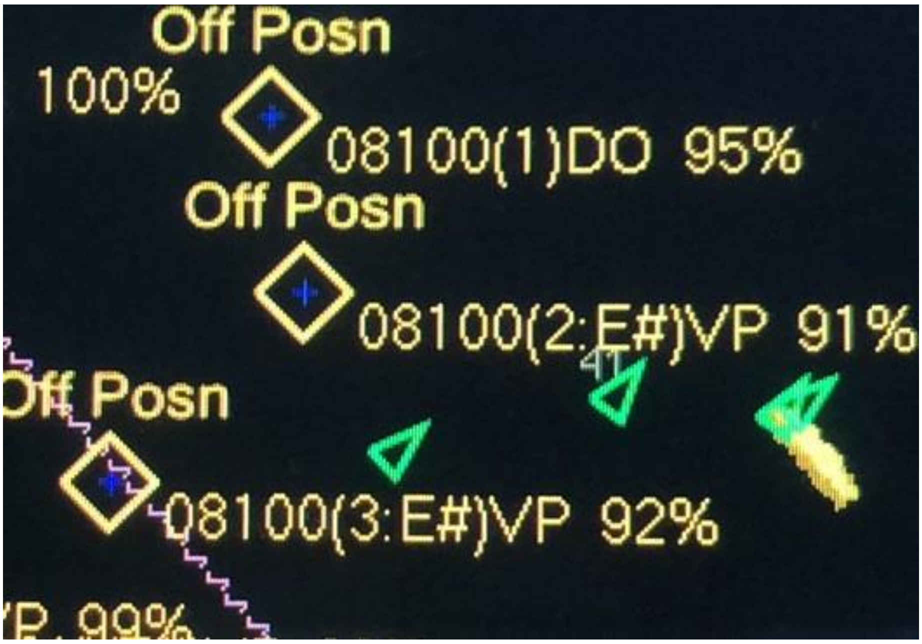

Figure 12 – AIS FNL shown in yellow solid diamond
Source: Dalian: Author.

As shown in figure 12, the name of AIS FNL starts with a string of numbers followed by remaining battery percentage.

In general, based on the practice of patrol of M/V HAIXUN 01 in the East China Sea in recent years, the identification and naming methods of AIS FNLs are still changing. Since there is no definition of AIS FNL in the current AIS agreement and ECDIS display specification, the AIS FNL have to “borrow” symbols from other AIS transmitters fitted on ships or navigation markers

3.3.2 Inconsistent naming convention

The naming rules of AIS FNLs are still changing. At the beginning, the names usually start with the Mandarin Phonetic Symbols of the name of a fishing vessel and its number (see figure 9). Now there are names such as “NET MARK + other alphanumerics” (see figure 10), "YUWANGQU + number", "YUWANG + number or letter". (YUWANG means fishing net in Chinese.) In this way, OOWs can distinguish AIS FNLs from ships by the name.

For FNLs using Type 21 Off Position Aid-to-Navigation report, they will show in yellow caution colour with text "Off Posn" on top. Some fishers prefer such setting mainly because the yellow symbols are more clearly displayed on the radar and ECDIS screens of the merchant ships. At the same time, the state of charge of batteries in the AIS FNL will be shown in the “name” part, which is convenient for fishers to monitor the working status of the devices and recycle and charge them before they run out of power.

On the one hand, once AIS FNLs are activated on the radar screen, these long linear names will flood on the screen and interfere with OOWs' recognition of nearby ship symbols on the radar. On the other hand, for foreign navigators who do not know pinyin (Chinese phonetic alphabet), they may find it difficult to recognize AIS FNLs with names created by inconsistent naming rules.

3.3.3 Clogged AIS channel and ship’s overloaded AIS receiver.

AIS technology was initially invented to ensure the navigational safety of ships and to facilitate search and rescue. It has limited system capacity. The AIS protocol divides 1 minute into 2250 time slots. In practical applications, when the channel load rate is greater than 40% (which means that 900 time slots are being used), AIS will be blocked. Every AIS FNL uses two timeslots to transmit a signal once at a time. The prevailing AIS FNL applying AIS transponder technology transmits signals six times per minute regardless of whether the AIS channel is free. Assuming that there are 150 AIS FNLs around a merchant ship, the 900 time slots accounting for two fifth of the channel load will be used up. The AIS channel may then be blocked up and AIS equipment of the merchant ships may fail to identify other ships. On the other hand, AIS equipment onboard has limited capacity to obtain AIS targets. The number of AIS objects that can be received may be limited to 100. In another word, if the AIS equipment onboard is occupied with all signals transmitted by AIS FNL nearby, they may fail to receive other important objects like AIS signal from a fishing vessel or a VLCC or an oil tanker, so that collision risks increase between ships.

In addition, manufacturers can set the MMSI code, broadcast mode, transmission power and transmission frequency of the AIS FNL at will, which does not comply with the relevant regulations of radio management at sea.

3.4 Suggestions for improvement of the FNL

Regarding three major challenges elaborated in chapter 3.3, the author proposes three corresponding suggestions.

3.4.1 Assign reserved bits to AIS FNLs

There are bit fields now reserved in AIS standard for future use. ITU, if applicable, can set up a new type of message for AIS FNLs. AIS FNLs can be displayed as a specially designed symbol so that navigators can distinguish these devices from real ships.

Before formal regulations being developed by international organizations, domestic manufacturers can try to produce such a kind of AIS FNL under the guidance of national maritime and fishery authority. The Chinese government, for example, can then choose a water area to conduct device trial for further promotion and application. Once there is a mature product that meets the requirements of all parties, relevant administrative departments and maritime organizations can establish technical and management standards to control the use of these devices.

3.4.2 Unified naming convention

Maritime and fishery department can consider the establishment of a unified naming convention so that all ships can recognize the object directly by its name showed on the radar screen. For example, the first eight letters can be “NET MARK”.

3.4.3 AIS FNLs based on primary-secondary mode

Guo et al (2018) argued that the adoption of a primary-secondary mode can cut down the total number of indicators to be detected, and therefore reduce resource consumption. In detail, among several FNLs fitted on one fishing net, a primary device and multiple secondary devices can be installed. The secondary devices are connected and send messages periodically to the primary device in a designated radio communication mode (such as WIFI and Zigbee or group B AMRD communication mode) and a designated channel (dedicated channels for group B AMRD defined by ITU and another channel may be used). The primary device receives the messages from the secondary devices and transmits the information in a message complying with the transmission frequency, transmission cycle and message format required in Recommendation ITU-R M.1371 and ITU-R M[AMRD] after processing. Onboard electronic equipment displays the position and range of the fishnet indicator once the message is received. The display of AIS fishnet indicators should follow the regulations in revised IMO MSC SN/Circ. 243. The schematic diagram is shown in figure 13.

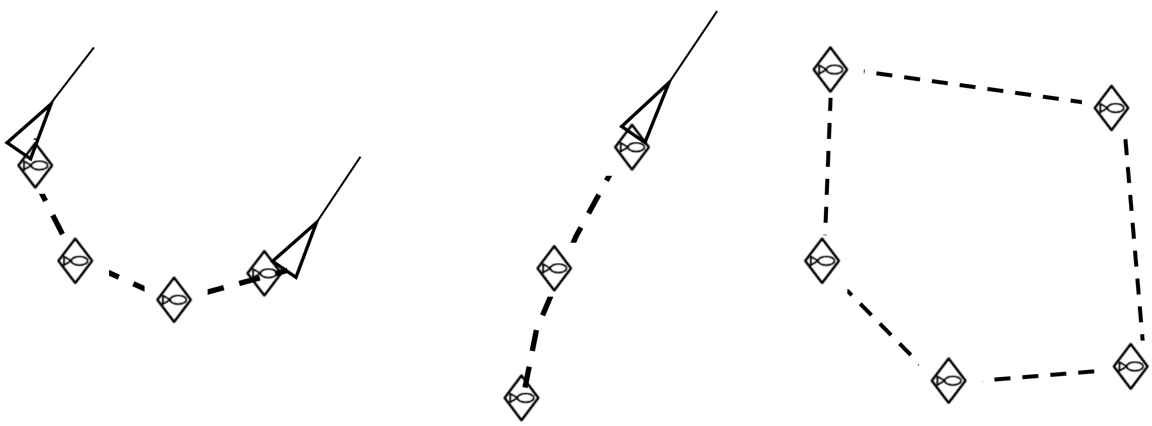

Figure 13 – Example of AIS fishnet indicators displayed on the AIS ship platform
Source: Guo, X. F., Hu, Q., & Li, L. (2019). *Research on technical standard for autonomous maritime radio device (AMRD).* Unpublished research paper, Beihai Navigation safety Center, Tianjin, China.

