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The future is coming : research on maritime communication technology for realization of intelligent ship and its impacts on future maritime management

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WORLD MARITIME UNIVERSITY

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THE FUTURE IS COMING:

Research on Maritime Communication Technology for Realization of Intelligent Ship and its Impacts on Future Maritime Management

By

KE JIACHENG

The People's Republic of China

A research paper submitted to the World Maritime University in partial Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)

2017

DECLARATION

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

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

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(Date): 29th June, 2017

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Professor

Dalian Maritime University

Assessor: ________________

Co-assessor:_______________

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Fate is sometimes wonderful. After ten years, as a new student again, I went back to Dalian Maritime University (DMU) to study. I am so proud to be a member of Maritime Safety and Environmental Management (MSEM) at World Maritime University (WMU) and DMU that the past 13 months will always be part of the best memories of my life. The study would not have succeeded without the generous support of the people and organizations to which I would like to express my thanks.

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Last but not the least, my deepest gratitude goes to all my family members for their constant encouragement and support by which I can finish the project with full energy, especially my beloved new born daughter. Your coming to the world, lights up my whole world. Your smile is the best drive for me never to give up!

ABSTRACT

Title of Research Paper: **The Future is Coming: Research on Maritime Communication Technology for Realization of Intelligent Ship and its Impacts on Future Maritime Management**

Degree: **MSc**

People are not unfamiliar with the word AI, yet the word which often appears in science fiction movies before, is frequently appearing in the news currently. Some call it the fourth industrial revolution, and the shipping industry will certainly be affected by it.

The development of intelligent ship is a hot topic in shipbuilding industry, the widespread concern of intelligent ship derives from its relative advantages over conventional ships. First of all, the author summarized the shortcomings of conventional ship and analyze the superiority of intelligent ship in this paper. Furthermore, combing with the E-Navigation strategy, the communication technology which plays the core role for the realization of intelligent ship was introduced in detail. The ultimate goal of intelligent ship is to realize unmanned ship. The reduction or disappearance of seafarers will bring an earthquake for the shipping industry. In the end of this paper, as a law enforcement officials in China MSA, the author discussed the impact of unmanned shipping on maritime management, recommended the relevant aspects to study further.

KEY WORDS: Artificial Intelligence (AI), Intelligent Ship, Communication Technology, e-Navigation, Future Maritime Management

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LIST OF ABBREVIATIONS

AAWA	Advanced Autonomous Waterborne Applications
ADSL	Asymmetrical Digital Subscriber Loop
AI	Artificial Intelligence,
AIS	Automatic Identification System
ANS	Automatic Navigation System
BDI	Baltic Dry Index
BDS	Beidou Navigation Satellite System
BGAN	Broadband Global Area Network
CCS	Chinese Classification Society
COLREG	Convention on the International Regulations for Preventing Collisions at Sea
CPS	Cyber-Physical System
CR	Cognitive Radio
CSSC	China State Shipbuilding Corporation
DP	Dynamic Positioning
DTN	Delay Tolerant Networks
ECDIS	Electronic Chart Display and Information System
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
GAN	Global Area Network
GHG	Greenhouse Gas
GPS	Global Positioning System
HFO	Heavy Fuel Oil
IALA	International Association of Lighthouse Authorities
IEA	International Energy Agency

IEC	International Electrotechnical Commission
IHO	International Hydrographic Organization
ILO	International Labor Organization
IMO	International Maritime Organization
INMARSAT	International Maritime Satellite Organization
IPN	Interpenetrating Polymer Network
ISPPC	International Sewage Pollution Prevention Certificate
ISDN	Integrated Services Digital Network
ITU	International Telecommunication Union
LAN	Local Area Network,
MAN	Metropolitan Area Network
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MIMO	Multiple-Input and Multiple-Output
MLIT	Ministry of Land, Infrastructure, Transportation and Tourism of Japan
MSC	Maritime Safety Committee
MUNIN	Maritime Unmanned Navigation through Intelligence in Network
NHTSA	National Highway Traffic Safety Administration of United States
NO_x	Nitrogen Oxides
R-BGAN	Regional Broadband Global Area Network
SA	Situational Awareness
SBC	Safety Board of Canada
SCC	Shore Control Center
SDR	Software Defined Radio
SEEMP	Ship Energy Efficiency Management Plan
SMAA	Shipowners Mutual Assurance Association

SOLAS	International Convention for the Safety of Life at Sea
SOC	System on Chip
SO_x	Sulphur Oxides
SSD	Ship State Definition
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers,
UAV	Unmanned aerial vehicle
USV	Unmanned Surface Vessel
VC	Virtual Captain
VDR	Voyage Data Recorder
VHF	Very High Frequency
VSAT	Very Small Aperture Terminal
VTS	Vessel Traffic System
WAN	Wide Area Network
WIC	World Internet Conference
WiMAX	Worldwide Interoperability for Microwave Access
WSN	Wireless Sensor Network

CHAPTER 1

INTRODUCTION

1.1 a Game Ended in Defeat - a Prelude of an Era

In May 2017, AlphaGo, an artificial intelligence (AI) computer of Google, challenged the world’s No. 1 human chess player Ke Jie. After the game, Ke lost the first battle. Just few months ago, AlphaGo had beat the master go player Lee Sedol 3-0 in a best-of-five competition. (See figure 1.1)

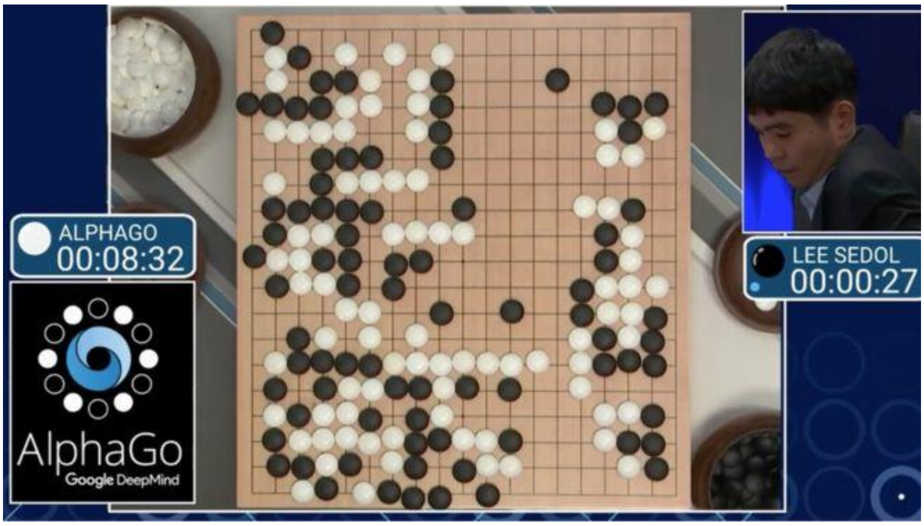

Figure 1. 1 - A landmark moment for AI

Source: Pictures from BBC NEWS. (2017)

Before the start of this man-machine battle, Li Kaifu, the former president of Google in Greater China, said publicly: Ke will lose without suspense. According to the international professional go grading system Elo rating, it can be calculated that the winning probability of AlphaGo is 99.8%. (David Silver, 2016) It is no exaggeration to say that this is a match between a crane and a weightlifter. That's the real victory of AI. In the past one year, the successive failures of human masters may be the beginning of a great story. In the next decade, if the AI which owns the ability to determine accurately obtains a wide range of applications, the financial, medical, legal, transportation, public security and other fields will undergo enormous changes. Just like the Internet has changed the world so great over the past 20 years, we can imagine that the intelligent technology will be in the same role over the coming decades.

The shipping industry plays an important role in the process of globalization, as more than 90% of the global trade is carried out by sea. (Yi, 2016) To some extent, its efficiency directly determines the development of the global economy. Although the global economic situation has not been clear in recent years, the world seaborne trade volumes have generally moved in tandem with economic growth, industrial activity and merchandise trade, albeit at varied speeds. (See Figure 1-2)

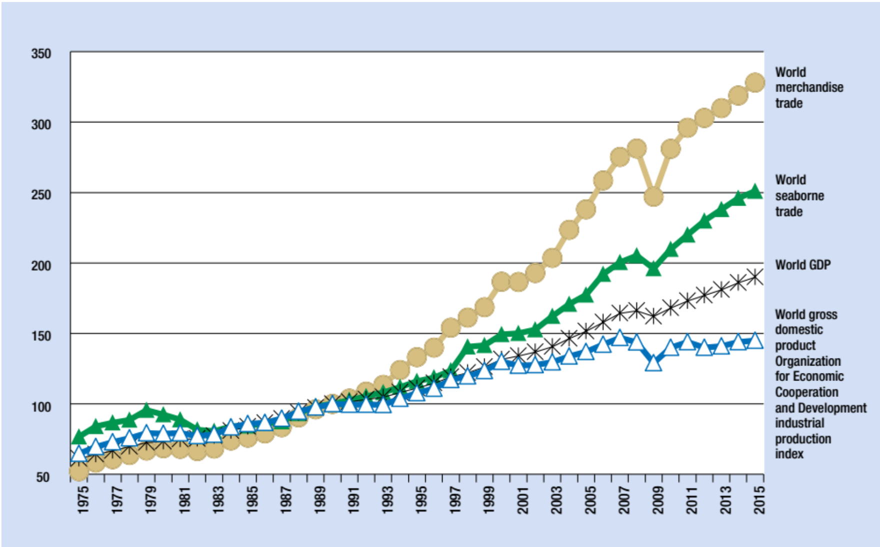

Figure 1. 2 - the world seaborne trade volume, 1975-2015

Source: UNCTAD. (2016). *Review of Maritime Transport*

In 2016, the Baltic Dry Index (BDI), which is the vane of global shipping industry, was hit by a record low. Such a bad start has left the industry mired in a sense of pessimism. Although the index had risen somewhat later, the market was still at a low ebb. (See Figure 1.3) Eight years after the financial crisis, the global economy is still weak, the core problem of the global economy has changed from growth to development. The future of the global economy is no longer depending on easing or stimulus, it will depend on the improvement of total factor productivity by improve the production efficiency. (Li, 2014)

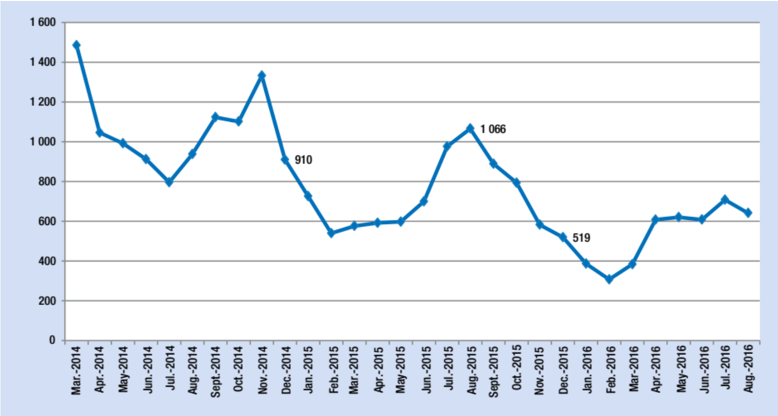

Figure 1. 3 - Baltic Dry Index, 2014–2016

Source: UNCTAD. (2016). *Review of Maritime Transport, (1985 = 1,000 points)*

The rapid development of intelligent technology may give a fillip to the shipping industry. (Zhang, 2014) At present, the efficiency of the navigation mainly depends on experience and knowledge of the crews, this mode will inevitably exist inappropriate decision and operation, resulting in unnecessary manpower or financial loss. The intelligent ship is based on big data, and applies the advanced information technology to realize the perception, judgement and analysis, as well as decision-making and control, so as to ensure the safety and efficiency of the ship. Therefore, the basic functions of intelligent ship are safety, economy, efficiency and environmental protection. The concept of intelligent ship is not new. It has been around for decades. The difference is that today we have mastered most key technology of it. Many famous ship research and development institutions have identified the research of intelligent ship as one of the focuses of future task. Intelligent ship represents the future trend of the shipping industry, just as the smartphone has changed the whole communication industry in short time. (Li et al, 2015) Vendors which did not keep pace with the times were soon eliminated. In order to gain an advantage in the future competition, the governments have also expressed concern and policy support for the intelligent ship and china is no exception.

On May 2, 2017, the China's Ministry of Transport and the Ministry of Science and Technology released an announcement about special planning in the field of the traffic scientific and technological innovation in the period of the 13th Five-Year. The development targets of intelligent ships are pointed out clearly. (See Figure 1.4)


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科技部 交通运输部关于印发"十三五"交通领域科技创新专项规划的通知

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2017年5月2日

Figure 1. 4 - the policy of developing intelligent ship in China

Source: the official website of the Ministry of Transport. (2017)

http://zizhan.mot.gov.cn/zfxxgk/bnssj/kjs/201706/t20170607_2215134.html

Intelligent ship is the product of technological progress. In various fields of science and technology, the breakthroughs in communication technology have laid the foundation for the realization of intelligent ships. The communication devices and network construction methods determine the level of intellectualization. Combining China's actual situation, develop more suitable communication technology is of great significance to the future of Chinese shipping industry. The highest level of intelligent ships is unmanned. Then the crew will reduce or even disappear, that will bring a huge change to the traditional shipping industry, and also bring meditation to us.

1.2 Objectives of Research

The previous article has expounded the significance of intelligent technology. The realization of intelligent ships will have immeasurable impact on shipping industry. In China, the exploration and research in the field of intelligent merchant ship is still in its infancy. It is of great significance for the Chinese relevant administrations to look for the gaps and formulate technical standards and regulation. Therefore, the objectives of this research paper are listed as follows:

a) Critically review the drawbacks of conventional ship;
b) Analyze the superiority of intelligent ship;
c) Summarize the latest developments trends of intelligent ship;
d) Introduce the key technologies of intelligent ship, especially the modern communication technology.
e) Discuss the impact of unmanned ship on the international conventions and future maritime supervision.

1.3 Methodology

The intelligent ship involves multi-disciplinary fields of understanding however the focus of this research paper has been put on the technical, and regulatory aspects only.

The research work for this dissertation in chapter 2, 3, 5 and 6 are based on wide range of literature review such as International Maritime Organization (IMO) documents, international conventions, journals and information on websites. The materials of Maritime Unmanned Navigation through Intelligence in Network (MUNIN) and Advanced Autonomous Waterborne Applications (AAWA) project were reviewed to get up to date knowledge of Ship Intelligence.

The author had repeatedly exchanged questions with the DNV GL through e-mail, and understand the dynamic states of the intelligent ship industry. Opinions and advices of the supervisors Dr. Yang (DMU) were exchanged all through the research work.

1.4 Structure of the Research Paper

The research paper is mainly comprised of seven chapters: **Chapter one** provides background information, research objectives and methodologies to be used in subsequent parts; **Chapter two** broadly reviews the development history of intelligent ship and introduce the latest trend of shipping intelligence; **Chapter three** critically reviews the drawbacks of the conventional ship, from the two main aspects of safety and environment, analyze the and shortcomings and introduce the superiority of intelligent ship; **Chapter four** summarizes the key technology of the intelligent ship and the current official standard about it; **Chapter five** primarily summarizes the communication technology for realization of intelligent ship, combing with the E-Navigation strategy; **Chapter six** discuss the impact of unmanned ship on the international conventions and future maritime supervision. **Chapter seven** makes final summary and conclusion, highlights and limitations of this research paper and implications for further researches also have been outlined

CHAPTER 2

BOOMING OF AI TRANSPORTATION

AND RAPID DEVELOPMENT OF INTELLIGENT SHIP

2.1 AI Technology Applied in Transportation

2.1.1 AI in Land Transportation

In recent years, the AI technology has made significant breakthroughs in many fields, among which are closely related to everyone's life, the driverless cars are beginning to come into view. (Xu & Zhang, 2017). On May 8, 2012, the Motor Vehicle Management Service in Nevada issued the legal license plate for the Google driverless car. (See Figure 2.1) The Google driverless car uses a detailed map for navigation, tracks objects nearby with the radar, and analyze the different pavement and boundary lines to identify Lane markings by the camera loading on the front windshield of the car. In addition, the Google driverless car is also equipped with a stereo vision system, laser ranging system, GPS/ inertial navigation system, and wheel angle encoding system.

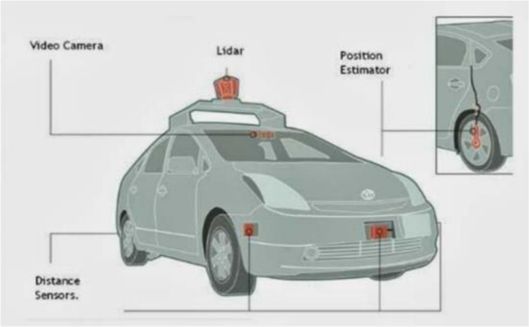


Figure 2. 1 - The Google Driverless Car and its work principle

Source: Shweta N. D. et al. (2016). The Google Driverless Car. *International Journal of Scientific Research in Science, Engineering and Technology*

All these the data from the systems get together into the high-speed central processing system, thus, the driverless car can be rapid and accurate in the perception of traffic information and make right judgments. (See Figure 2.2)

Figure 2. 2 - Google Driverless Car on the road

Source: Lang S. Y., Zeng X. G. & Zhao Y. Y. (2016). The future ship: form manning to unmanned. China Ship Survey

At present, the major automobile manufacturing company all take the unmanned vehicle project incorporated into their roadmap of development. In May 2015, the Google said its driverless car program was developing from the automated status to exclude human intervention completely. In December 2015, the Baidu (a Chinese company) driverless car project realized fully automatic driving on the mixed road among the city, the loop and the highway for the first time, and it planned to realize commercialization in three years, achieve mass production in five years. In addition, BBA, Volvo, Ford and other car manufacturers have also launched their own unmanned driving technology project now.

2.1.2 AI in Aerial Transportation

Unmanned aerial vehicle (UAV) is an important means of early warning in the air, battlefield investigation and surveillance and precise attack in the future informational warfare. Besides the military applications, the UAV also begins to be significant in the field of civil usage. Now, the UAV have been used for aviation photography, traffic patrol and disaster monitoring etc.

In December 2013, Jeff Bezos, the CEO of Amazon, announced a trial on a plan which is using the UAV Amazon Prime Air to carry out the delivery in the United States, but due to the restrictions of the U.S. Federal Aviation Administration on the UAV, the plan fails to implement in 2015. (See Figure 2.3) In September 2014, German DHL (DHL, Dalsey, Hillblom and Lynn) delivered a batch of drug to Iceland with the drones successfully. This is the first time to change the concept for UAV delivery service into reality in the global scope.

Figure 2. 3- Amazon Prime Air. A future delivery system.

Source: News picture. (2013)

http://www.politico.com/gallery/2013/12/billionaires-and-their-toys-001327?slide=0

The Chinses company SF express also carried out the delivery service plan basing on the UAVs, and it has completed the test in Dongguan (Guangdong Province). At present, SF express unmanned aircraft delivery services are mainly applied for the remote areas where the human delivery is difficult, they use UAVs for distribution between different outlets. On December 16, 2015 in Second World Internet Conference (WIC) in Wuzhen, Liu Qiangdong, the chairman of the board of directors of JD Group, is also actively committed to the development of UAV delivery, to ensure the realization of "the last mile distribution" for the remote areas.

2.1.3 AI in Marine Transportation

Compared with rapid development of the driverless car and UAV in the field of AI technology, the research of unmanned ship has experienced a long time, but it still had been in a relatively backward state. (Zhang, 2016). In recent years, the intelligent level of ships has been continuously improved, and the new concepts and technologies emerge in endlessly, such as the big data, cloud computing and the Internet of things. The realization of unmanned ship has owned the hardware foundation and scientific and technological support. (See Figure 2.4) With the continuous development and research of unmanned ship technology, it is possible to see the unmanned vessels sailing on the sea commonly in the coming future.

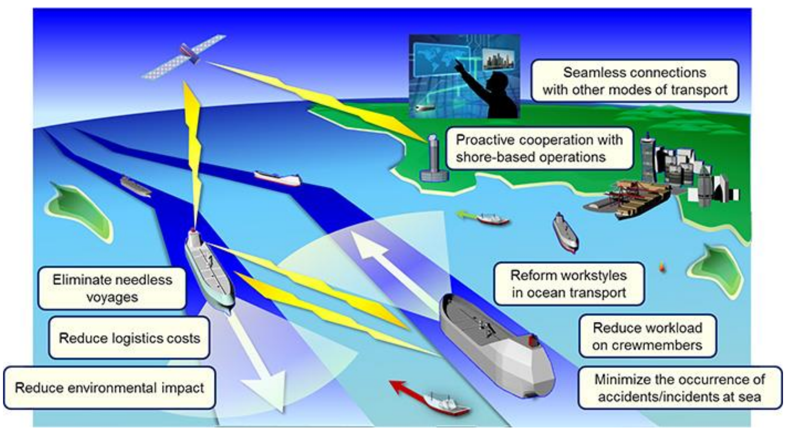


Figure 2. 4 - Intelligent marine transportation

Source: picture form DNV presentation material. (2017)

2.2 The Intelligent Ship

2.2.1 Difference and Relationship Between Intelligent Ship and Unmanned Ship

What is the relationship between intelligent ships and unmanned ships mentioned in this paper? If the ship applied the intelligent technology during either the period of shipbuilding or operation, it can be called the intelligent ship. (Qi, 2015) Figure 2.5 illustrates how the conceptual increase in autonomy from a simple and robust fail to safe mechanism via automatic, autonomous and up to “intelligent” control reduces the “determinism” of the control system.

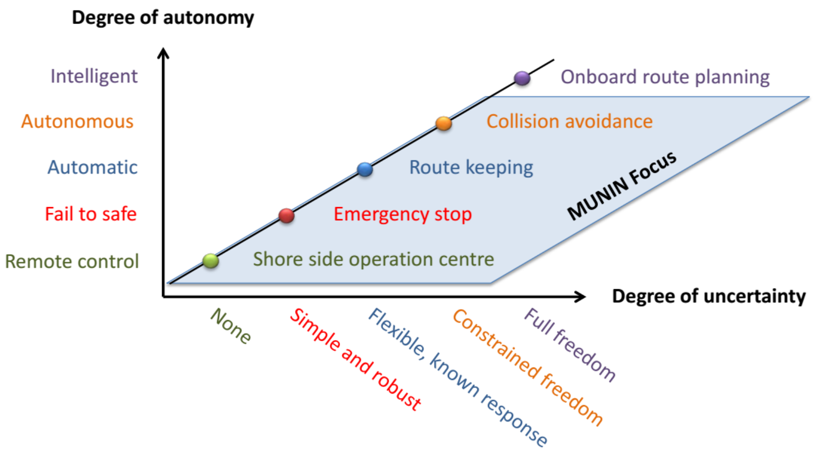


Figure 2. 5 - Autonomy vs. uncertainty

Source: MUNIN project related research materials. (2015)

As far as the present level of science and technology, the unmanned ship, which is the same concept as the autonomous ship, is the ultimate form of intelligence ship and it represents the highest level of intelligent technology. (Huang, 2015) At present, completely unmanned merchant ship might not be a very realistic scenario in the near future, the distance of the realization of completely unmanned shipping can be divided into several stages. (See Figure 2.6)

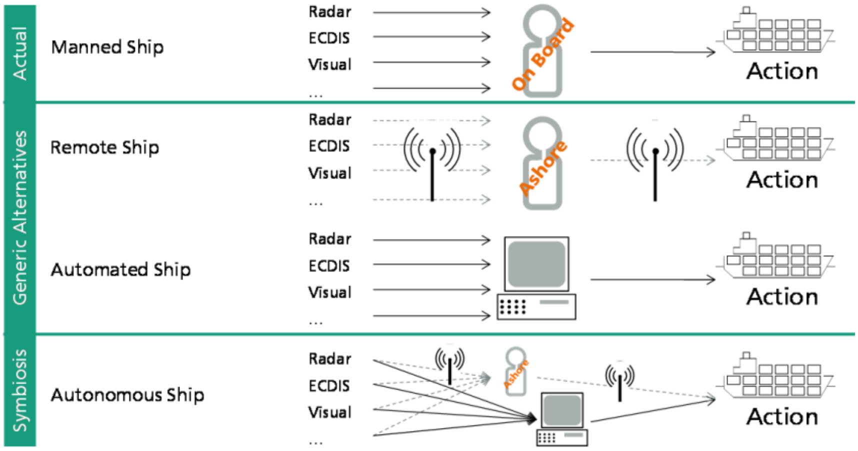


Figure 2. 6- From manned to autonomous ship

Source: MUNIN project related research materials. (2014)

2.2.2 Development History of Intelligent Ship

What must be said is that the conception of intelligent ship is not new. There is a long way for the exploration on it. (Zhang, 2016) In 1986 in Japan, the Intelligent Ship Project introduced the idea of unmanned robot ships navigating in a convoy. It aimed at bringing about the intelligent ship that can function without help from the crew. In 1994, a similar concept was expressed by the naval architect Kai Levander regarding a crewless ship operating in inland waters. That was “Ship without crew” for short-sea shipping. They want to build a ship with no crew onboard which could travel aided by the GPS chain and guided from the traffic stations. Pilots could board near the harbor and take the ship into port. An automated mooring system secures the ship to the quay without help from the crew. In 1996, Bertram & Kaeding, carried out the combination of AI and tele-operation. It is a bold attempt and exploration. Yet it is feasible but not economically attractive, due to the high maintenance cost. After entering the twenty-first Century, with the development of communications and navigation technology, the research of intelligent ship has made great progress, and the intelligent ship has come into a new period of rapid development.

In 2007, the Waterborne TP, a cluster of European maritime stakeholders, proposed the definition of the autonomous ship in a vision paper concerning the future developments in the shipping industry. In the same year, the United States Navy issued the Navy Unmanned Surface Vessel (USV) Program, which pointed out the future direction of USV for academia and relevant industry. This program divided the involved technology into two kinds: mature technology but not mature in application and immature technology. The former one includes the hull release and recovery technology, control technology, conventional weapons assembly technology; the latter one includes the autonomy technology, automatic target identification technology, automatic collision avoidance and obstacle avoidance technology etc.

In 2012, the DNV GL introduced the concept of ReVolt, which is a kind of short-sea cargo ship. (See Figure 2.7) It is Unmanned container feeder vessel which is battery powered and sails in the territorial waters of Norway.

Figure 2. 7- DNV-GL ReVolt Concept ship

Source: https://www.dnvgl.com/technology-innovation/revolt/index.html

In the September of 2012, the European Commission funded 3.8 million dollars in the Maritime Unmanned Navigation through Intelligence in Network (MUNIN) project. It is a test of unmanned bulk carrier simulation. The MUNIN project aimed to propose the concept of unmanned vessels and verify their feasibility. The operation model of MUNIN project is multilateral. (See Figure 2.8)

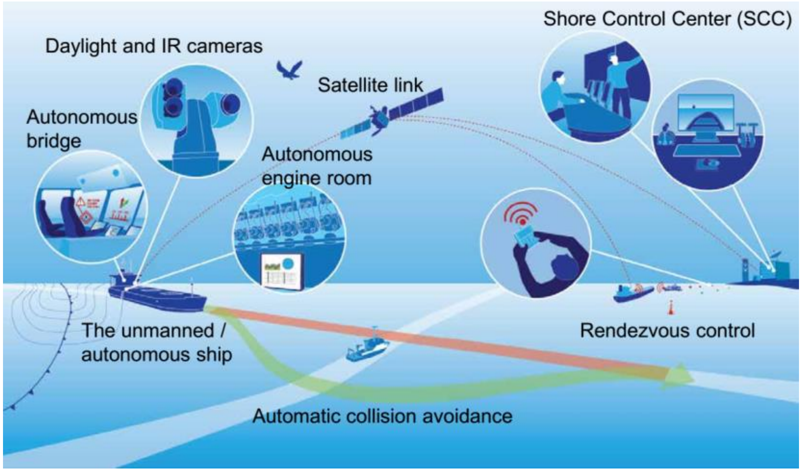


Figure 2. 8 - MUNIN vision

Source: Ørnulf Jan Rødseth. (2014). Beyond the e-Navigation implementation plan: Development towards the unmanned merchant vessel

The research project includes target detection on the water surface, automatic control of the engine, autonomous navigation and shore based remote control. (See Figure 2.9) The ship mainly relies on its independent decision-making system on board to achieve autonomous navigation. At the same time, all the parameters of the sensors sent back to the control center on shore through the real-time satellite, which is controlled by the remoted control personnel. Even if it is doubtful whether the unmanned merchant ships will be a reality in the short term, the concept of an autonomous ship provides an important pathway for a sustainable development of maritime transport.