3.5Envisage of Usage of AIS Fishing Net Locator at sea within a Framework of Maritime Autonomous Surface Ship

In recent decades, MASS has grown in popularity. Various issues including climate change, environmental abnormalities and national security call for the development of MASS in commercial, scientific, and military communities (Liu et al, 2016). Meanwhile, in order to minimize both needs for human control and the effects on effective, safe and reliable MASS operation due to human error, further development of fully autonomous MASS is required (Campbell, Naeem, & Irwin, 2012; Liu et al, 2016).

It is very challenging for MASS to cope with all different operating conditions in complicated and hazardous environments without human supervision. Potential unknown failures in sensor, actuator and communication can make full-autonomy even harder. Hence, MASS requires an effective and reliable automated system. Within such a system, Liu, et al (2016) believed that basic elements including hull and auxiliary structural elements, propulsion and power system, guidance, navigation and control (GNC) systems, communication systems, data collection equipment as well as ground station must be included and improved. Fossen (1994; 2002; 2011) argued that the fundamental elements for autonomously operating USVs generally comprise guidance, navigation and control subsystems. Guidance system keeps generating and updating feasible and optimal trajectory commands to the control system based on the information provided by the navigation system, assigned missions, vehicle capability, and environmental conditions. Navigation system is responsible for identifying the current and future states of MASS and its surrounding environment according to the past and current states of the MASS as well as environmental information obtained from its onboard sensors. Control system is responsible for determining the appropriate control forces and moments in accordance with instructions offered by the guidance and navigation systems, while satisfying wanted control goals. Figure 14 shows the general structure of GNC systems. This paper, in order to provide a solution for MASS to pass clear of fishing nets at sea, will focus on the guidance technology, in particular path re-planning methodologies when encountering obstacles such as fishing nets, as well as navigation technology, namely the sensing, state estimation, environment perception and situation awareness capabilities of MASS.

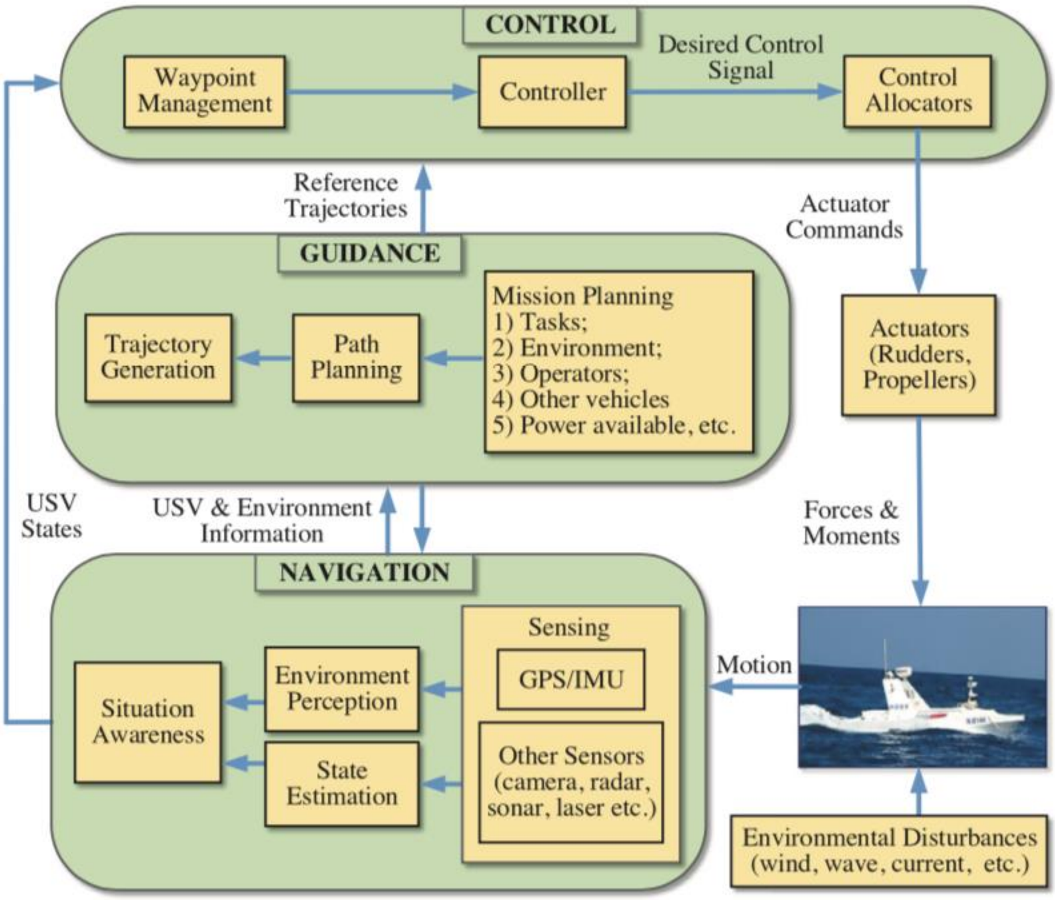

Figure 14 – General structure of MASS guidance, navigation, and control systems
Source: Liu, Z. X., Zhang, Y. M., Yu, X., & Yuan, C. (2016). Unmanned surface vehicles: An overview of developments and challenges. Annual Reviews in Control, 41, 71-93.

Guidance system

It is vital for increasing MASS autonomy to have a feasible guidance system. To accomplish tasks under sophisticated and strict constraints, MASS requires more advanced guidance capabilities (Fossen, 2002; Kendoul, 2012). Liu et al (2016) provided a brief classification of MASS guidance systems in figure 15. Regarding fishing nets, protocol-free collision avoidance under path re-planning should be considered.

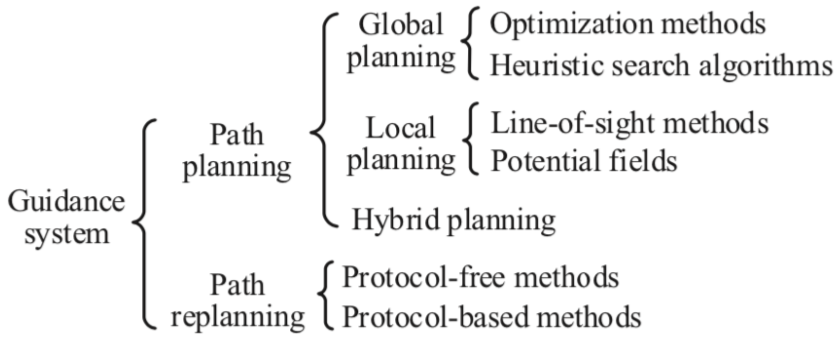

Figure 15 – Classification of MASS guidance systems with respect to functions and methods

Source: Liu, Z. X., Zhang, Y. M., Yu, X., & Yuan, C. (2016). Unmanned surface vehicles: An overview of developments and challenges. Annual Reviews in Control, 41, 71-93.