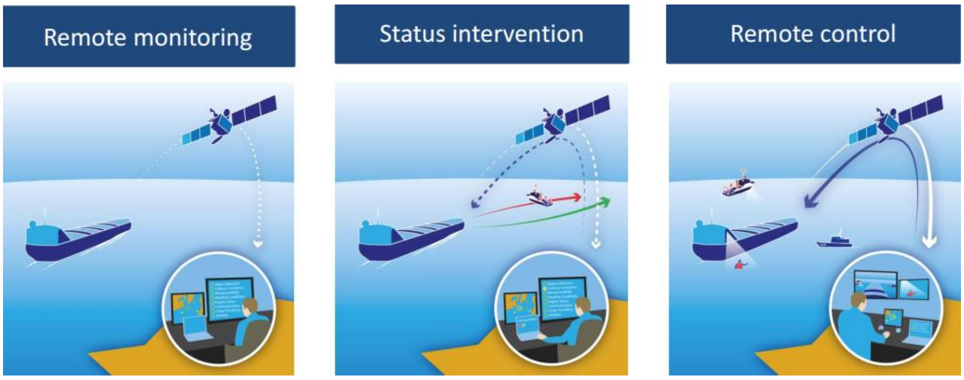


Figure 2. 9 - Operational Modes of MUNIN
Source: MUNIN project related research materials. (2014)

In 2013, a strong interest was also expressed by Rolls-Royce that introduced the concept of a remote-controlled containership. Oskar Levander, the vice president of innovation, engineer and technology in Rolls-Royce, announced that his company would focus on technology research of intelligent ships and related fields. They have designed and described the details about the industrial design and working model of the intelligent ship. They named this project the Advanced Autonomous Waterborne Applications (AAWA). (See Figure 2.10) It seems that the Rolls-Royce want to play a major role in the future developments.

Figure 2. 10- The AAWA project and its timeline
Source: Compiled by the author based on the information from the Rolls-Royce marine magazine （27th May 2016）

2.2.3 Big Moves in the First Half of 2017

2.2.3.1 Norway: YARA

Norway has been a leader in the adoption of electric cars and it has experimented with electric-powered ferries to cross its famous fjords. In May 2017, the fertilizer company Yara and industrial group Kongsberg announced that the two sides have teamed up to build the “YARA Birkeland”, which is the world's first fully electric propulsion and self-sailing cargo ship, and it will achieve zero emission. Initially the ship will be manned in 2018, but remote operation is expected to begin in 2019 and fully autonomous operation in 2020. (See Figure 2.11)

Figure 2. 11- YARA Birkeland

Source: https://phys.org/news/2017-05-norway-self-sailing-electric-cargo-ship.html

The new ship is expected to reduce NOx and CO_2 emissions and relieve the pressure of the road traffic. YARA Birkeland will be used in maritime technology innovation more efficient and more environmentally friendly shipping standards. The switch is expected to reduce CO2 emissions by 678 tons per year, according to Yara, with the electricity used to charge the ship's batteries coming almost exclusively from hydro plants. It is equivalent to the clear as many as 40 thousand trucks in the urban areas which are densely populated. With a range of more than 65 nautical miles (120.38 kilometers), the ship will be able to haul roughly 100 containers at a speed of 12 to 15 knots. More than 100 diesel trucks are needed to plant ship products from

YARA's Porsgrunn to the ports of Brevik and Larvik every day before. By ships, the products can be transported to the customers all over the world. With this new autonomous battery-driven container vessel they move transport from road to sea and thereby reduce noise, NO_x, CO_2 and dust emissions, relieve the pressure of the road traffic, improve the safety of local roads indirectly.

3.2.3.2 Japan: FY2017

On May 16, 2017, the TOKYO-Mitsui O.S.K. Lines, Ltd. (MOL) announced that its joint project with Mitsui Engineering & Shipbuilding Co., Ltd. on developing a technological concept for autonomous marine transport system, which was selected by Japan’s Ministry of Land, Infrastructure, Transportation and Tourism (MLIT) for its FY2017 Transportation Research and Technology Promotion Program. This project will remove unnecessary flight, reduce logistics costs, achieve the seamless connection with other modes of transport, change the work type of marine transportation, minimize the workload of the crew and the probability of maritime accidents, and reduce the impact on the environment. Many organizations have participated in the project. Among them, the MOL analyze the operation of ships, in order to improve the ship performance in the operational condition; Mitsui Engineering & Shipbuilding of the integrate shipbuilding system from the aspect of shipbuilding process; the National Institute of Maritime, Port and Aviation Technology coordinate the cooperative research projects to promote the common purpose of cooperative research; from the academic point of view, the Tokyo University of Marine Science and Technology promote the research progress of the project; from the view of ship classification regulations, the Class NK define the class rules and the indispensable relevant social provisions for autonomous vessel during its implementation; from the technical point of view, the Japan Ship

Technology Research Association ensure technology safety assessment of the autonomous vessels. (See Figure 2.12)

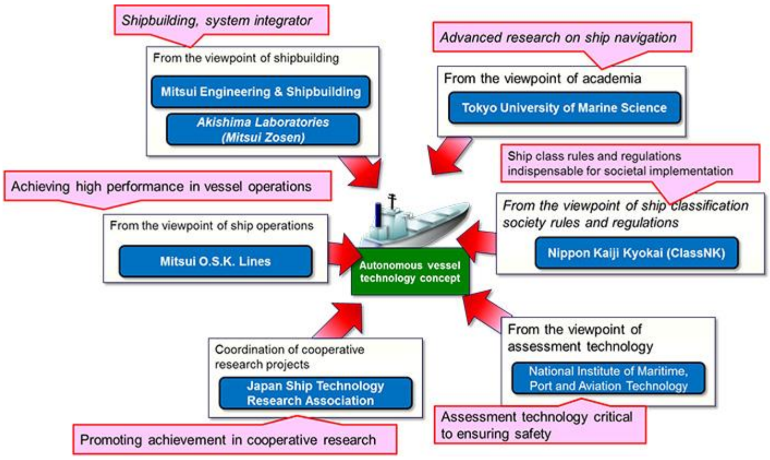


Figure 2. 12- Autonomous vessel technology concept in FY2017

Source: Japan. MLIT. (2017)

3.2.3.3 Finland: One Sea

The One Sea project in Finland is a high-profile ecosystem, which brings together the leading experts on marine research, as well as a strategic cooperation of state-of-the-art information technology. The project first began in 2016. (See Figure 2.13)

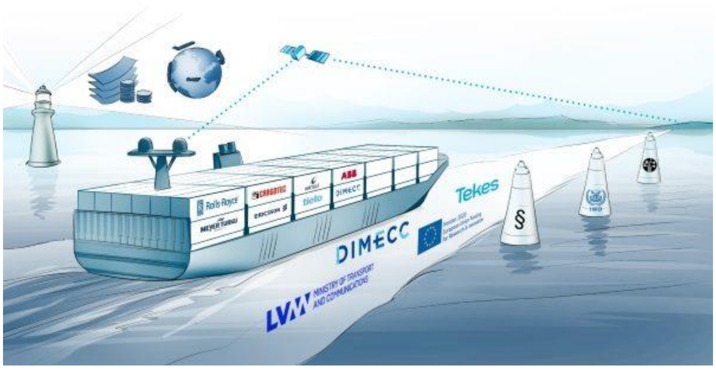


Figure 2. 13 - One Sea project

Source:https://www.oneseaecosystem.net/one-sea-autonomous-maritime-ecosystem-introduced-roadmaps-autonomous-shipping/

The government of Finland plans to achieve the remote control of ship by cooperation in the Baltic experimental area in 2017. In 2020, a fully remotely control ship (manned) and specially approved unmanned remotely controlled ships will be achieved with autonomous design. In 2023, the degree of autonomous control of unmanned vessels will be gradually promoted. The full-scale testing will be carried out in 2025, to achieve the independent unmanned commercial navigation in Baltic sea. (See Figure 2.14)

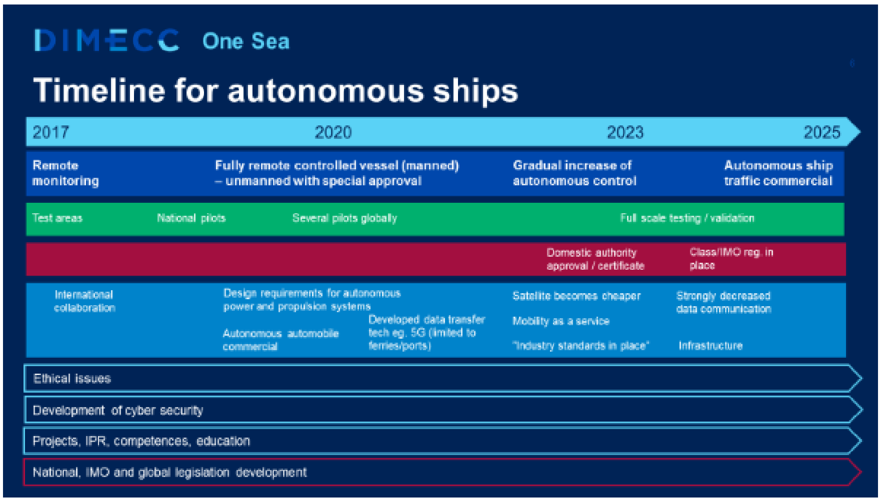


Figure 2. 14 - Timeline for autonomous ships in the Baltic Sea

Source:https://www.oneseaecosystem.net/one-sea-autonomous-maritime-ecosystem-introduced-roadmaps-autonomous-shipping/

2.3 Research Status of Intelligent Ship in China

Because of the strategic significance of intelligent ships, China has paid close attention to the development of that. In 2012, China's Maritime Safety

Administration started a project called “Unmanned Multifunctional Maritime Ships Research and Development”. In May 2016, the State Council issued a plan named Chinese Manufacture 2025, which deployed a comprehensive push to implement the strategy of manufacturing power. And the intelligent ship has been mentioned in Chinese Manufacture 2025. In August of the same year, China adopted and issued an outline of action on promoting the development of big data.

China has made some achievements in intelligent ships for scientific investigation and experimentation. Such as, Tianxiang 1, developed by Chinese Meteorological Bureau; Haiteng 01, developed by the Shanghai Maritime University. The Jinghai 1 which was developed by Shanghai University obtained a large number of valuable data in the investigation of the South China Sea in 2013. Jinghai 2 charted the inshore reefs topography of Antarctic water areas with the expedition ship Snow Dragon in 2014. (Zhang, 2016) There is also an unmanned official ship named Haixun 166-01, which belongs to China MSA. At present, most unmanned ships have been connected with the Beidou system, they can realize the marine surveying, mapping and patrol missions. (See Figure 2.15)

Figure 2. 15- Existing unmanned ship in China

Source: pictures from different news website. (2017)[1]

Besides those, China is also developing unmanned vessels for commercial use. According to the report from people.com.cn (one of the official news websites in China), China's first large-scale (DWT 38800 tons) intelligent ship I-dolphin entered the design and construction phase in 2017. This intelligent ship project is the first civil project in the innovation plan of China State Shipbuilding Corporation (CSSC). At present, the ship technical specifications, intelligent management and control system of order specification of I-dolphin has been completed, some modules have passed the ship trial test equipment, and construct the exemplary business model of intelligent ship. The first generation of intelligent ships will have more than 300 sensors that can continuously sense the operations and conditions of the ship, producing data over 10G per day. Zhang Hongjun, the president of the Institute of Systems Engineering, said the final resulting "thinking ability" would allow the machine to share 50% of the crew's work.

[1] (a) Tianxiang 1, (b) Haiteng 1, (c) Jinghai 2, (d) Haixun 166-01 (top left to bottom right in turn)

CHAPTER 3

REVIEW OF DRAWBACKS OF CONVENTIONAL SHIP AND SUPERIORITY OF INTELLIGENT SHIP

3.1 Safety Issues

3.1.1 Navigation Safety and Human Factor

The safety of navigation is the most important factor for ships. Marine transportation is a system which is composed of man, ship, goods and environment, the human plays a leading role in these system elements. That is, the marine transportation is a human centered system, (Frenken, 2000). Because people can play the subjective initiative in the system and adjust the ship's cargo handling and other sailing behavior according to the different conditions of cargo, ship and the environment.

The human factor is a high uncertainty systematic factor, so the unilateral increase of ship hardware level is still difficult to avoid occurrence of accidents at sea. The accident of the Royal Majesty was caused by the mistake of the sailor's failure to spot the position of the ship marked by the electronic chart in time. (Chen, 2008) Therefore, trying to avoid the interference of human factors has become an important breakthrough point for the analysis of maritime accidents and the protection of maritime safety. According to the report of Shipowners Mutual Assurance Association (SMAA), more than 53% of the loss of the accident in port or at sea are due to human factor (Fu, 2015).

IMO statistics on the global maritime traffic accidents also show that the main causes of marine traffic accidents are human factors: 84%-88% tanker accident, 79% towing ship grounding, 89%-96% ship collision, 75% ship fire and explosion are caused by human factors (Data from MUNIN). Safety Board of Canada (SBC) attributed 74% of maritime accidents to human error (Chen, 2008). Among them, the misjudgment of the captain or the pilot shared 45%, and 42% of the reason is due to the obstacles in communication between the pilot and the captain, the negligence of the pilot and officer of watch and the lack of communication among the crews. Although these data are not the same, we can still see the main factor determining the safety of navigation is mankind itself.

3.1.1.1 Physiological Factor: Inevitable Fatigue.

In order to study the influence of human factors on maritime accidents and countermeasures, the Human Element Group was set up by the IMO in the 59th Conference of Maritime Safety Committee (MSC) in 1991. In the further study of human factors, the researchers found that the fatigue of the crew is the most important element in the human factors leading to maritime traffic accidents. Among the human factors in the marine accidents, fatigue resulted in 75% of the accidents, and 38% of the personal casualties were related to the fatigue of the crew (Lin, 2014). For the special occupation group like seafarers, their living and working conditions are very different from those of the land. One typical thing is that the ship's large swing will lead directly to seasickness and physical consumption in case of large waves during sailing. The fatigue of the crew is similar to fatigue in the general workplace, which shows the physiological fatigue characteristics such as muscular weakness, sleepy and impaired concentration. The fatigue of crew is partly because of the common causes of fatigue, and the other part is caused by the particularity of marine transport. The maritime transport is continuous operation 24 hours and 7 days, and the crew may be living on board 30 to 60 days or longer. The working environment is bad, especially in the engine room. Its ambient temperature is about 40 to 50 degrees Celsius, this will make people get syncope, dehydration, exhaustion etc.; the mechanical vibration of the hull often makes the staff difficult to get enough sleep (Sun, 2013); the longtime sailing leads to the disorder of biological rhythms; the 24 hours shift system leaves some duty officers to be on duty when they are low in the biological rhythms, resulting in some tragic sea accidents. (Frenken, 2000) During sailing, the fatigue caused by lack of rest and the fatigue caused by ultra-low arousal environment both exists. (Lin, 2014) The former occurs in ports or narrow waterways, the moment which require the crew to pay high attention; the latter occurs when the ship is sailing in wide seas. Long term studies and accident analyses revealed that the risks of these two situations are in the same level. (Fu, 2015)

3.1.1.2 Psychological Factor: Inevitable Pressure

The psychological quality of the crew will affect their decision and judgment on the problems encountered during the voyage. The space of the ship is narrow and the amateur life is monotonous. It is easy to make the crew have boring mental state, to stimulate the internal contradictions. Keeping good mentality is an important way to reduce accidents caused by human factors. (Lin, 2014) Navigation work has its inherent characteristics, such as complexity, risk, emergency and special environment. All these require the crew have strong ability to resist to pressure. The mood swings caused by the boring work or other circumstances will also affect the competency of crew. So, the crew's responsibility also has an important impact on the safety of the ship. However, the sense of responsibility is not easy controlled by the administrators onshore.

3.1.2 the Superiority of Intelligent Ship on Safety Issues

Compared with the artificial driving of conventional ship, the advantages of intelligent ships with remote control are obvious in terms of safety.

First of all, save manpower. Crew recruitment is a difficult problem for many shipping enterprises. With intelligent ships, large cargo ships do not need to be equipped with large numbers of crew members. The work attitude of intelligent ship is not in inferior to that of the traditional crew. Even because of the presence of Big Data, these ships are equivalent to be equipped with all of the world's most experienced captain when they just come out of the dock. The safety of the ships has been greatly improved. The reduction of manning not only can greatly alleviate the shortage of crew members of oceangoing cargo vessels, but also save a large amount of crew salaries for shipping enterprises. According to statistics, 44% of cost for international shipping is associated with the seafarers. (Chen, 2014) If some of these funds are used for safety management, then the safety level will be greatly improved.

Secondly, the reduction or cancellation of manning will result in a great change in the structure design and equipment layout of the ship. As no more facilities and systems are installed for seafarers, the ships will be greatly simplified, and more considerations based on safety, not comfort, can be added to ship design.

Additionally, the reduction or cancellation of manning can avoid most marine accidents caused by human factors. Moreover, even in the event of collision, pirate, storm, etc., the remote control is much safer than manual driving, and at least it avoids the loss of life. In addition to the analyses for unmanned ship, analyses are also done for a conventional manned ship, thus enabling comparison of the two ship types. The result of the probability analyses is shown in (See Table 3.1) The result from this analysis is that the unmanned ship is safer than a manned ship at a factor of between 5 and 10.

Table 3. 1 - Accident occurrence probabilities for the unmanned, autonomous and the conventionally operated vessel

		Collision	Foundering	Foundering with factor
Unmanned vessel	Propulsion failure event tree	$4.8 \cdot 10^{-8}$		
	Blackout event tree	$9.6 \cdot 10^{-8}$		
	Total	$1.4 \cdot 10^{-7}$	$1.5 \cdot 10^{-3}$	$2.2 \cdot 10^{-5}$
Conventional vessel	Propulsion failure event tree	$1.1 \cdot 10^{-6}$		
	Blackout event tree	$1.2 \cdot 10^{-7}$		
	Total	$1.2 \cdot 10^{-6}$	$8.0 \cdot 10^{-3}$	$1.2 \cdot 10^{-4}$

Source: Jensen, F. (2015) Hazard and Risk Assessment of Unmanned Dry Bulk Carriers

3.2 Environment Issues

The emerge of intelligent ship cannot eliminate all the pollution caused by ship fundamentally, but due to a substantial reduction of manning or even disappearance, the associated pollution will decrease and disappear, such as sewage and garbage.

3.2.1 Marine Pollution and Human Behavior

3.2.1.1 Sewage

According to the Annex IV of MARPOL 73/78, sewage means: *(1) drainage and other wastes from any form of toilets and urinals; (2) drainage from medical premises (dispensary, sick bay, etc.) (3) drainage from spaces containing living animals; (4) other waste waters when mixed with the drainages defined above.* From the definition, we can see that the discharge of sewage is almost directly related to human existence onboard. After sewage discharged into the water, because of the oxidation and decomposition by bacteria and other microorganisms, these processes must consume the dissolved oxygen in the water. In the case of excessive or frequent pollution, the content of dissolved oxygen in the water decreases, destroying the natural purification process, changing the entire ecological characteristics of the water, so that fish and other marine animals would be killed, or migrate. The nutrient salt in sewage from ships may algae soaring, reduce the amount of dissolved oxygen in the water, resulting in anaerobic conditions so that low-level forms replace the higher forms of the marine flora and fauna. In this way, the contaminated bathing and fishing grounds will become filthy stinking and infectious bacteria departments. In addition, each milliliter contains millions of bacteria in untreated sewage; these bacteria can cause a variety of infectious diseases to human.

3.2.1.2 Garbage

According to an annual report of Scientific Research Academy of Sciences of the United States in 1997, there are over 5.6 million tons ship garbage discharged into the sea per year. And in every square mile of the water, there are more than 46 thousand pieces of plastic waste. Without doubt, almost all of the marine garbage discharging can be associated with the human behavior. (Yang，2011) The garbage from ships means: all kinds of food wastes, domestic wastes and operational wastes, all plastics, cargo residues, incinerator ashes, cooking oil, fishing gear, and animal carcasses, generated during the normal operation of the ship and liable to be disposed of continuously or periodically except those substances which are regulated in other MARPOL Annexes.

3.2.1.3 Harmful Emission

Emissions of Greenhouse Gas (GHG)

As it shows in RMT 2016: *The Third IMO Greenhouse Gas Study 2014 (IMO, 2014c) estimated that international shipping emitted 796 million tons of* CO_2 *in 2012, compared with 885 million tons in 2007. This represented 2.2 per cent of the global emissions of* CO_2 *in 2012, compared with 2.8 per cent in 2007. The study also forecasted* CO_2 *emissions from shipping to increase by 50, to 250 percent, by 2050.* Global warming has made the control of GHG emissions an urgent problem. To this end, The IMO has proposed a series of measures to reduce GHG emissions from ships, and the global shipping industry needs to contribute to controlling emissions. The IMO proposed Energy Efficiency Design Index (EEDI) for new building ships, (See Figure 3.1) and Energy Efficiency Operational Indicator (EEOI) as the evaluation standard. As far as the existing ships are concerned, a new regime which is known as Ship Energy Efficiency Management Plan (SEEMP) is established for a company and/or a ship to improve the energy efficiency of ship's operations (IMO, 2009).

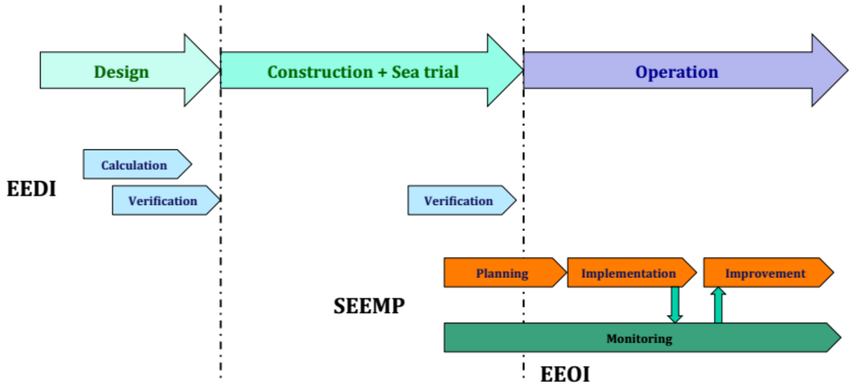


Figure 3. 1– EEDI, EEOI and SEEMP during a life of ship

Source: Nakazawa, T. (2016). *Impact of Maritime Innovation and Technology*. Unpublished lecture handout

Emissions of Nitrogen Oxides (NO_x) and Sulphur Oxides (SO_x)

Harmful gases are unavoidable as ships travel to burn fossil fuels. The MEPC continued its work on developing regulations to reduce emissions of other toxic substances from burning fuel oil, particularly NO_x and SO_x. These significantly contribute to air pollution from ships, and are covered by MARPOL annex VI, amended in 2008 to introduce more stringent emission controls.

3.2.2 the Superiority of Intelligent Ship on Environment Issues

During the daily life, the crew must produce domestic sewage and garbage. Apparently, they will decrease as the number of crew are decreasing. When ships become completely intelligent and turn into unmanned ships with land remote control, the pollution will disappear. The Superiority in this respect is that conventional ship cannot be compared.

For conventional ships, measures can be taken to reduce carbon emissions only from the two aspects of design and operation, and the effect is limited. As mentioned above, compared to the conventional ship, the design of unmanned ships will be more simplified because many of the structures designed for the crew will be cancelled, such as the bridges, crew rest areas, food warehouses and so on. The ship will become lighter and require less fuel. The advantages of reducing carbon emissions from these changes are more obvious than those of conventional ships. According to the British company Rolls Royce is expected, if the unmanned technology is applied, the efficiency of a freighter will be expected to increase by 20%, while carbon emissions reducing by 20%. (Huang, 2015)

Furthermore, fuel costs will be significantly reduced as it is fully designed for sailing. Consuming less fuel means less toxic gas emissions. In the long run, the design direction of intelligent ships is to use electric propulsion, and electric propulsion ships have almost no toxic gas emissions. This is not a dream, and in some areas of short distance navigation, the technology has begun to come into use. (YARA project)

3.3 Other Concerns to the Practicability of Intelligent Ship

3.3.1 Pirate Attack

The security of unmanned cargo ship is a hot topic in the industry. Some who question the usefulness of unmanned ships argue that the number of pirate attacks will soar with the spread of unmanned cargo ships. Pirates are more likely to succeed because the ship do not have the protection or protection from their crew or guards, just as thieves prefer to steal while the owner is away on holiday. There is, of course, some truth in this statement, but this does not preclude the worldwide spread of intelligent ships.

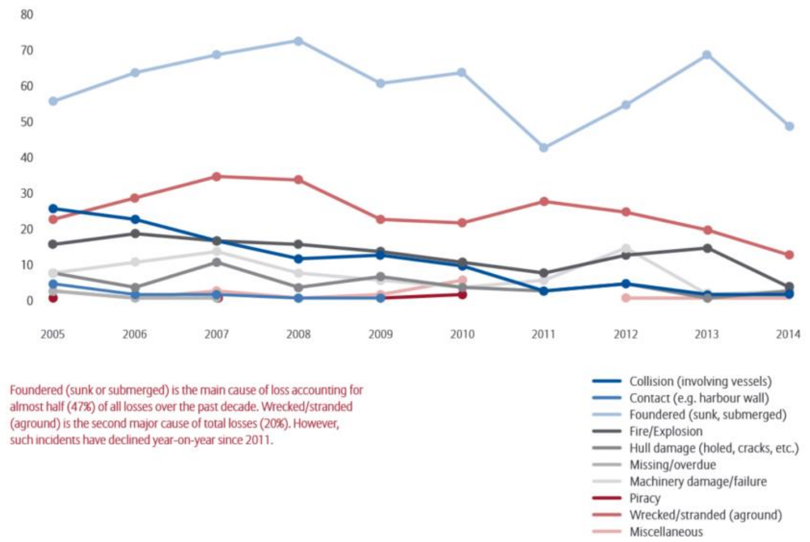


Figure 3. 2 - Total Ship Losses

Source: Allianz Global Corporate & Specialty (2015). Safety and Shipping Review 2015.

Firstly, piracy has never been a bottleneck in the development of shipping industry. Pirates have been responsible for 5 total losses in the period from 2005 to 2014, thus accounting for only 0.4% of all losses during that period. (See Figure 3.2) Pirate attacks have been on the decline for the past few years. This is because more countries are concerned about the problem and take effective measures in time, such as naval escort. Therefore, piracy attacks do not pose a major threat to the development of the shipping industry.

Moreover, no crew means pirates may not be able to take hostages any longer. The main purpose of the pirate attack is money, not goods. Ships and goods are nothing more than bargaining chips. They have no direct benefit to pirates, because they are hard to sell even when they have owned ships and goods.

Furthermore, due to the application of remote control technology, the pirates may not be able to control the ship if they boarded it, and even the operator onshore can directly move the ship to the nearest port where the police and the army are waiting for them.

3.3.2 Cyber Risk

Compared to pirate attacks, the cyber malicious attacks is the biggest risk for unmanned ship. Almost all the operations of unmanned ship are based on the network, once the network paralysis or input instructions have been tampered with, the consequences will be unimaginable. The countermeasure to this risk is to constantly improve the level of technology and to strengthen the protection of shore control center (SCC) and prevent illegal personnel from entering carefully. In the current marine insurance, the losses caused by cyber-attacks are excluded. When unmanned ships begin to engage in commercial transportation, this should be improved and perfected as soon as possible.

3.3.3 Unemployment of Seafarers

Crew size of ocean going ships has been reduced significantly over the past 150 years. (See Figure 3.3) Since the ultimate development direction of intelligent ships is unmanned ships, then with the reduction of crew members, the problem of crew unemployment has aroused the concern and concern of many people.

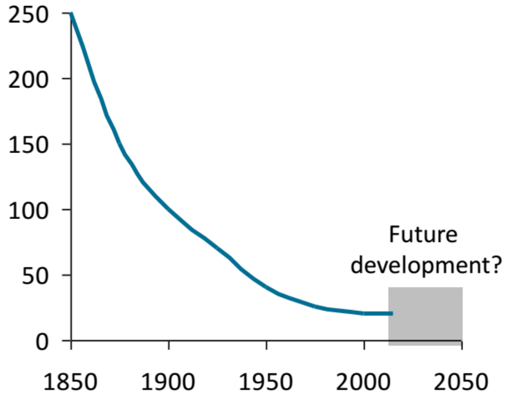


Figure 3. 3- Development of crew size of ocean going ships

Source: Qi, S. (2005). Unmanned ship: a vision in 20 years. *World Shipping, 28 (3),* 3-5

A reduction in crew size is essentially a trade-off between increased capital costs and reduced (crew related) costs plus other potential benefits associated with automation on board (See Figure 3.4).