It is argued by Yu & Zhang (2015) that in the process of path reprogramming, collision avoidance acts as a main role. But it is generally ignored in the basic guiding principles in MASS since barrier-free path is usually assumed (Liu et al., 2016). Unfortunately, recent statistics indicate that 60% of casualties at sea are caused by collisions (Naeem et al., 2012a). Lobster traps, buoys, fishing nets, submerged rocks, other obstacles to sea traffic, new buildings, variable water levels and Marine debris can all become collision hazards. If collisions of this type cannot be avoided, MASS may collide with any object in its planned path. In addition, the collision avoidance module can enhance the autonomy of the USV by autonomous path reprogramming, thus avoiding approaching objects.

There are various types of collision avoidance module under experiment. In Soltan, Ashrafiuon, and Muske (2011), obstacles are assumed to be enclosed by elliptical shapes and a set of ordinary differential equations are defined for collision avoidance. This technology is validated by using multiple dynamical obstacles in simulation and stationary obstacles in experiments.

Xu, Stilwell, and Kurdila(2013) present a path re-planning approach based on the level set methods, which is employed to compute the minimum risky path.

In Kim, Kim, Shin, Kim, and Myung (2014), an angular rate-constrained Theta (ARC − Theta) is proposed to regenerate paths in real-time with consideration of constraints in both yaw rate and heading angle of USV.

An optical-flow based approach is designed to provide local reactive collision avoidance in El-Gaaly et al. (2013). This research employs a monocular camera, overcoming the challenges of water reflections and visual noises in an acceptable range.

In Bertaska et al. (2013), a lattice-based path planning method is implemented with prior knowledge of the USV characteristics

Most of the existing research focuses only on detecting and avoiding obstacles above the water. Until recently, little attention has been paid to underwater collision avoidance in USVs, despite of the significant risk of collision from submerged obstacles, including reefs and shallow banks. Pioneering work on this issue is carried out in Heidarsson and Sukhatme (2011) and Onunka, Brightand Stopforth(2013), where active acoustic sonar is mounted on their USVs in order to provide information on underwater obstacles. Additionally, a direct method based on inverse dynamics in the virtual domain (IDVD) strategy is reported in Yakimenko and Kragelund (2011) to compute a near-optimal collision-free trajectory.

Navigation system

A reliable and effective navigation system is essential to control MASS safely and efficiently. Such a system should have strong sensing, state estimation, environment perception and situation awareness capabilities (Liu et al., 2016).

In addition, marine environment will impose strict restrictions on sensory requirements. Therefore, heterogeneous sensors are usually employed in order to make the best use of different sensors' characteristics and achieve superior navigation performance.

In order to perform missions in real-world environment, USVs are normally required to detect obstacles, recognize and track targets and map environments all in real-time. Furthermore, the unique conditions experienced in marine environment, such as environmental disturbances (winds, waves, and currents), sea fog and water reflection, can also impact the performance of environmental perception.

Passive perception methods adopting visual/infrared sensors are widely applied in environment perception applications. These technologies all need further development. While AIS FNLs can use the current available technology and channel to transmit data and information to MASS whose safety of navigation can then be improved.

Currently, IMO (2018a) is conducting regulatory scoping exercise to assess the degree to which the existing regulatory framework under its purview may be affected in order to address MASS operations. This process started from a proposal jointly submitted by Denmark, Estonia, Finland, Japan, the Netherlands, Norway, the Republic of Korea, the United Kingdom and the United States to MSC on 27 February 2017. The co-sponsors of this document recalled that the maritime industry was witnessing a growing deployment of MASS "to deliver safe, cost-effective and high-quality results" and in this case, MASS could include ships with different levels of automation. They believed that there are significant theoretical and commercial research and development ongoing on all types of MASS, including remotely controlled and autonomous navigation, vessel monitoring and collision avoidance systems, but except for technological solutions, there was a lack of clarity about the correct application of existing IMO instruments to MASS. Therefore, the co-writers were of the view that it was necessary for IMO to make sure that MASS designers, builders, owners, and operators have access to a clear and consistent regulatory framework for purpose of being able to demonstrate compliance with IMO instruments. This document, MSC 98/20/2 (IMO, 2017), invited the Committee to undertake a regulatory scoping exercise to determine how the safe, secure and environmentally sound operation of Maritime Autonomous Surface Ships (MASS) might be introduced in IMO instruments. The Committee supported this proposed new output in general in the report of the MSC issued on 28 June 2017 on its ninety-eighth session and agreed to include it in the 2018-2019 biennial agenda of the MSC and the provisional agenda for MSC 99, an output on "Regulatory scoping exercise for the use of Maritime Autonomous Surface Ships (MASS)", with a target completion date of 2020. Later on 1 May 2018, the Legal Committee of IMO also agreed to include a new output entitled "Regulatory scoping exercise and gap analysis of conventions emanating from the Legal Committee with respect to Maritime Autonomous Surface Ships (MASS)" in its biennial agenda and the provisional agenda for LEG 106, with a target completion year of 2022 and an aim to complement the work undertaken by the MSC (IMO, 2018b). In 2018, the ninety-ninth session of MSC established a Working Group on MASS to develop a framework and a plan of work for the regulatory scoping exercise. As a result, the framework for the regulatory scoping exercise, including the aim and objective, a preliminary definition of MASS and degrees of autonomy, the list of mandatory instruments to be considered, the applicability in terms of type and size of ships, the methodology for the exercise and a plan of work, was established by the Working Group and endorsed by MSC 99. MSC 99 also agreed that it should review only instruments under its remit and, noting that an output had been approved by the LEG Committee for the conduct of a regulatory scoping exercise on MASS for instruments under its purview, had invited the MEPC and the FAL Committees to contribute as appropriate, by undertaking a review of instruments under their purview, respectively. MSC 99 agreed further that it should take a coordinating role and provide relevant information to other IMO committees on aspects under their responsibility needing consideration and, in this respect, had invited them to take into account any relevant decisions made by it, in order to harmonize the results of the respective scoping exercises. In January 2019, MSC 100 finalized such a framework and requested the Secretariat to develop a web platform and assist with certain tasks during the scoping exercise, such as pre-populating the platform, assigning relevant permissions to users and dealing with any other administrative issues, as appropriate.

The framework for the regulatory scoping exercise for the use of maritime autonomous surface ships (MASS), to facilitate the process of such an exercise, organized the degrees of autonomy as follows:

Degree one: Ship with automated processes and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.

Degree two: Remotely controlled ship with seafarers on board: The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.

Degree three: Remotely controlled ship without seafarers on board: The ship is controlled and operated from another location. There are no seafarers on board.

Degree four: Fully autonomous ship: The operating system of the ship is able to make decisions and determine actions by itself.

Moreover, the methodology to review a list of mandatory instruments related to maritime safety and security and their subsidiary mandatory instruments includes two steps. The first step is to identify provisions in IMO instruments which, as currently drafted:

.1 apply to MASS and prevent MASS operations; or

.2 apply to MASS and do not prevent MASS operations and require no actions; or

.3 apply to MASS and do not prevent MASS operations but may need to be amended or clarified, and/or may contain gaps; or

.4 have no application to MASS operations. were identified in the plan of work and procedures.

After the completion of the first step, a second step will be carried out to analyze and determine the most appropriate way of addressing MASS operations, taking into account, inter alia, human element, technology and operational factors by:

.1 equivalences as provided for by the instruments or developing interpretations; and/or

.2 amending existing instruments; and/or

.3 developing new instruments; or

.4 none of the above as a result of the analysis.

And the process for the regulatory scoping exercise is shown in figure 16.