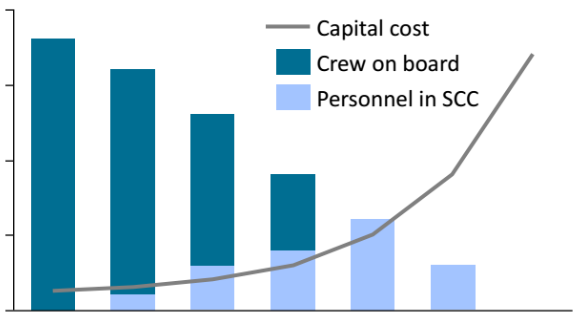


Figure 3. 4- Principal correlation between crew size and new building cost

Source: Qi, S. (2005). Unmanned ship: a vision in 20 years. *World Shipping, 28 (3),* 3-5

On the face of it, reducing the number of crew members may save some of the expenses for the ship owners and thus gain greater commercial benefits (See Table 3.2), which will lead to a great increase in the unemployment rate of seafarers in the future. According to this statement, 1.2 million of the world's crew will be forced to lose their jobs. (Zhang, 2015) However, through investigation, the actual situation may not be so. The emergence or disappearance of unmanned ship cannot change the reality that the people who are willing to become seafarers and are willing to continue to work as seafarers are decreasing. (in China)

Table 3. 2 - Assumed composition of the crew on a reference vessel (USD)

Pay group	Number	Total salary per month
Master	1	5,786
Chief Off.	1	3,780
2nd Off.	1	3,053
3rd Off.	1	2,946
Boatswain	1	2,001
Able Seamen	3	1,806
Ord. Seamen	1	1,375
Ch. Eng.	1	5,270
1st Eng.	1	3,780
2nd Eng.	1	3,053
3rd Eng.	1	2,946
Electrician	1	2,642
Fitter/Repairer	2	2,001
Fireman/motorman	2	1,806
Chief Steward	1	3,053
Chief Cook	1	2,001
Total	20	47,299

Source: ITF (2011). *Annex 1 to ITF UNIFORM "TCC" COLLECTIVE AGREEMENT for Crews on Flag of Convenience Ships 1 January 2012-14*

According to the China Crew Development Report 2015 which was released by the Ministry of transport of China in June 2016, it showed the future of the recruitment and dispatch of seafarers. Although the absolute number is still growing, the growth rate has decreased year by year. There are 13% new seafarers in 2012 more than that in 2011, but that in 2015 only increased by 5.2%. From 2011 to 2015, the overall enrollment of maritime major continuously declined, and was rapidly shrinking in the proportion of 20-30% by year. (See Table 3.3 and Figure 3.5) With the decreasing number of students, not only the maritime colleges face the dilemma of unsustainable development, but also the intermediary and services company will face the situation of no one available and business had to shrink in the long run. There are three reasons for these:

Table 3. 3 - Number of students enrolled in marine training institutions in China from 2011 to 2015

Major	Number of students				
	2011	2012	2013	2014	2015
Navigation	24251	15654	11912	9321	8193
Marine Engineer	19662	12192	9940	7832	6767
Total	43913	27846	21852	17153	14960

Source: Ministry of Transport of China. (2016)

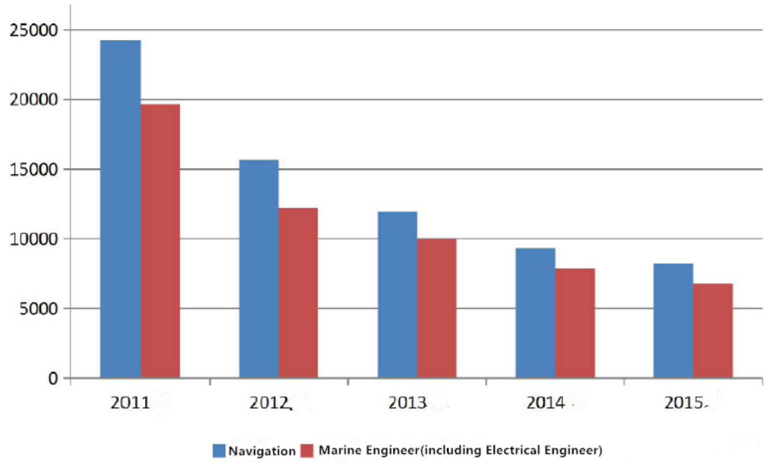


Figure 3. 5- Number of students enrolled in marine training institutions in China from 2011 to 2015

Source: Ministry of Transport of China. (2016)

Firstly, because of the one-child policy, the decline occurs in the proportion of Chinese young labor. China's demographic dividend gradually disappears, resulting in the number of employees China decreased gradually. (Figure 3.6) The shipping industry is also facing serious challenges that the advantage of Chinese human resource is weakening. It is a necessary trend that the number of Chinses seafarers is decreasing gradually.

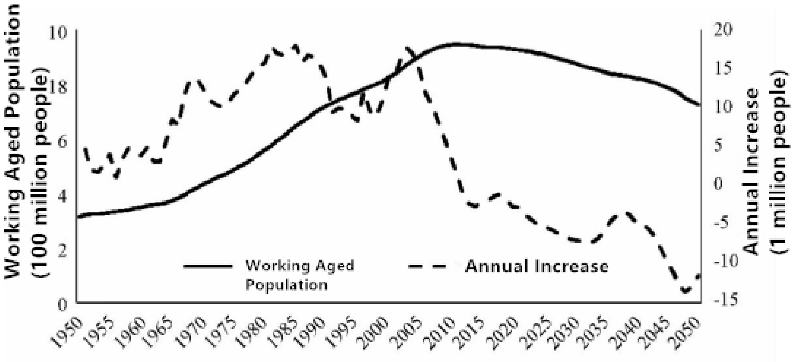


Figure 3. 6- Changes in the working age (15-59) population from 1950 to 2050 in China

Source: United Nations. Department of Economic and Social Affairs. Population Division. (2013). World Population Prospects: The 2012 Revision.[2]

Furthermore, crew treatment is no longer as attractive as it used to be. With the great changes caused by the reform and opening up in the past thirty years, as the old traditional industries, China shipping industry has experienced a transform from the “second navy” to “vehicle”. (Yi, 2016) The wage gap between land and sea is getting more and more narrow. At the same time, the sense of identify and sense of honor from the occupation of seafarers is losing.

Additionally, with the continuous development of China's economy, people's concept of employment has changed. As a profession, seafarers often lack long-term career planning, which leads most people to worry about engaging in this occupation and will be separated from the land for a lifetime.

To sum up, the attraction of the onboard work is far from being the same in China than before. Even if the intelligent ship did not appear, the number of crew members is still declining. The future career planning of students who major in navigation will

[2] The figures after 2013 are official forecasts

become an more important topic. From this point of view, the emergence of intelligent ship provides the possibility of employment for those who do not wish to work on the ship, that is, to command ships in the remoted control center and engage other relevant jobs onshore. For a period of time, the experience of seafarers who were replaced by machines remained important for the management of intelligent ships.

3.3.4 Technical Reliability

As for reliability, Tesla's car crash (2^{nd} July. 2016) may have lost many points for driverless technology. In the fatal car accident, Tesla's driverless car did not notice the trailer's white body, failed to start the braking system in time, leading to death of the owner. This undoubtedly gives some people reasons to attack AI, saying that technology cannot take the place of human beings. However, the National Highway Traffic Safety Administration of United States (NHTSA) analyzed the data from 2014 to 2016, which all equipped with automatic driving function of Tesla Model S and Model X. It was found that, with the installation of automatic driving, the average number of crashes reduced from 1.3 per million miles to 0.8 per million miles. The traffic accident rate has dropped by nearly 40%. (See Figure 3.7) And if 90% of America's highways turn into driverless cars, the number of accidents will fall from 6 million to 1.3 million and the death toll will fall from 33 thousand to 11.3 thousand. So, it's just a matter of probability, and driverless cars are safer than manual cars.

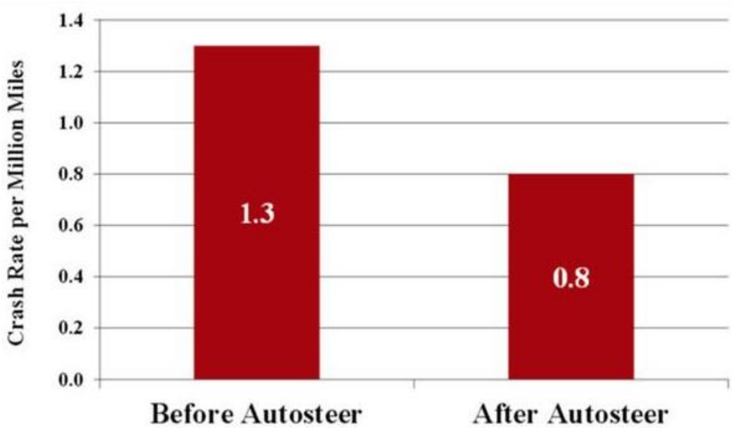


Figure 3. 7– Crash rates in MY 2014-16 Tesla Model S and 2016 Model X vehicles before and after autosteer installation

Source: NHTSA. (2017)

As the driverless car, the emergence and development of the intelligent ship will also have been accompanied by doubts and problems. However, as time goes by, the answer will be more and more clear, and the question will be less and less. The intelligent ship for commercial use will be an inevitable trend. Facing the situation that intelligent ship will bring great changes to the shipbuilding industry, what the whole industry should do is to determine how to meet the stern challenges of ship design, construction and supporting as soon as possible. The innovations of technology should be concerned first.

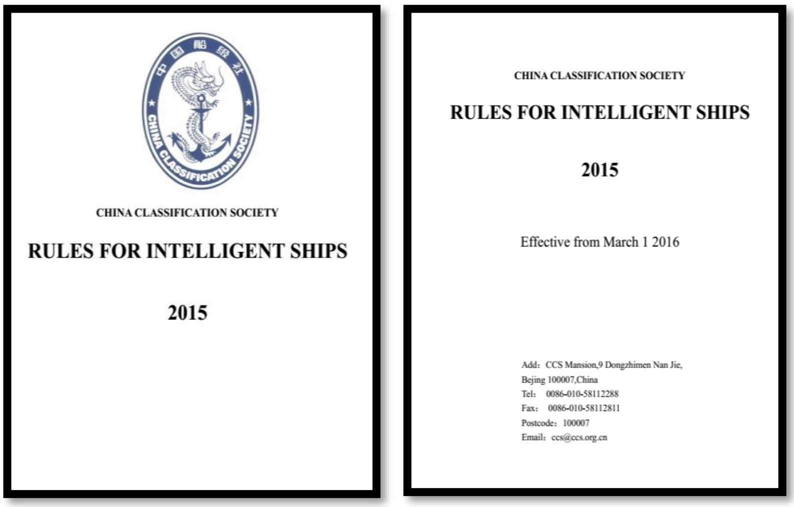
CHAPTER 4

TECHNOLOGY INNOVATIONS FOR INTELLIGENT SHIP AND OFFICIAL STANDARDS

4.1 The Official Standards of Intelligent Ship

4.1.1 CCS Rules for Intelligent Ships 2015

So far, Chinese Classification Society (CCS) Rules for Intelligent Ships 2015 (See Figure 4.1) is the first rules of classification society which covers the whole life cycle from design, construction, to operation of the intelligent ship. It has a profound practical significance and historical significance to lead the technology advance. (Xu, 2017) In the Rules for Intelligent Ships, there are six separated modules, which are intelligent navigation, intelligent hull, intelligent machinery, intelligent energy efficiency management, intelligent cargo management and intelligent integration platform, it contains all the basic functions which the intelligent ship should have.


CHINA CLASSIFICATION SOCIETY

RULES FOR INTELLIGENT SHIPS

2015

CHINA CLASSIFICATION SOCIETY

RULES FOR INTELLIGENT SHIPS

2015

Effective from March 1 2016

Add：CCS Mansion,9 Dongzhimen Nan Jie,
Bejing 100007,China
Tel： 0086-010-58112288
Fax： 0086-010-58112811
Postcode：100007
Email：ccs@ccs.org.cn

Figure 4. 1 - CCS Rules for Intelligent Ships 2015

Source: CCS. (2016). Rules for Intelligent Ships 2015

In addition, the content of the Rules is based on the existing standard system, and can be integrated with the current CCS specification requirements. At the same time, the standardized and open way of writing, take full account of the future development of intelligent ship technology, so as to facilitate new applications in the future, improve and refine existing technical requirements. It has the historical significance of the integration of mature technology. The Rules also make clear requirements to the function of intelligent computer system, software development, testing, trial data and personnel. Considering the continuous development of intelligent ship technology, the Rules make the principle requirement to the application of new technologies: when the equipment and system which use new technology, and it can reach the same level of security requirements of CCS after the risk assessment and test, the design of these systems and equipment can deviate from the CCS requirements. It also provides the risk assessment method and the basis for the approval of new technology, which has the practical significance of putting the technology first. A ship, which has, upon its request, undergone plan approval and surveys by CCS and its compliance with the requirements of the Rules is confirmed, may be assigned the following Intelligent Ship class notation: i-Ship (Nx, Hx, Mx, Ex, Cx, Ix) where the letters in the parentheses stand for functional notations of intelligent ships, which may be assigned in accordance with the functions possessed by the ship. Functional notations can be added based on the development of technology. (See Table 4.1)

Table 4. 1 - The Intelligent Ship class notation in CCS Rules

Functional Notation	Functions	Requirements in the Rules
N	intelligent navigation	Chapter 2
H	intelligent hull	Chapter 3
M	intelligent machinery	Chapter 4
E	intelligent energy efficiency management	Chapter 5
C	intelligent cargo management	Chapter 6
I	intelligent integration platform	Chapter 7
x	optional function	Chapters 2 to 7

Source: CCS. (2016). Rules for Intelligent Ships 2015. Arranged by author

x – additional notation for optional function. One small letter stands for one additional notation for function and a functional notation may have multiple additional notations for function. Detailed requirements are given in Chapters 2 to 7.

4.1.2 Lloyd's Register Guidance Document for Intelligent Ship 2016

In July 2016, the Lloyd's Register (LR) released a guidance document for the intelligent ship. It covers many aspects, and is suitable for the designer, shipyard and ship owner, ship operators and equipment manufacturers. The first part of the document defines the level of ship automation. It is divided into six grades from AL1 to AL6. According to the characteristics, each level is defined clearly and accurately from the design to the operation phase and explains related investment opportunities and risks. In addition, these levels provide the process which must be conformed to meet the demand of the customers, and also provided safety and practical problems to meet the statutory and classified requirements. These processes help customers identify from the initial business requirements to the systematic classification during the operation. Nowadays, the intelligent ships are becoming a reality. The intelligent ships needed by the market are the ships that can be operated under different control levels. The Lloyd's cooperate with customers to define a guidance about the safety, maintenance, monitoring and the performance for a new generation of intelligent ship, to promote the industrial application of big data and electronic network connection technology. It is committed to making the navigation safer.

4.2 Technologies for the Realization of Intelligent Ship

4.2.1 Communication and Navigation technology

Communication technology is used to realize the information interaction between ships, systems and equipment, as well as the ships and shore stations, ships and navigation aids. The commonly used communication methods include: Very High Frequency (VHF), maritime special network, maritime satellite, mobile communications network (mobile phone network) and so on. (See Figure 4.2) Navigation technology is used to guide a ship move from one point to another point of the designated route, usually including positioning, destination selection, path calculation and path guidance. The ship's commonly used navigation technologies include early radio navigation and satellite navigation which is now widely used.

Beidou satellite navigation system provides a new opportunity for the development of ship navigation in china.