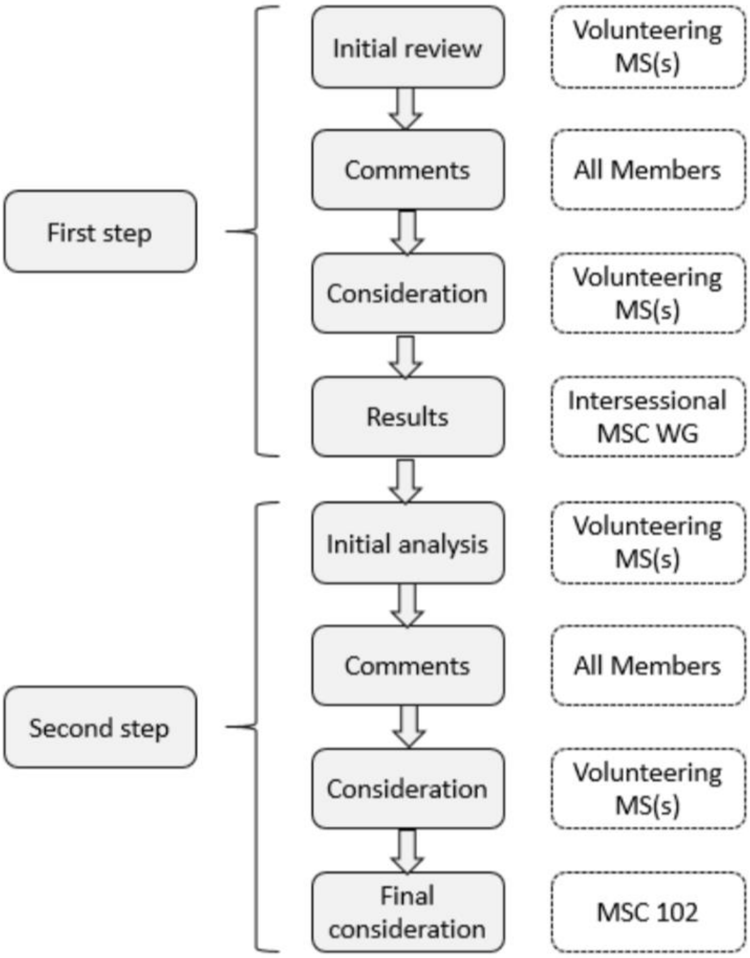

Figure 16 – The process for the regulatory scoping exercise of MASS
Source: International Maritime Organization. (2018a, December 12). Report of the maritime safety committee on its one hundredth session: submitted by Secretariat (MSC 100/20/Add.1). London: Author.

Mandatory requirements related to AIS locate in Chapter V, Regulation 18 and 19 in SOLAS. According to the work allocation agreed at MSC 100, China took lead of the RSE for SOLAS chapter V with the participation of Denmark, Japan and Singapore. China submitted a summary of results of the first step of the RSE for SOLAS chapter V to intersessional working group on maritime autonomous surface ships on 2 August 2019. In this document, China stated that during the initial review, the following assumptions were developed, agreed and used for the unified understanding of the degrees of autonomy so as to facilitate the review process:

.1 MASS of degree one is considered as a conventional ship with some additional functions to support human decision making. The specific automated process and decision support are not considered due to their diversities.

.2 No matter if MASS can be operated from another location, seafarers on board are assumed to be able to meet all the operation and control requirements. (For degrees one and two).

.3 As long as MASS is not fully autonomous; the role of ship Master is still required. Nonetheless, for degree three, the scope of duty of ship Master will be extended/amended.

.4 For degree of autonomy four, it is assumed there will be no seafarers on board when a ship is fully autonomous.

The group developed four extended interpretations for application options to achieve common understanding for the smooth implementation of the RSE (see table 1).

Table 1 - Extended interpretations for application options to achieve common understanding for the smooth implementation of the RSE

	Application options	**Extended interpretation**
1	.A: apply to MASS and prevent MASS operations	relevant to MASS operation but not possible for MASS to implement
2	.B: apply to MASS and do not prevent MASS operations and require no actions	relevant to MASS operation, possible for MASS to implement and descriptive texts are appropriate
3	.C: apply to MASS and do not prevent MASS operations but may need to be amended or clarified, and/or may contain gaps	relevant to MASS operation and possible for MASS to implement, but descriptive texts are not appropriate
4	.D: do not apply to MASS operations	not relevant to MASS operation

Source: International Maritime Organization. (2019b, August 2). Consideration of the results of the first step of the regulatory scoping exercise Summary of results of the first step of the RSE for

SOLAS chapter V: submitted by China (ISWG/MASS 1/2/16). London: Author.

For Regulation V/18, approval surveys and performance standards of navigational systems and equipment and voyage data recorder, three members chose option .C with following reasons: The Master needs additional navigation equipment for decision making; In the context of MASS, varieties of performance standards for systems to which this regulation refers may require revision; Performance standards should be updated with implementation of remote control functionality.

Paragraph 2 of Regulation V/18 has a list of performance standards. This paragraph states that when systems and equipment, including associated back-up arrangements, are installed on or after 1 July 2002 to perform the functional requirements of Regulations 19 and 20, such systems, equipment and arrangements, where applicable, shall conform to appropriate performance standards not inferior to those adopted by the Organization. Paragraph 3 further clarifies that those systems and equipment replaced or added to on ships constructed before 1 July 2002, shall, in so far as is reasonable and practicable, comply with the requirements of paragraph 2.

For AIS, there are three instruments listed in the footnote under paragraph 2 of Regulation V/18. One is Resolution A.813(19), the general requirements for electromagnetic compatibility for all electrical and electronic ships’ equipment are adopted by the Organization. It invites Governments to ensure tests for all ships' electrical and electronic equipment to the relevant electromagnetic compatibility standards. Another two are recommendation on performance standards for a universal shipborne automatic identification system (AIS) (Resolution MSC.74(69), annex 3) as well as guidelines on annual testing of the automatic identification system (AIS) (MSC.1/Circ.1252). Annex 3 of Resolution MSC.74(69) contains information about the requirements for the universal shipborne AIS. It says that AIS should automatically provide information with the required accuracy from the ship to ships and to competent authorities and frequency to facilitate accurate tracking. And AIS should improve the safety of navigation by assisting in the efficient navigation of ships, protection of the environment and operation of Vessel Traffic Services

(VTS). MSC.1/Circ.1252 offers guidelines on annual test for determination of the compliance of shipborne AIS to appropriate performance standards.

Regarding MASS, the performance standards of AIS could be extended further. Shipborne AIS onboard LoA 3 and 4 MASS could receive AIS information not only from ships but also from FNLs to support their decision-making during a voyage. This additional information could be integrated into the navigation system of MASS to maneuver the ship, avoid collision with FNLs and pass clear the fishing nets area.

In terms of Regulation V/19, Carriage requirements for shipborne navigational systems and equipment, for degree one, two members chose option .C, with the following comments: manning requirements / automated processes should be taken into account and specification of the equipment and the PS for the equipment and the decision support systems (NDSS) is needed; automated processes and decision support systems might present gaps with some carriage requirements. For degree two, three members chose option .C, with the following comments: manning requirements / automated processes should be taken into account and specification of the equipment and the PS for the equipment and the decision support systems (NDSS) is needed; the location of required equipment should be clarified; additional navigational equipment carriage requirements may be required in order to safely and properly operate ships remotely even though crew on board take over the control of the ship.

Regarding degrees three and four, nine members chose option .C with the following comments: Manning requirements / automated processes should be taken into account. Specification of the equipment and the PS for the equipment and the decision support systems (NDSS) needed; The location of required equipment should be clarified; Functions and data requirements are needed for remote control and autonomous operation; Additional requirements and redundancy need to be considered, due to the absence of crew; A number of requirements under this regulation would be irrelevant to MASS while other navigational equipment carriage requirements may be required in order to safely and properly operate unmanned ships; For degree three, most of the equipment is still needed and can by remotely operated but require regulating and VDR need to be amended to specify what types and capabilities of equipment will be needed to provide relevant data and information.

Paragraph 2.4 of Regulation V/19 regulates the types and tonnages of ships which should be equipped with AIS. Paragraph 2.4.5 requires that AIS shall provide information, including the ship’s identity, type, position, course, speed, navigational status and other safety-related information, automatically to appropriately equipped shore stations, other ships and aircrafts; receive automatically such information from similarly fitted ships; monitor and track ships; and exchange data with shore-based facilities. Obviously, in this part, the exchange of AIS information happens only between ships, shore stations and aircraft.

Paragraph 2.4.7 of Regulation V/19 refers to the revised guidelines for the onboard operational use of shipborne automatic identification systems (AIS). IMO developed these Guidelines to promote the safe and effective use of shipborne AIS, especially to inform the navigator about the operational use, limits and potential uses of AIS (IMO, 2015). This document states that SOLAS Regulation V/19 requires shipborne AIS to exchange data ship-to-ship and with shore-based facilities. Therefore, the purpose of AIS is to help identify ships, assist in target tracking and SAR operation, simplify information exchange (e.g., reduce verbal mandatory ship reporting) and provide additional information to assist situation awareness. This instrument also underlines that in general, data received via AIS will improve the quality of the information available to the OOW, whether at a shore surveillance station or on board a ship. AIS is a useful source of supplementary information to navigational systems (including radar) and therefore can be used as an important 'tool' to enhance users’ situation awareness.

For traditional vessels where human beings are relied on maneuvering the ship, data transmitted from fishing nets via AIS supplement the information available and helps mariners to know better and earlier about the surrounding. As a result, navigators onboard can make decisions and take actions with a better situation awareness, taking into account, the traffic condition as well as the distribution of fishing nets in the vicinity.

For MASS, the use of AIS FNLs can be discussed separately in four different situations based on the definition of the degrees of autonomy, the assumptions developed during the initial review for the unified understanding of the degrees of autonomy as well as the application option chosen by various members.

For MASS of degree one and two, although seafarers can control (on degree one MASS) or take over (on degree two MASS) the ship to handle complicated situations such as a dense traffic with a large number of fishing nets around, automated processes and decision support systems can integrate information from AIS FNLs in order to provide officers or the captain with an optimized route to avoid other ships together with fishing nets.

Regarding MASS of degree three, remote operators at shore lean heavily upon sensors along with automated processes and decision support systems to maneuver the ship safely. At present, sensors applied onboard MASS are still in development. Fishing nets are small targets with a wide and dense distribution. How to detect these obstacles on the planned route is a big challenge for seafarers far away at shore. Radar cannot detect small buoys fitted on the top of fishing nets. Ordinary visual sensors suffer from low depth resolution and accuracy and they are susceptible to light and weather condition (Liu et al, 2016). Even LIDAR, which is good at near range obstacle detection and of high depth resolution and accuracy, can find it extremely difficult to catch targets of fishing nets in a severe whether condition due to its sensitivity to environment and MASS motion. Sonar has limited detecting range in each scanning and is impressionable to the noise from near surface. At night, visual sensors can only transmit back blurry image of the lights displayed by buoys of fishing nets. Although long-wave infrared (IR) cameras can be an ideal solution to overcome the impact of various light conditions (such as night and fog) on environment perception, enabling both day and night operation, unfortunately, since the buoys of fishing nets are floating on the surface of waters, infrared sensors may miss these buoys in heavy sea conditions.

MASS of degree four has to embrace full autonomy. It means that this type of ship should be able to detect obstacles, recognize, track targets and map environments, all in real-time without human supervision (Liu et al, 2016). If MASS cannot fully capture the scenario in a fishing nets area, it may encounter these drifting objects head-to-head. There are two possible adverse outcomes. One is that the vessel catches fishing nets in one or both of its propeller(s). It is likely that the entanglement can disable the propeller, limits maneuverability of the vessel or even force the MASS to stop its propulsion system and rely only on thrusters to control the ship, waiting for assistance. Another situation is that some of the propellers equipped with cutting knife device will cut all fishing nets encountered. The fishers will suffer from a huge loss and disputes will arise between MASS and fishing vessels. Without human onboard, it is an option for MASS to receive the location of fishing nets from AIS FNLs and process these data to pass clear of fishing nets and prevent propeller entanglement with these obstacles.

The Intersessional Working Group on Maritime Autonomous Surface Ships (ISWG) considered the summary of results of the first step of the RSE provided by China (ISWG/MASS 1/2/16) for SOLAS chapter V, titled "Safety of navigation" and in its report submitted to MSC on 25 September 2019, the Group agreed on the commencement of the second step.

China drafted an initial review of the results of the second step of the RSE for SOLAS chapter V. And the supporting member States offer two rounds of comments. China then updated and uploaded the initial results onto the GISIS platform, giving full consideration to the comments received. MSC 102/5/9 (IMO, 2020) summarizes the most appropriate way of addressing MASS operations for four degrees of autonomy.

For degree one, Option II "amending existing instruments" is chosen.

For degree two, two paralleled ways are recommended. One is to amend current provisions, including carriage of equipment. Another one is to develop new instruments in order to accommodate remote control functions. Additional performance standards for some navigational equipment of remotely controlled MASS most likely also need to be developed. Separate guidelines (mandatory or non-mandatory) for these performance standards are suggested.

For degree three, since there are a good many potential gaps identified involving many regulations, it seems unwise to develop amendments to existing regulations on a large scale only to accommodate MASS operation. The existing provisions can be applied to conventional ships. And a separate and dedicated mandatory instrument for MASS of this level can be developed. Additional performance standards for some navigational equipment of remotely controlled MASS will also need to be developed. Separate guidelines (mandatory or non-mandatory) for these performance standards are suggested.

For degree four, with similar reasons mentioned in degree three, developing new instruments is considered as the most appropriate way of addressing MASS operations.

In general, member States are of the view that taking into consideration of the RSE results for SOLAS chapter V and developing new instruments for MASS is highly recommended. What’s more, SOLAS should consider MASS operation in a holistic way and develop a harmonized solution to accommodate MASS operation in the entire convention based on the RSE results of all chapters (IMO, 2020).

3.6 Summary

In general, the application of AIS FNLs, which brings convenience for fishers to locate and retrieve fishing nets, has led to several challenges. The assignment of reserved bits to AIS FNLs, establishment of unified naming convention and design of AIS FNLs in primary-secondary mode can be approaches to improve the application of AIS FNLs.

Meanwhile, in an era of MASS, AIS FNLs can facilitate the navigation of unmanned ships. In this regard, the improvement of the use of AIS FNLs is beneficial for further development of the maritime world.

Chapter 4 INTRODUCTION OF THE SMART TERMINAL OF CLASS B AIS AND CORRESPONDING SUGGESTIONS

4.1 Introduction of the smart terminal of class B AIS

The smart terminal of Class B AIS is a futher exploration of the use of Class B AIS equipment onboard Chinese fishing vessels to prevent collision between fishing vessels and merchant ships.Such a terminal can broadcast collision prevention warining automatically on VHF Channel 16. Its warning message usually starts with the call sign or the MMSI number of the target ship, giving the relative bearing and the distance between the fishing vessel and the approaching shipand ends with the sentence “navigate with caution”.

The working principle of this smart terminal is to firstly receive the information, in particular the dynamic information concerning the position, couse over ground, speed over ground and heading of the ships in the vicinity, through AIS equipment. If after analyzing,risk of collsion exists between the fishing vessel and another vessel nearby, the terminal will send a safety message on VHF Channel 16 automatically in order to give an early warning to the target merchant shipso asto reduce and avoid collisions between them.

According to the introduction of manufacturers, the research and development of the smart terminal of class B AIS began at the end of 2013. At that time, in a certain sea area, within a week, two collision accidents happenedbetween fishing vessel and merchant ship, resulting in the loss of lives of many fishers. Based on the problems identifiedduring the marine accident investigation, the fishery department, as the leading party,conducted a research programme together with some research institutions and manufacturers on collision prevention between fishing vessels and merchant ships and came up initially with a concept to design an early warning system to prevent collision using the AIS equipment as a carrier.

The first-generation of the product receives the information of the nearby ships through AIS. The system sets up an alarm ring with a fixed radius and once there is a ship entersthis area, it will trigger an audible and visual alarm on the bridge todraw fishers' attention and give early warnings. But the drawback ofsuch a setting is that the alarm is too frequent in a dense traffic area and becomes a pain in the neck forfishers on duty.They would then choose to turn off the system and use it only in foggy daysor in other conditions of poor visibility. As a result,the utilization ratio of this function is relatively low and its effect on collision preovention is limited.