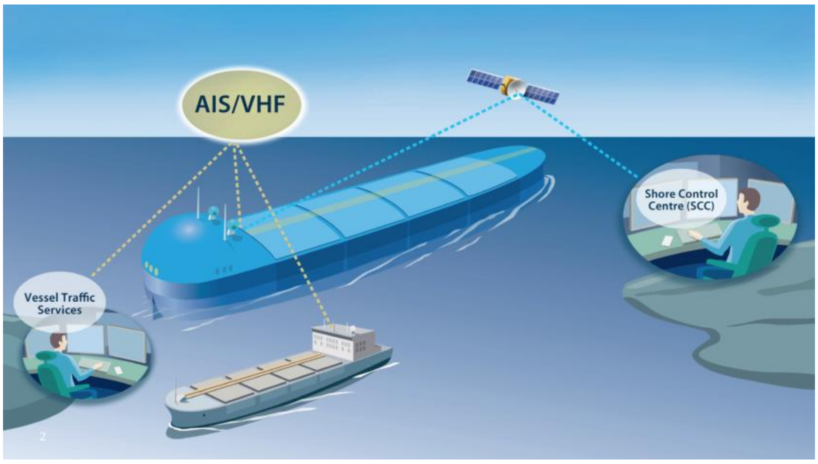


Figure 4. 2 - Communication system of intelligent ship

Source: MUNIN Brochure. (2014).

4.2.2 Information Sensation Technology

The marine information sensation technology refers to a technical means which is based on the perception of the ship to various sensing devices, sensor network and information processing equipment to get all kinds of information from the ship itself and the surrounding environment, so that the navigation can be more safe and reliable. The information can be divided into state information and surrounding environment information. State information includes the information of various equipment and navigation status, mainly rely on the sensors of pressure, temperature, speed and liquid level. The environment information includes the information of surrounding objects, weather condition and geographical features, it is mainly relied on Automatic Identification System (AIS), marine radar, video camera, sensors, Voyage Data Recorder (VDR), Electronic Chart Display and Information System (ECDIS) and ship shore interaction system. (See Figure 4.3)

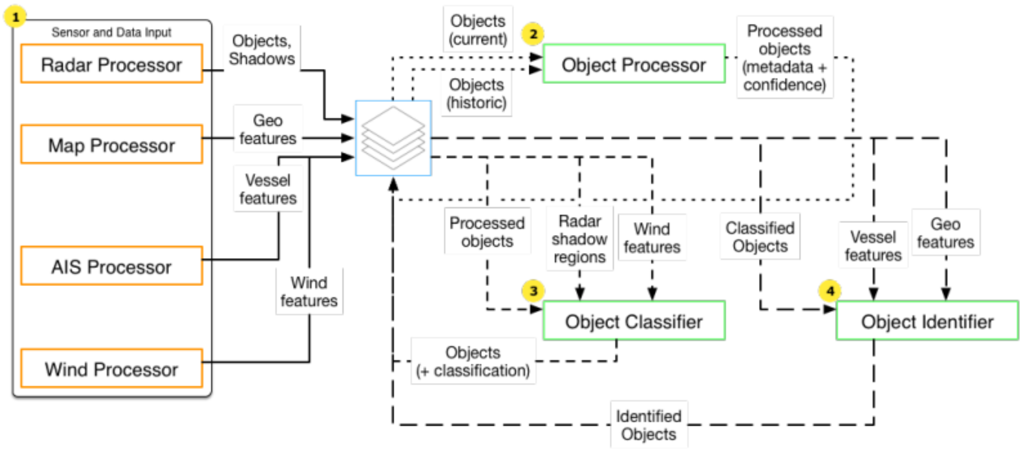


Figure 4. 3- Information sensation system of intelligent ship

Source: Hans-Christoph Burmeister. (2016). Autonomous navigation result from the MUNIN tested.

4.2.3 Energy Efficiency Control Technology

The development of intelligent ship should conform to the development trend of green ship. Economically, efficiency is the money. It is necessary to make an assumption about the price of Heavy Fuel Oil (HFO) and Marine Diesel Oil (MDO) in order to carry out a financial analysis. The fluctuations of their price are especially large and the trend is elusive in the recent past. (see Figure 4.4) Based on a forecast for crude oil prices published by the International Energy Agency (IEA) World Energy Outlook, future fuel price will still be in an upward trend. (See Table 4.2) Reducing fuel consumption is of great significance to shipping enterprises.

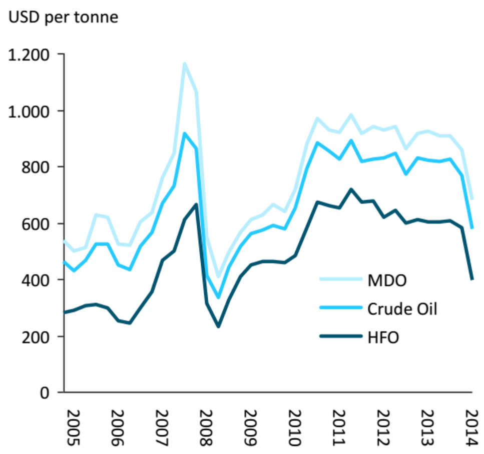


Figure 4. 4 - Crude oil and marine fuel price development from 2005 to 2014

Source: Ministry of Transport New Zealand (2015) Transport-Related Price; EIA (2015). Europe Brent Spot Price FOB; Insee (2015). International prices of imported raw materials - Heavy fuel oil (Rotterdam) - Prices in US dollars per ton

Table 4. 2 - Forecast of crude oil price from 2020 to 2035

	2020	2025	2030	2035
Crude Oil [USD/barrel]	119.5	121.9	123.6	125

Source: IEA. (2012). World Energy Outlook 2012

As has just been discussed in Chapter 3, improving ship efficiency will also be of great significance to human development from the point of view of environmental protection. The relationship between environmental factors and ship energy consumption is worthy of further study. The Total Heat Recovery Plant shown in figure 4.5 is one effective method.

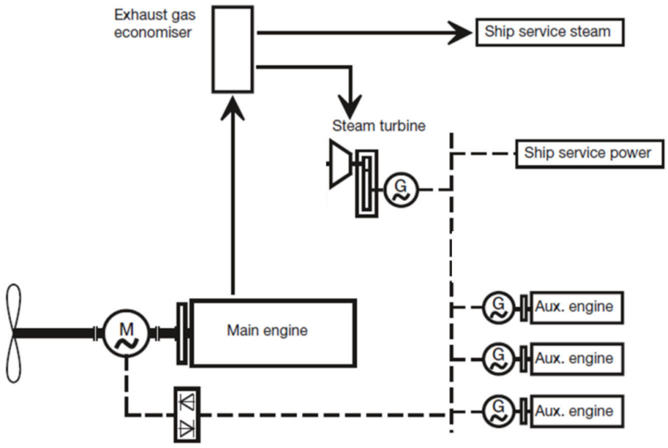


Figure 4. 5 - Schematic of the Total Heat Recovery Plant

Source: Wärtsilä. (2005). Marine technologies for reduced emissions.

4.2.4 Navigation Route Design Technology

Route designing refers to the real-time and intelligent choice of a ship in a position within the channel, according to the traffic control information in the navigation area, ship density, situation of the company, shipping information and channel information, in order to optimize the route to achieve safe and efficient and environmental protection. At present, the usual route design methods include linear programming method, mixed integer programming model, genetic algorithm (See Figure 4.6), simulated annealing and other intelligent algorithms.

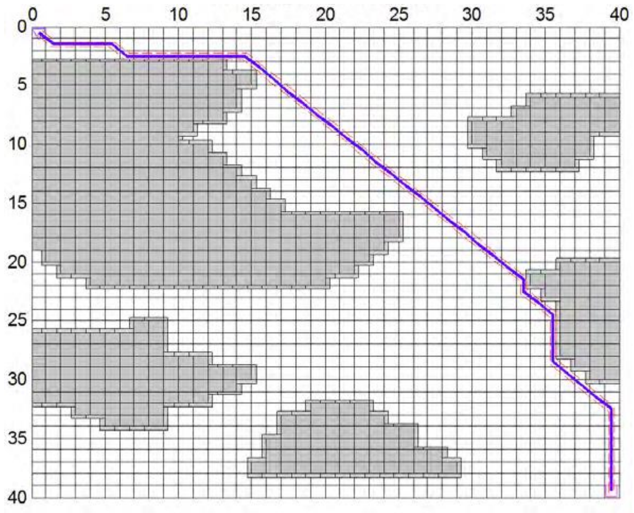


Figure 4. 6 - Optimal route designing by genetic algorithm

Source: Liu H. (2015). Making optimal route of ship based on genetic algorithm.

4.2.5 Condition Monitoring and Fault Diagnosis Technology

Condition monitoring technology is a prediction method of equipment running state based on the development trend of monitoring equipment vibration. By understanding the health condition of equipment, it is judged that the equipment is in stable state or deteriorating. In the future, the ship fault diagnosis can be considered as the basis of the big data, and the multi scale analysis method can be used to construct equipment condition monitoring system. (See Figure 4.7) Fault diagnosis technology means that master the running status of equipment during its operation without equipment disassembly. According to the useful information obtained by testing the diagnosed object analysis, judge whether the state of the diagnosed object is in an abnormal state or fault state, determine the deterioration state of the parts and diagnose the cause of fault, and forecast the development trend of state deterioration.

Figure 4. 7 - The operator’s workstation

Source: MUNIN Brochure. (2016)

4.2.6 Distress Warning and Rescue Technology

Water traffic accidents occur frequently, especially collisions and grounding accidents, which often result in serious economic losses and casualties. Ship collision is one of the most common types of water traffic accidents, which accounts for a large proportion of all the water traffic accidents. Ship distress warning and rescue technology can effectively reduce the accident rate and reduce the loss of the accident. Wuhan University of Technology have developed a collision warning system for bridge area to ensure the safety of navigation in the bridge area. (See Figure 4.8).

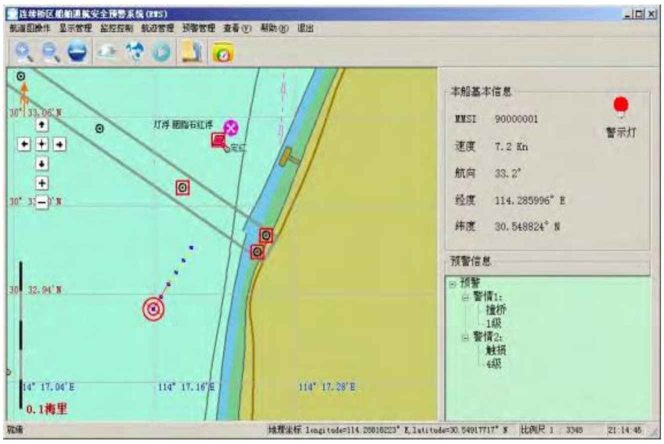


Figure 4. 8 - Ship collision warning system

Source: Unmanned ship research group. (2016). Wuhan University of Technology

There is an example in AAWA project. If extremely large number of crafts or other objects are detected and the path planning algorithms are not capable to identify them and thereby the system cannot determine how the navigation should proceed. In this type of scenario the vessel will immediately send a “pan-pan” message to the operator indicating that it is in urgent need of assistance. (See Figure 4.9)

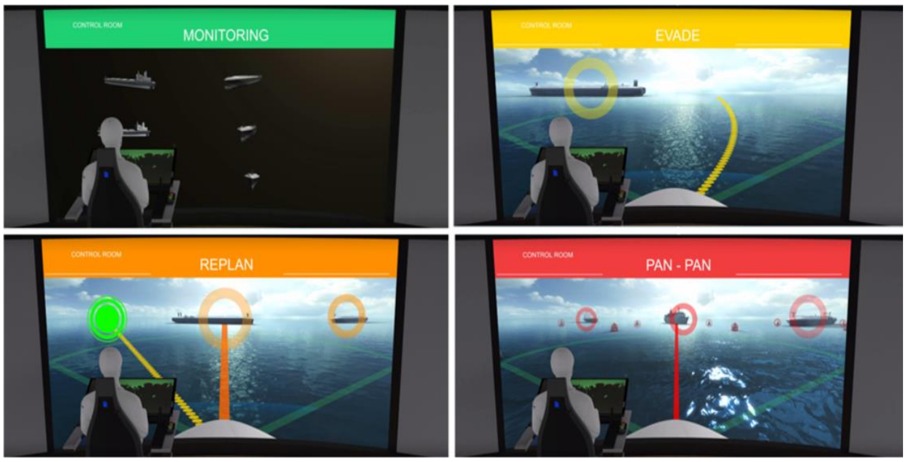


Figure 4. 9 - Different scenarios require different levels of operator involvement

Source: Rolls-Royce. (2016). AAWA Position Paper

4.2.7 Autonomous Navigation Technology

It is defined in the CCS Rules for intelligent ships:

Intelligent navigation makes use of computer technology and control technology to carry out analysis and processing of information that is perceived and obtained, as well as design and optimization of ship's route and speed; if feasible, the ship can prevent collision automatically in open water, narrow channel and complex environmental condition and realize autonomous navigation.

when the intelligent ship faces an emergency situation and issues a warning signal, after that, the operator onshore is not timely response, or the ship does not receive timely response signal, the ship will enter the automatic state. According to the emergency situation, as well as the preset program stored in the computer, the program is executed in the planned order. It can also be started the auto rollback policy execution immediately. The execution of the automatic fallback strategy can also be initiated immediately.

As described in AAWA project, *a solution for the integration of a complete autonomous ship navigation architecture is being developed, which takes advantage of a Rolls-Royce Dynamic Positioning (DP) system developed for future autonomous ships and links it with an Automatic Navigation System (ANS), including Situational Awareness (SA), Collision Avoidance (CA), Route Planning (RP), and Ship State Definition (SSD) modules developed in the AAWA project.* Figure 4.10 shows a schematic of the ANS architecture.

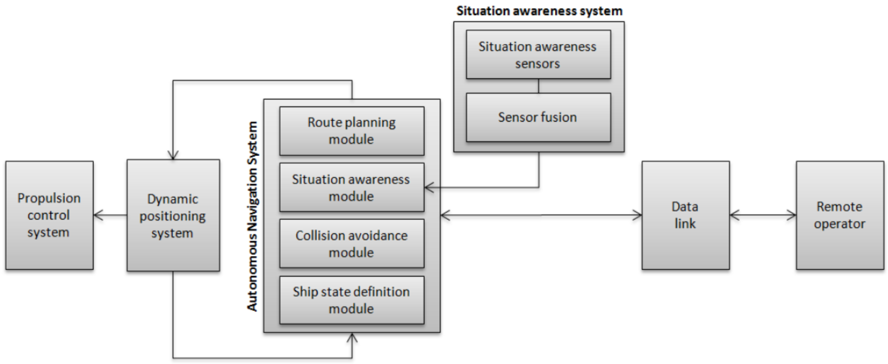


Figure 4. 10 - Autonomous Navigation System (ANS) architecture
Source: Rolls-Royce. (2016). AAWA Position Paper

The goal of autonomous navigation technology is to achieve the appropriate judgment during sailing, like a seasoned captain. The highest level in the ANS system is named the Ship State Definition (SSD) module or "Virtual Captain" (VC), which combines information from different ANS sub-systems (SA, DP, RP and CA), as well as from other ship automation systems and the operator to determine the current state of the ship's systems. The state of the ship determines the allowed ship operation mode, such as autonomous, remote control or failsafe. The state information from the VC is also used to continuously inform the operator about the stage of the ship.

CHAPTER 5

COMMUNICATION TECHNOLOGY

FOR REALIZATION OF INTELLIGENT SHIP

5.1 Significance of Communication Technology for Realization of Intelligent Ship

The study on intelligent ship is a comprehensive project which contains multidisciplinary and multidomain fusion, with certain forward-looking and innovative nature. The exploration and research work of intelligent ship will promote the development of science and technology. The technologies which has been discussed in Chapter 4 play an irreplaceable role in the development of intelligent ships. The realization of the intelligent ship brings many challenges to the whole shipping industry. It requires the ship not only to be capable to face the complex marine environment in order to ensure the safety of navigation, but also to comply with the complex rules of navigation. Especially in ultra-far sight, it is necessary for intelligent ship to design their route autonomously, perceive the environment, avoid collision and obstacles automatically. All of these technologies are based on the exchange and identification of all kinds of data. Therefore, the communication technology is an important basis for the realization of intelligent ships. It perfectly matches the E-Navigation strategy initiated by IMO, a concept based on the harmonization of marine navigation systems and supporting shore services driven by user needs (Zhao, 2008). The shipping industry is discussing how to use the

E-Navigation system now, that is, how to use the communication technology onshore to control their ship remotely.

5.2 e-Navigation Strategy and Drawbacks of Current Communication System

In May 2006, the definition of e-Navigation was put forward for the first time at the 16th Conference of the International Association of Lighthouse Authorities (IALA). Subsequently, at the 52nd Conference of NAV and COMSAR held in July 2006, the IMO put forward the concept of e-Navigation formally. Since then, e-Navigation has developed rapidly. At present, under the guidance of IMO, with the joint efforts and cooperation of IALA, International Hydrographic Organization (IHO), International Telecommunication Union (ITU), International Electrotechnical Commission (IEC) and other international organizations and countries, the basic framework of e-Navigation is becoming clearer and clearer. The physical structure of e-Navigation can be divided into ship-side and the shore-side. The whole system contains three elements, namely basic architecture, communication system and navigation system. As shown in Figure 5.1, the communication system is the infrastructure of the e-Navigation system, which is responsible for the communication between shore-ship, ship-ship, shore-shore. Under the framework of e-Navigation, the communication system mainly includes two parts, voice and data, and the range of communication should be covered from the port to the open sea and even the polar regions. In order to support the data exchange, the main direction of development of communication technology is digitalization, high bandwidth, wide coverage and low cost.

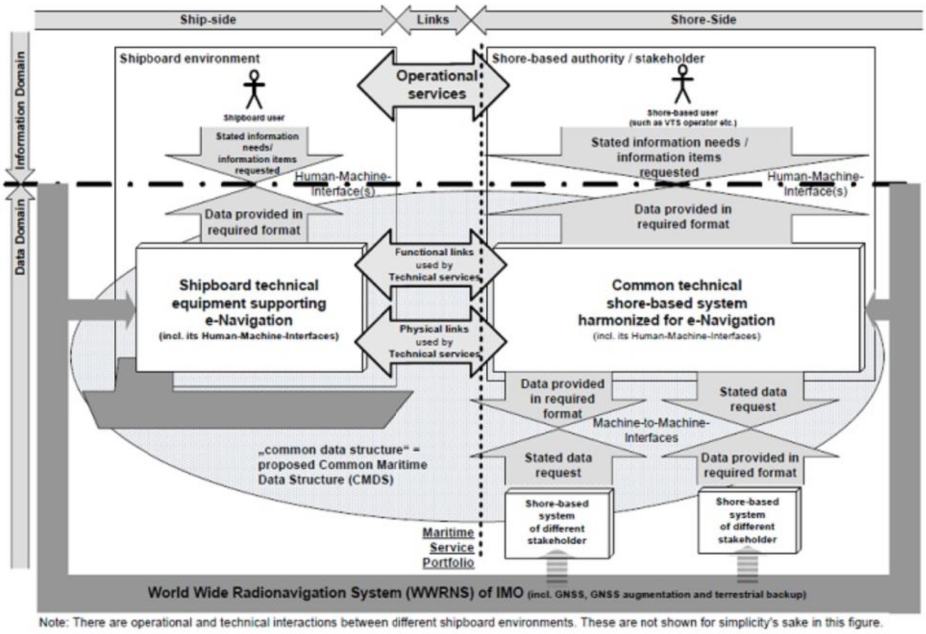


Figure 5. 1- E-Navigation Architecture

Source: IMO. (2011). Development of an E-Navigation Strategy Implementation Plan, Report of the Working Group

Developing a maritime wideband communication system will greatly contribute to the maritime distress, urgency, safety, and general communications. (Zhang, 2013) However, there are some drawbacks in current marine communication technology. If the cost is low, the coverage and speed is too limited. Taking the VHF as an example, the maximum data rate is merely 9.6 kbps. (Wen, 2013) Contrarily, if it is wide coverage, the cost is too high to maintain the moderate bandwidth. (e.g., voice service costs 13.75 U.S. dollars per minute) (Yang, 2016) Therefore, under the framework of e-Navigation, new communication systems need to be developed.

5.3 Breakthroughs in Modern Communication Technology

Since entering the 21st century, the development and application of Internet have a great impact on human society. Network communication system onshore has experienced a rapid development in recent years, the technology has reached a mature level, the application has penetrated into all areas of human society and has entered the commercialization stage. The e-Navigation strategy puts forward urgent demand for the maritime communication system. Maritime satellite communication system which is represented by Beidou Navigation Satellite System (BDS), the Internet which takes the TCP/IP protocol as the core, the telecommunications network which is based on the Asymmetrical Digital Subscriber Loop (ADSL) technology, the digital cellular mobile communication network, the broadcasting television network and Wide Area Network (WAN), Local Area Network (LAN), Metropolitan Area Network (MAN), wireless LAN, all of these can achieve global coverage of communication as much as possible. In particular, the development of TD-LTE technology, Worldwide Interoperability for Microwave Access (WiMAX) technology, WiFi technology, large-scale Multiple-Input and Multiple-Output (MIMO) technology, the 4G/5G technology, will make the modern network can transmit the voice, data and image information to anywhere on earth when there is demand. The network technology will continue to move towards an open, integrated, high speed, high performance, broadband and intelligent direction. These evolving network technologies will provide strong technical support for the construction of maritime communication system.

5.3.1 Maritime Satellite Communication Technology

In the future marine communication system, satellite will be more and more dominant. Since the International Maritime Satellite Organization (INMARSAT) began to provide the global maritime satellite communications service in 1982, the development of the communication satellite system has gone through four generations. The fourth-generation maritime satellite communication system provides convenient services of high-speed mobile broadband satellite on land, sea and in the air. The e-navigation strategy and the development of new broadband multimedia services will fully open a new era for the applications of the broadband mobile satellite communication.

5.3.1.1 Inmarsat/VSAT/ Iridium satellite

The communication technology of Inmarsat, Very Small Aperture Terminal (VSAT) and iridium satellite has many advantages which are wide coverage, broadband and applicable to a variety of business transmission. They are the important part of China’s e-Navigation strategy. (See Figure 5.2) With the growing demand of marine communication services, the development of new satellite communications technologies will inevitably become the future trend of development. INMARSAT have been developing this type of product, such as the Inmarsat Global Area Network (GAN), Inmarsat sub Regional Broadband Global Area Network (R-BGAN), Inmarsat Broadband Global Area Network (BGAN) and Inmarsat handset (ISTPHONE) etc. Among them, the R-BGAN products achieve mobile satellite broadband data communications business. The BGAN system which is led by the Inmarsat and supported by the European Space Agency is a new generation of Inmarsat global satellite broadband LAN system. It is able to access the broadband Internet, broadcast real-time mobile video, and be compatible with 3G and other avant-garde communication means. The BGAN will cover 85% of the global land area to provide seamless network. The terminal equipment can carry high-speed Internet access up to 492 kbit/s, to support the voice, fax, Integrated Services Digital Network (ISDN), Short Message Service (SMS) and other business applications. (Yang, 2012) Meanwhile, the Ka band satellite is developed to meet the demand of broadband communication. Comparing the C band and Ku band which is the current mainstream satellite band in China, the Ka band satellite communication is only in its infancy. It is also one of the prioritized developing maritime satellite communication system in the strategy of e-Navigation.

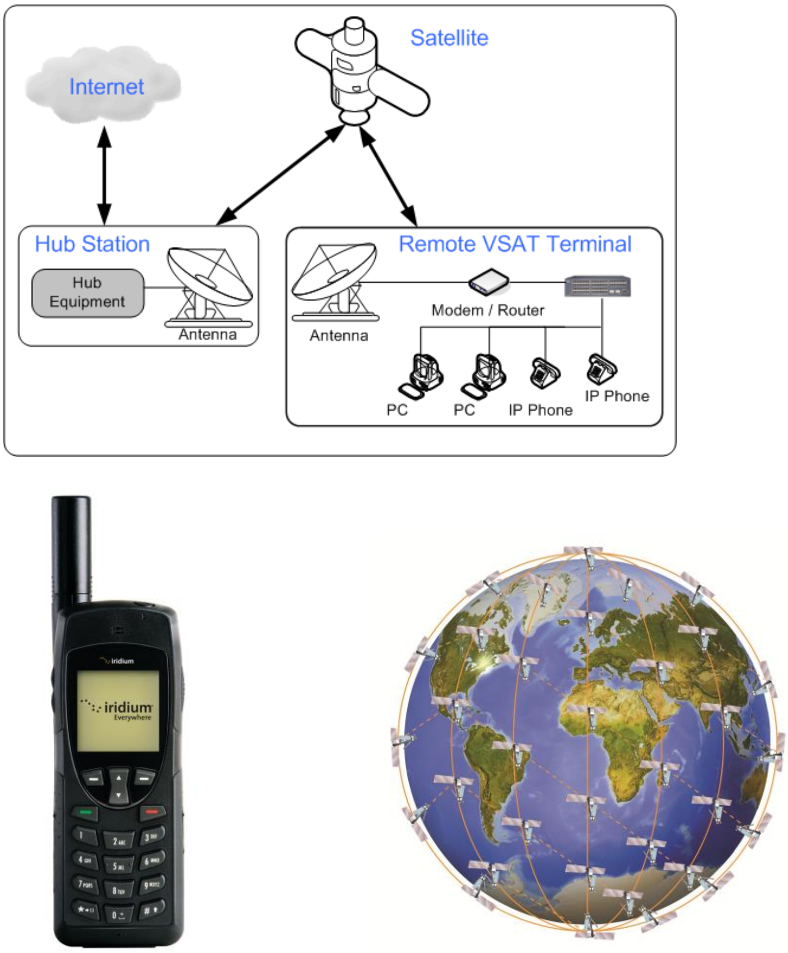


Figure 5. 2 - Different satellite communication technologies (VSAT/ iridium satellite)

Source: Liu, L. M. (2015). *Research on the modern navigation communication system based on intelligent optimization algorithm.*

5.3.1.2 BDS

BDS is a kind of Global Navigation Satellite System(GNSS), which is researched, developed and operated by China independently. It has been officially announced to provide services for much of the Asia Pacific region, and will be formed by the more than 30 satellites to provide services for global users in 2020. With the construction and operation of the BDS, it makes China get rid of the long-term dependence on Global Positioning System (GPS). Besides the function of positioning, navigation and timing in other GNSS, the BDS has the originality of short message communication, that certainly will become an important part of China's e-Navigation project. The accession to the IMO standards is facing challenges, which requires a large number of domestic support work, including the release of specification documents, the test data of actual service performance, the development, test and practical application of domestic ship borne receiver equipment. The BDS/GPS integrated positioning technology will be vigorously developed and perfected, and as the China's e-Navigation strategy, the standardization work of BDS in IMO is also significant.

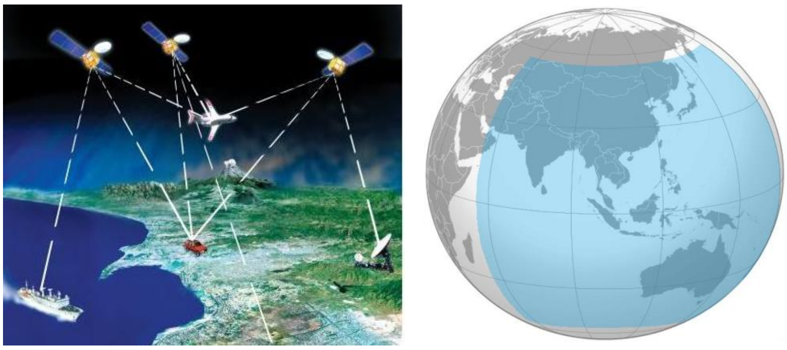


Figure 5. 3 - BDS and its service coverage area
Source: http://www.beidou.gov.cn/

5.3.1.3 Satellite AIS

The AIS was born in 1990s. Its main purpose is to facilitate the exchange of navigation data between the ship and shore, in order to enhance the safety of navigation and monitoring of the shipwreck. However, the AIS works on the VHF band, which determines its limited coverage, only about 20 to 30 nautical miles. Recently, people urgently need to go beyond VHF coverage area in order to handle dangerous vessels better, enhance security and record the dangerous operation. The satellite AIS is using a single or multiple low orbit satellites (the altitude of satellite orbit is from 600km to 1000km), equipped with a AIS receiver to receive and decode AIS message and transfer the information to the corresponding satellite earth station, so that the management agencies on land can master relevant dynamic information of the ship. A few years ago, the United States, Norway and other countries began to study the satellite AIS technology. In recent years, these countries proposed the use of satellite AIS of ship under the framework of ITU and IMO relevant sub-committee, namely the use of satellites in low earth orbit, so as to realize the monitoring of ships in the high sea.