Subsequently, the manufacturer launched a second-generation device. By reading the CPA (closest point of approach) and TCPA (time to closest point of approach) of the approaching ship fromAIS equipment, the system can sendan accurate alarm about ships with which risk of collision actually exist.Usually, the TCPA is set up as 10 to 30minutes whereas CPA as 3 nautical miles. Once the alarm condition is reached, the smart terminal will automatically start an alarm for the fisherson the fishing vessel's bridge and this alarm cannot be turned off manually. At the same time, the system would connect to VHF Channel16 and wait for two minutes. During this period, fishers can manually confirm the alarm, coordinate actions with the approaching ship via VHF, or change the course or reduce speedso as toincreasethe CPA and TCPA.

But if the crew of the fishing vessel does not take anyaction and the risk of collsion still exist, the smart terminal will disable the permission for fishers to talk on VHF channel16, and after listening on the channel, it will automatically broadcast on the VHF channel 16 a security message lasting for about 30 seconds when the channel is available. The call starts generally with the call sign,name or MMSI code and the relative bearing of the target ship.Meanwhile, the system would judge the nationality of the target ship according to its MMSI code and uses Chinese or English alarm accordingly. The power of the VHF transmitter of the smart terminal system is 1W, which meansthat merchant ships can preempt the channel with transmitters of 25W. Fishers can select the broadcast time period in the system menuand the default setting is at night.

The second-generation of the smart terminal of Class B AIS was introducedduring the time period from 2013 to 2014. It was welcomed by fishers and gained recognizationfrom the fishery administration. Such kind of Class B AIS was promoted when fishing vessels were updating their AIS equipment. Then, it has been widely used by fishers.

In the beginning, the automatic alarm function of the smart terminal of Class B AIS was introduced with the aim of reducing and preventing collision between fishing vessels and merchant ships. However, its wide use onboard Chinese fishing vessels along the coastal waters of China caused a series of troubles including the overuse of VHF Channel 16 and the fatigue of OOWs.

4.2 Advantages of the appilication of the smart terminal of class B AIS

Accoring to relevant manufacturers, during the trial period of the promotion of Class B AIS with smart terminal, the number of collision accidents between fishing vessels and merchant ships decreased significantly.

4.2.1 Improve the safety level of fishing vessels by giving merchant ships early warnings to avoid collision

Generally speaking, navigationaland communication equipment onboard fishing vessels are relatively less advancedcompared with those installed onboard merchant ships. Specifically, merchant ships establish communication on VHF while fishing vessels use fishery radio to contact with their partner ships. Only a few of fishing vessels have VHF on their bridge which a minority would use it to cantact with merchant ships. Consequently, when there is a potential risk of collision between these two types of ships, the two parties cannot coordinate actions conveniently in a way traditionally used by merchant ships. What's worse, since fishing vessels are usually of smaller tonnage andin poorer condition, a collision between merchant ships and fishing vessels would result in a tragedy in which the fishing vessel is destroyed and lives of fishers lost.

In such a contect, the smart terminal of Class BAIS achieves the following two functions: Firstly, to prevent marine accident by calling attention via VHF from an approaching merchant ship wheneverthe risk of collision exists; secondly, sending alarm to fishers on the bridge of a fishing vessels so that they can strengthen lookout and take actions accordingly.

4.2.2 Overcome language barriers between Chinese fishing vessels and foreign merchant ships

The smart terminal can automatically determine the ship's nationality by the MMSI codetransmitted in the AIS information. If the coming ship isa foreign ship, the system will automatically use English for voice message broadcast.This solves the problem that manyChinese fishers cannot communicate fluently in English. Therefore, this function is especially popular among fishers.

4.3 Drawbacks of the appilication of the smart terminal of Class B AIS

There are two main disadvanges, including the overuse of VHF Channel 16 and the overload information on OOWs,resulted from the wide use of the smart terminal of Class B AIS.

4.3.1 The broadcast is too frequent in dense fishing areas, occupying too many public resources on VHF Channel 16

In accordance with the Radio Regulations, only distress, urgency, very brief safety communications together with calls to establish communications which will then be conducted on another suitable working channel may use Channel 16. The first discipline contained in Resolution A.954(23) (IMO, 2004) which elaborates proper use of VHF channels at sea says that calling on channel 16 for purposes other than distress, urgency and very brief safety communications, when another channel is available, should be avoided.

In coastal waters of China where maritime traffic is extremely busy witha vast number of merchant ships and fishing vessels coming and going, the number of fishing vessels and that of merchant ships are not in the same order of magnitude (there are 863,900 Chinese domestic fishing vessels registered in 2018). As a result, the alarm condition set in the system of start terminal of Class B AIS can be met easilyand the frequency of voice message broadcasted automatically from fishing vessels will increase significantly. As all of them use the same channel, that is VHF Channel 16, to providethe approaching merchant ships with an early alarm, this channelcan be very busy and crowded with such a broadcast. According to the Radio Regulations, the VHF Channel 16 is designated as an international distress frequency for distress, urgency and safety priority calls. The frequency may also carry routine calls used to establish communication before switching to another working channel. But when conducting non-distress or non-emergency communications, it should avoided the radio silenceperiodsand be as quick as possible. However, it takes about

30 seconds for a smart terminal system to transmits one piece of voice message, not being able to meet the above radio telephone requirements. The long-playing and high-frequency broadcast on VHF Channel16 by the smart terminal of Class B from fishing vessels may lead to a situation where merchant ships may miss the best time to communicate and coordinate with other ships on VHF Channel 16, whichmight cause potential dangers to navigational safety at sea.

4.3.2 The prolonged voice message of high-frequency and low-quality can result in fatigue of OOWs

According to Regulation 12.3 of Chapter IV of SOLAS, everyship is required tostand by on VHF Channel 16 all the time during a voyage at sea.Here, ‘every ship’ refers to SOLAS ships as well as cargo ships of 300 GT and upwards based on the scope of application of SOLAS Chapter IV. But in dense fishing areas, according to incomplete statistics, the voice message broadcastedby the smart terminal of Class B AIS can occupy 62.5% of the time in a 4-hour duty period, resulting inauditoryand psychological fatigue of OOWs. At the same time, these voice messagesare produced by a speech synthesis system and are of various version. It could be a male voice, or a female voice, speaking in Mandarin or in English. What’s more, for one particular ship, since most of the broadcasts are targeted at other ships, the attention of OOWs and look-outs onboardto the information transmitted on VHF Channel 16 will decline gradually. In the worst situation, crews on the bridge of a merchant ship will selectively ignore the broadcast on VHF Channel 16 which is filled with automatic voice message. Then the good intention of such a device for fishing vessels to draw attention from approaching “risky” merchant ships fails.

4.4 Suggestions for improvement of the smart terminal of class B AISused onboard fishing vessels

4.4.1Promote the continuous optimization of the smart terminal of class B AISto balance the needs of all parties

The improvement of the smart terminalshould focus on solving the main problemsreflected during its practical use, that is, the prolonged occupation of VHF Channel 16 and its interference with OOWs onboard merchant ships.Therefore, a new mechanism should take into account the needs of both merchant ships and fishing vessels, so that fishing vessels can use this device to send early warning effectively and automatically to those merchantships after calculation, whenever risk of collision exist, while merchant ships will not be disturbed by the excessive and sometimes useless information transmitted on VHF Channel 16 and be able to keep a regular communication with other merchant ships on this channel.

A new smartsystem should consider giving priority to the use of DSC (Digital Selective Call) technology to make point-to-point calls to targeted merchant ships. The VHF equipment onboard merchant ships automatically monitors the Channel 70 to receive DSC calls. Aftercalculating CPA and TCPA for the determination of a potential risk of collision between the fishing vessel and an approaching merchant ship, the smart terminal of the Class B AIS can select a non-public channel and use the MMSI code of the incoming ship to initiate a point-to-point DSC call. The channel selected can be a specified and set-in-advance channel, or it can also be determined by scanningfor a free channel in real time.After receivinga DSC call on VHF from a fishing vessel, OOWs onboard merchant ships can pick up the call manually or allow an automatic acknowledgement. Then, the VHF device will automatically changethe channel specified by the calling party to establish communication between the two parties and after the establishenment of this communication link, the smart terminal can broadcast a pre-set voice message to remind mariners onboard merchant ships to pay attention to the potential collision risk.

In a case where the merchant ship does not respond to the DSC call and the risk of collision continues, after waiting for a certain period of time, or when the CPA and TCPA reduce to a specified value (the time period and the specified CPA / TCPA are to be determined with further discussions), the smart terminal can switch to VHF Channel 16 and make a call to warn the navigators onboard themerchant ship.

Through consultation with the relevant manufacturers who produce Class B AIS with the smart terminal, the suggestion proposed above is technically feasible. They can add a circuit for DSC call on the hardware and write a corresponding program in the software.

4.4.2Strengthen inter-ministerial cooperation andestablish industry standards for the smart terminal of Class B AIS

Collision preventionbetweenmerchant ships and fishing vessels has long been one of the priority topics of the competent authority for maritime safety, that is the Ministry of Transport and the competent authority for fishery production, namely the Ministry of Agriculture and Rural Affairs. With the rapid development of science and technology, more and more innovative practices will be used to solve thislong-standing problem. MOT and the MOAneed to expedite scientific and technological innovation as well as service innovation and strike a balance between the safety needs of both merchant ships and fishing vessels. At the same time, the two ministries should enhance inter-ministerial cooperation in regulation formulation and standard establishment. They need to transform innovations into equipment with maturedesign concepts and unified standards as soon as possible. The two parties should accumulateenough experience that can be replicated by administrations in supervising the use of such devices and share itwith the whole world. Meanwhile, MOT and MOA shouldwork togetherin international organizations such as IMO and ITU, proposing mature ideas with Chinese wisdom and China experiences.

4.5 Summary of Chapter IV

In general, the application of the smart terminal of Class B AIS onboard Chinese fishing vessels is a double-edged sword. On the on hand, it prevents collision accidents from happening between fishing vessels and merchant ships by giving early warnings in chosen language on VHF Channel 16. On the other hand, too often the voice message being transmitted on this public safety and emergency channel can lead to a congested frequency and the prolonged voice message of high-frequency and low-quality can result in information overloadonnavigators.

Therefore, manufacturers should optimize the collision prevention function of the smart terminal of class B AIS. This chapter introduces a new mechanism to establish point-to-point DSC call for the transmission of the safety message. Further, MOT and MOA should strength collaboration in orderto establish industrial standards and management regulations for the proper use of such a device.

Chapter 5 CONCLUSIONS AND SUGGESTIONS

With an aim to protect fishing nets from being damaged by merchant ships passing by, fishers install AIS FNLs on their valuable tools which can then be located with AIS signals and shown on radar screens. But challenges come along including that in areas with dense fishing nets, such a large quantity of AIS FNLs, which may transmit without listen on the time slot, occupy too many resources of AIS channel. Besides, as a newly emerged AIS application, AIS FNLs at present can only be displayed as green triangles, blue diamonds or yellow diamonds, using symbols originally designated for ships and AtoNs. This use may confuse navigators who might find it difficult to identify real ships from many AIS FNLs on the radar screen. Moreover, AIS equipment on board merchant ships have limited capability to receive AIS information transmitted from other stations. If the shipborne receiver was occupied with too many AIS FNLs, important messages from merchant ships may be missed.

For the Smart Terminal of Class B AIS fitted onboard fishing vessels, it broadcasts early warning calls automatically on VHF channel 16 with a purpose to avoid collision with merchant ships in the vicinity. However, the voice message, which contains the name, call sign, MMSI, relative position and distance of the approaching vesseland a sentence to remind the targeted vessel to stay away, which takes more than 30 seconds. On this channel for distress, urgency and safety calls, in waters with dense fishing vessels, the high frequency of broadcasts from the Smart Terminal of Class B AIS occupies too many resources and leads to auditory fatigue of OOWs. This result is not conducive to the safe navigation of merchant vessels.

In coastal waters of China, the traffic is extremely dense with a huge number of merchant ships and shipping vessels coming and going. The development and utilization of the two AIS-based equipment are both innovative maritime practices based on this reality. To a certain extent, they have served as a reminder for fishing vessels to alert merchant ships nearby for the protection of fishing nets and collision avoidance between the two types of ships. But the wide use of these two kinds of equipment, especially the spreading application of AIS FNLs, has caused interference in the communication channels originally used for navigation safety, collision avoidance and distress alert. As a result, navigation environment along the coast of China becomes more and more complex.

According to the ITU Radio Regulations, if the primary functions of AIS can be guaranteed, it is allowed to use AIS for other sorts of communications related to maritime safety, besides ship to ship use and VTS applications. And the AIS system can be expanded for future use by many users for diverse applications. Therefore, AIS FNLs can use bits reserved in AIS to establish their own identity with a newly created symbol. With a unique mark and a unified naming convention, AIS FNLs can then be identified by navigators on board merchant ships and are possible to contribute more to the safety of navigation and the protection of fishing nets. In addition, design and allocate AIS FNLs based on primary-secondary mode can save time slots used by these devices.

For the Smart Terminal of AIS FNLs, a new smart system giving priority to the use of DSC (Digital Selective Call) technology to make point-to-point calls to targeted merchant ships can be considered. Regulations should be established. And MOT and MOA should enhance cooperation for the promotion of proper use of AIS and VHF technologies.

REFERENCES

Bertaska, I. R., Alvarez, J., Sinisterra, A., von Ellenrieder, K., Dhanak, M., Shah, B., et al. (2013). Experimental evaluation of approach behavior for autonomous surface vehicles. In *Proceedings of ASME 2013 dynamic systems and control conference*. American Society of Mechanical Engineers, V002T32A003.

Bole, A., Wall, A., & Norris A. (2014). *Radar and ARPA Manual.* ELSEVIER.

Campbell, S., Naeem, W., & Irwin, G. W. (2012). A review on improving the autonomy of unmanned surface vehicles through intelligent collision avoidance manoeuvres. *Annual Reviews in Control, 36,* 267-283.

El-Gaaly, T., Tomaszewski, C., Valada, A., Velagapudi, P., Kannan, B., & Scerri, P. (2013). Visual obstacle avoidance for autonomous watercraft using smartphones. In *Proceedings of autonomous robots and multirobot systems workshop*.

Federal Communications Commission. (2018, November 28). *FCC rules prohibit marketing, sale, or use of fishing net buoys that use radio frequencies reserved for marine navigation safety communications (Enforcement Advisory No. 2018-04)*. Washington, D.C.: Author.

Fossen, T. I. (1994). Guidance and control of ocean vehicles: Vol. 199. New York: Wiley

Fossen, T. I. (2002). *Marine Control Systems – Guidance. Navigation, and Control of Ships, Rigs and Underwater Vehicles.* Marine Cybernetics, Trondheim, Norway.

Fossen, T. I. (2011). *Handbook of Marine Craft Hydrodynamics and Motion Control.* John Wiley & Sons.

Gao, S. (2006). Research and development of shipborne automatic identification system. *Tianjin Hanghai, 2,* 47-50.

Gong, J., & Tang, H. (2015). The collision avoidance system provides protection for fishing boats. *China Ship Survey, 6,* 92-93, 126-127.

Guo, X. F., Hu, Q., & Li, L. (2019). *Research on technical standard for autonomous maritime radio device (AMRD).* Unpublished research paper, Beihai Navigation safety Center, Tianjin, China.

Han, W. (2008). Several issues to be considered in application of AIS (Class B) Ship Station. *China Maritime Safety, 8,* 34-37.

Heidarsson, H. K., & Sukhatme, G. (2011). Obstacle detection and avoidance for an autonomous surface vehicle using a profiling sonar. In *Proceedings of IEEE inter- national conference on robotics and automation* (pp. 731–736).

Hu, B. H. (2013). Discussion on the application of AIS on fishing vessels. *China Water Transport, 13* (6), 60-63.

Insurance Marine News. (2010). AIS misuse is causing problems for vessels in fishing waters. Retrieved April 23, 2020 from the world wide web: https://insurancemarinenews.com/insurance-marine-news/ais-misuse-is-causing-problems-for-vessels-in-fishing-waters/

International Convention for the Safety of Life at Sea 1974, IMO, (1974).

International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 2010, IMO, (2010).

International Maritime Organization. (1997, June 6). *Adoption of amendments to performance standards for shipborne radiocommunication equipment: submitted by Secretariat* (MSC.68(68)). London: Author.

International Maritime Organization. (1998, May 12). *Recommendation on performance standard for universal Automatic Identification System (AIS): submitted by Secretariat* (ANNEX 3 of Resolution MSC.74(69)). London: Author.

International Maritime Organization. (2002, May 21). *Maintenance of a continuous listening watch on VHF channel 16 by SOLAS ships whilst at sea after 1 February 1999 and installation of VHF DSC facilities on non-SOLAS ships: submitted by Secretariat* (MSC.131(75)). London: Author.

International Maritime Organization. (2004, February 26). *Proper use of VHF channels at sea: submitted by Secretariat* (A 23/Res.954). London: Author.

International Maritime Organization. (2007, October 22). *Guidelines on annual testing of the Automatic Identification System (AIS): submitted by Secretariat* (MSC.1/Circ.1252). London: Author.

International Maritime Organization. (2007, October 8). *Performance Standards for Survival Craft AIS Search and Rescue Transmitters (AIS-SART) for Use in Search and Rescue Operations: submitted by Secretariat* (Resolution MSC.246(83)). London: Author.

International Maritime Organization. (2014a, May 23). *Policy on use of AIS aids to navigation: submitted by Secretariat* (MSC.1/Circ.1473). London: Author.

International Maritime Organization. (2014b, May 23). *Amended guidelines for the presentation of navigational-related symbols, terms and abbreviations:*

submitted by Secretariat (SN.1/Circ.243/Rev.1). London: Author.

International Maritime Organization. (2015, December 14). *Revised guidelines for the onboard operational use of Shipborne Automatic Identification Systems (AIS): submitted by Secretariat* (A.1106(29)). London: Author.

International Maritime Organization. (2017, February 27). *Maritime Autonomous Surface Ships Proposal for a regulatory scoping exercise: submitted by Denmark, Estonia, Finland, Japan, the Netherlands, Norway, the Republic of Korea, the United Kingdom and the United States* (MSC 98/20/2). London: Author.

International Maritime Organization. (2018a, December 12). *Report of the maritime safety committee on its one hundredth session: submitted by Secretariat* (MSC 100/20/Add.1). London: Author.

International Maritime Organization. (2018b, May 1). *Report of the legal committee on the work of its 105th session: submitted by Secretariat* (LEG 105/14). London: Author.

International Maritime Organization. (2018c, June 5). *Report of the maritime safety committee on its ninety-ninth session: submitted by Secretariat* (MSC 99/22). London: Author.

International Maritime Organization. (2019a, January 10). *Report of the maritime safety committee on its one hundredth session: submitted by Secretariat* (MSC 100/20). London: Author.

International Maritime Organization. (2019b, August 2). *Consideration of the results of the first step of the regulatory scoping exercise Summary of results of the first step of the RSE for SOLAS chapter V: submitted by China* (ISWG/MASS 1/2/16). London: Author.

International Maritime Organization. (2020, August 2). *Regulatory scoping exercise for the use of Maritime Autonomous Surface Ships (MASS) Summary of results of the second step of the RSE for SOLAS chapter V: submitted by China* (MSC 102/5/9). London: Author.

International Telecommunication Union. (2014, February). *Technical characteristics for an automatic identification system using time division multiple access in the VHF maritime mobile frequency band: submitted by Secretariat* (Recommendation ITU-R M.1371-5). Geneva: Author.

International Telecommunication Union. (2018, November 13). *Working document towards a preliminary draft new recommendation ITU-R M. [AMRD] Technical characteristics of autonomous maritime radio devices operating in* *the frequency band 156-162.05 MHz: submitted by Secretariat* (Document 5B/TEMP/274-E). Geneva: Author.

International Telecommunication Union. (2019, October). *Technical characteristics of autonomous maritime radio devices operating in the frequency band 156-162.05 MHz: submitted by Secretariat* (Recommendation ITU-R M.2135-0). Geneva: Author.

Jiang, K. Y. (2008). Application of AIS in the fishery industry. *China Fisheries, 6,* 29-31.

Kendoul, F. (2012). Survey of advances in guidance, navigation, and control of unmanned rotorcraft systems. *Journal of Field Robotics, 29*(2), 315–378.

Kim, H., Kim, D., Shin, J. U., Kim, H., & Myung, H. (2014). Angular rate-constrained path planning algorithm for unmanned surface vehicles. *Ocean Engineering, 84,* 37–44.

Lei, W. Q., & Chang, P. (2019). Discussion on the significance of enhancing navigation safety through regulating auto waterborne radio equipment. *China Maritime Safety, 5,* 46-50.

Liu, F. L. (2018). Application, research and prospect of Autonomous Maritime Radio Devices. *Digital Communication World, 4,* 30-31.

Liu, X., He, W., Chu, X., & Lv, Y. (2017). Design and application of fishing net locater based on Beidou navigation system. *Journal of Minjiang University, 5,* 36-42.

Liu, Z. X., Zhang, Y. M., Yu, X., & Yuan, C. (2016). Unmanned surface vehicles: An overview of developments and challenges. *Annual Reviews in Control, 41,* 71-93. http://dx.doi.org/10.1016/j.arcontrol.2016.04.018

Maritime Labour Convention (2006), ILO, 2006.

Naeem, W., Irwin, G. W., & Yang, A. (2012). COLREGs-based collision avoidance strategies for unmanned surface vehicles. *Mechatronics, 22* (6), 669-678.

Onunka, C., Bright, G., & Stopforth, R. (2013). Probabilistic uncertainty identification modelling in USV obstacle detection. *Journal of the South African Institution of Mechanical Engineering, 29,* 36–43.

Radio Regulations, ITU, (2020).

Soltan, R. A., Ashrafiuon, H., & Muske, K. R. (2011). ODE-based obstacle avoidance and trajectory planning for unmanned surface vessels. *Robotica, 29* (5), 691-703.

Wang, Z., Wang, Y. & Jiang, Q. (2019). Application of AIS onboard fishing vessels and its prospect. *Digital Communication World, 49,* 157-158.

Xu, B., Stilwell, D. J., & Kurdila, A. J. (2013). Fast path re-planning based on fast marching and level sets. *Journal of Intelligent & Robotic Systems, 71* (3–4), 303–317.

Yakimenko, O., & Kragelund, S. (2011). Real-time optimal guidance and obstacle avoidance for UMVS. In *Autonomous underwater vehicles*. New York: InTech.

Yang, Z. N., Wei, L., & Lin, Y. S. (2020). Brief discussion on the development of fishing vessel AIS intelligent terminal and associated counter measures from the point of view of marine transport safety management. *China Maritime Safety, 7,* 37-38. DOI:10.16831/j.cnki.issn1673-2278.2020.07.017

Yu, X., & Zhang, Y. M. (2015). Sense and avoid technologies with applications to unmanned aircraft systems: Review and prospects. *Progress in Aerospace Sciences, 74,* 152-166.

Zhang, G. (2003). The development status and application prospect of AIS technology. *Port Science & Technology, 6,* 16-18.