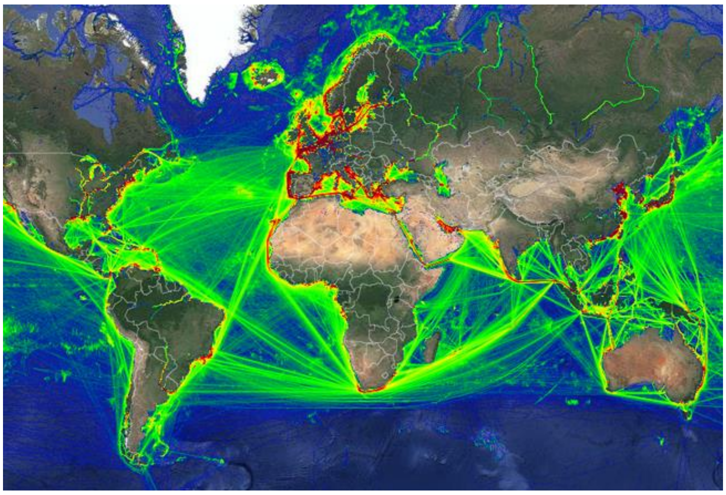


Figure 5. 4 - Global fleet track with satellite AIS data
Source: http://www.marinetraffic.com/en/p/satellite-ais

5.3.2 Ground Maritime Private Broadband Network

5.3.2.1 AIS 2.0

AIS will play an important role in the future data communication of e-Navigation system, but because AIS is not a large capacity high-speed communication system, its application in the future e-Navigation system has the bottleneck of communication bandwidth. The E-Navigation Committee has studied the radio spectrum of AIS and proposed the spectrum requirements for future AIS systems. The concept of AIS2.0 is proposed, that is, 4 communication channels will be added to the existing 2 channels and combined with the modernization of GMDSS. At present, IALA has built the basic communication mode of future e-Navigation strategy with the AIS2.0, digital communication based on VHF link and digital communication within 500kHz band. (Yang, 2012)

5.3.2.2 NAVDAT

Navigational Data (NAVDAT) is a new digital modulation scheme of the implementation of shore-ship safety information broadcast. The NAVDAT test in China has been reported on the fifteenth Committee of the e-NAV in IALA and received widespread attention and appreciation from representatives of all countries. Early in the twentieth Century, the 500 kHz band was used for maritime call and distress communications. However, with the development of GMDSS, its distress, alarm and communication functions are gradually disappearing. At the WRC 2007 (World Radiocommunication Conference), ITU has taken back the 500 kHz band and the digital modulation was carried out. The application is defined as NAVDAT. In addition, since the frequency of NAVDAT is similar to that of NAVTEX, the launching of NAVDAT can be accomplished by only minor modifications to the coastal radio transmitter. Even though NAVDAT can only solve the problem of single channel digital communication between shore and ship, its application prospect is fairly wide because of its high transmission rate and large coverage. With the compulsory deployment of Electronic Chart Display and Information System (ECDIS), the problem of data updating of electronic chart is becoming more and more obvious. If the electronic chart data can be updated by NAVDAT, the ship will be greatly facilitated. When ships enter and leave the port, they will have some new navigation information, navigational warning, navigation announcement information and so on. If they use NAVDAT to broadcast, the ship will be able to obtain the information in a timely and accurate manner. Weather and hydrological information can be of great help to navigation. If the information is broadcast in real time, it can better serve the ships in the relevant area. NAVDAT has now finished the data transmission test. At this stage, the main consideration is the planning and development of the system application. (Hu at el, 2013)

5.3.2.3 3G/4G/5G Public Mobile Communication Technology

According to the present situation of in the offshore area in China, where the communications is not smooth and the digital broadband network is blank, basing on the full investigation of actual requirements of the e-navigation core user in China, relying on the 3G/4G/5G public mobile communication, particularly the TD-LTE technology with Chinese intellectual property rights, to adapt maritime security, to improve the video communication data and voice communications, is one of the vital demand of development in ground communication system in China's e-Navigation strategy. (See Figure 5.5)

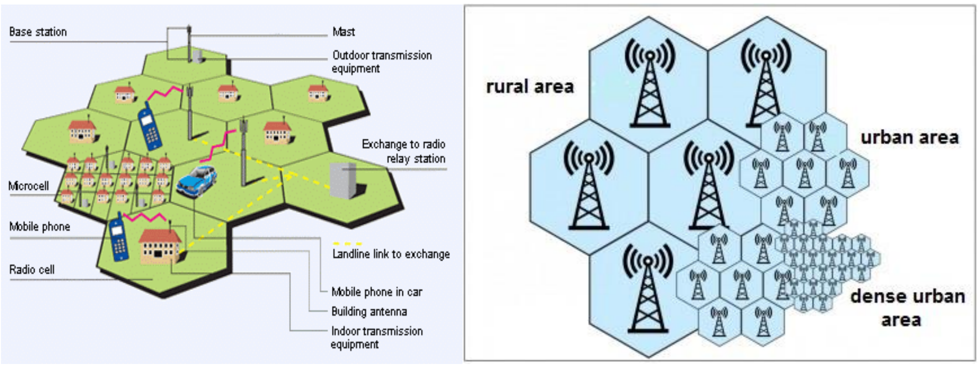


Figure 5. 5 - Mobile communication technology

Source: Liu, L. M. (2015). *Research on the modern navigation communication system based on intelligent optimization algorithm.*

5.4 Network Structures in Modern Communication Technology

5.4.1 Cyber-Physical System

The Cyber-Physical System (CPS) is a complex system with a comprehensive multidimensional calculation, network and physical environment. It can achieve dynamic real-time control and information services for large-scale engineering system, by the organic integration and deep cooperation with the 3C (Computer, Communication, Control) technology. The CPS realizes the integration design of computing, communication and physical system, which makes the system more reliable, efficient and real-time cooperative. It has important and extensive application prospects.

5.4.2 Delay Tolerant Networks

Delay Tolerant Networks (DTN) is a new research field which can efficiently utilize node mobility statistics and permit other nodes to store, carry, and forward data packets once a communication opportunity arises. (Yang, 2016) In some specific network environment (such as interplanetary network, military Ad hoc networks, sensor networks, vehicular Ad hoc network), the network disconnection phenomenon will appear frequently, thus, it cannot ensure the end-to-end path of the packet in the transmission process. This type of network is known as DTN. This network structure provides interoperability for many challenging networks (such as interplanetary networks, sensor networks, land mobile networks, etc.). The networks which face the challenges are often relatively slow, their network topology often changes and run poorly on existing network structures. DTN covers many existing networks, enabling them to make full use of their own network features and interoperate. At present, the hotspots of DTN research include opportunistic routing, congestion control, network security and so on. DTN has many potential applications, such as Interpenetrating Polymer Network (IPN), wireless sensor networks, vehicular networks and other restricted network environments. DTN is a network solution mainly for end-to-end connections and node resources with limited time to meet the reliable delivery of random asynchronous messages. The research and development of DTN for military, aerospace communications, disaster recovery, emergency rescue and other fields of information interaction provide scientific theory and technology support, and greatly promote the intelligent, ubiquitous and integrate trend of the communication network in the future. (See Figure 5.6)

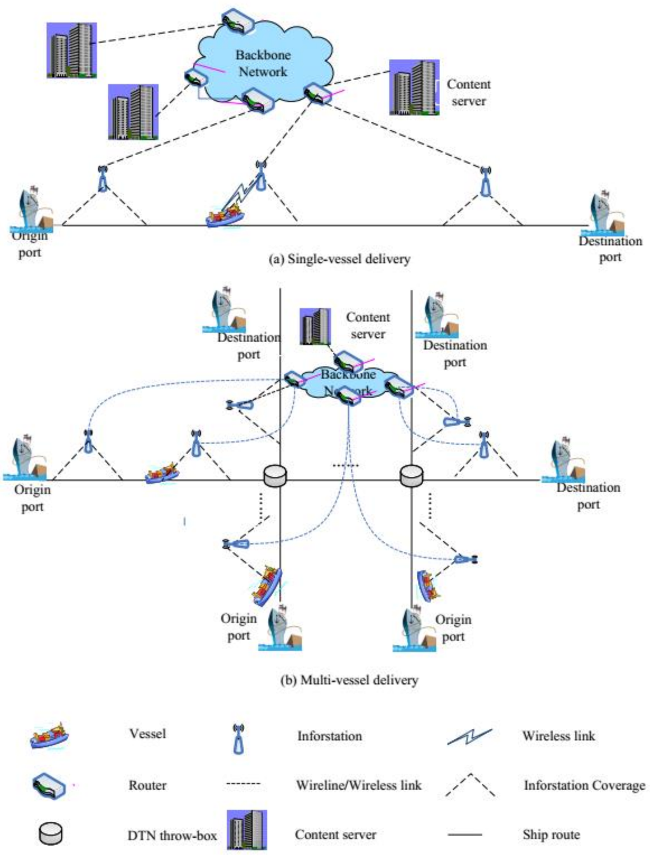


Figure 5. 6 - An illustration of the DTN network topologies

Source: Yang, T.L. (2016). Efficient Scheduling for Video Transmissions in Maritime Wireless Communication Networks

5.4.3 Cooperative Cognitive Radio Networks

Cognitive Radio (CR) is a further extension of Software Defined Radio(SDR). The basic definition of cognitive radio can be summed up as follows: cognitive radio is an intelligent communication system that can perceive the external communication environment. The cognitive radio system constantly perceived changes in the external environment by learning, and achieve adaptation to these changes by the adaptive adjustment of its own internal communication mechanism. On the one hand, the adaptive adjustment is to improve the stability of the system, and on the other hand, it is to improve the utilization of spectrum resources. It can be summed up the characteristics of cognitive radio is that the perception of the environment; the learning ability of the change in the environment; adaptability to environmental change; high reliability of the communication quality; full use of spectrum resources; the reconfiguration of the system function module. Because of these characteristics of cognitive radio, it plays a vital role in the application of cyber security. And that is the biggest challenge of intelligent ship in the future. (See Figure 5.7)

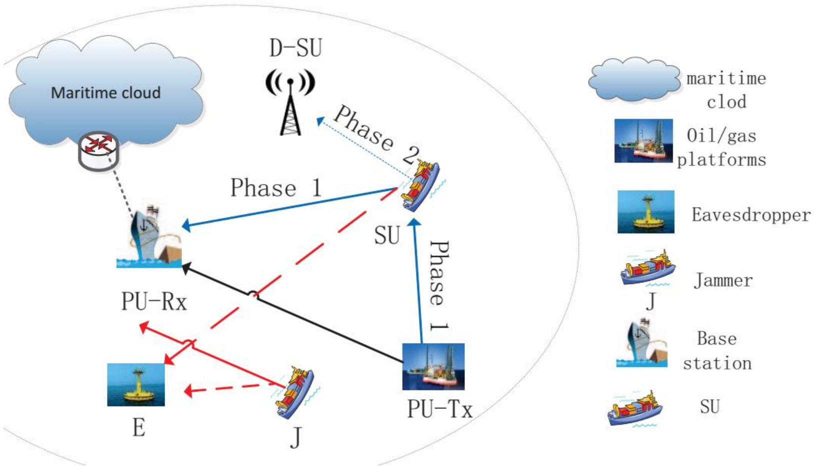


Figure 5. 7 - The system model of CR network

Source: Yang, T. T. (2016). *Resource Allocation in Cooperative Cognitive Radio Networks Towards Secure Communications for Maritime Big Data Systems*

5.4.4 Wireless Sensor Network

Wireless Sensor Network (WSN) is Multi-Hop Wireless Ad Hoc Network composed of a large number of tiny, low cost sensor nodes. It is used to collect and disseminate environmental data, and has become a new information acquisition, processing and transmission technology. With the rapid development of microelectromechanical system, SoC (System on Chip) is realized. A small chip can transmit logical instructions, perceive the real world, and even react. WSN, a network composed of a large number of micro sensor nodes with on-chip micro processing capabilities, has attracted the attention of many researchers in the industry and academia. Traditional sensor networks usually consist of two nodes: the sensor node (sensor) and the receiver node (sink). The sensor nodes are responsible for the perception of an event and the transmission of data packets; the receiver node is the destination node of data transmission, with man-machine interface, and can access other types of network system. Due to its low cost and low power consumption, WSN plays a significant role in the technology of e-Navigation strategy. (See Figure 5.8)

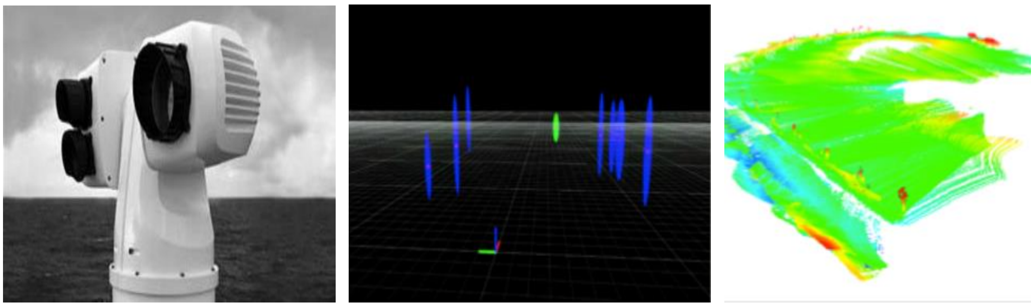


Figure 5. 8 - Sensor onboard and its view

Source: MUNIN & AAWA Brochure. (2016).

The structure of the sensor network is shown in Figure 5.9. The sensor network system usually consists of sensor nodes, sink nodes and management nodes. A large number of sensor nodes are randomly deployed inside or near the monitoring area, which can form networks through self-organizing methods. The sensor node monitoring data transmit along the other nodes hop by hop, monitoring data may be dealt with by a number of nodes in the transmission process, pass the multi-hop routing to the sink node, and finally reach the management node through the Internet or satellite. Sensor nodes are usually a micro embedded system, and its processing capacity, storage capacity and communication capacity are relatively weak, and it is powered by a battery with limited energy. In the network function, each sensor node is both traditional network node terminal and router, not only collect local information and process data, but also responsible for the storage, management and processing integration of the data transferred from other nodes, and cooperate to complete specific tasks. The processing capability, storage capacity and communication ability of convergence node are relatively strong, it connects the sensor network, Internet and other external networks, and realizes the communication protocol conversion between the two protocol stacks

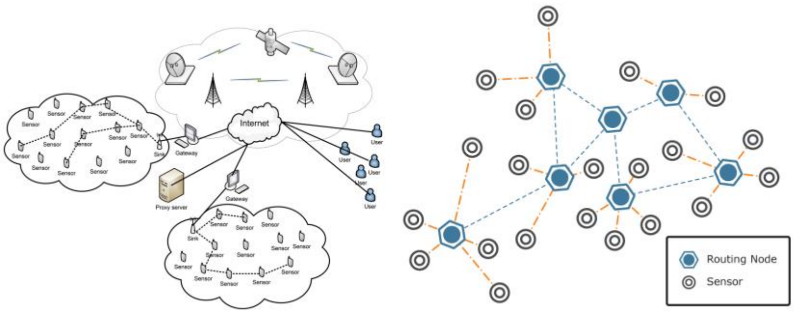


Figure 5. 9 - WSN architecture

Source: Liu, L. M. (2015). *Research on the modern navigation communication system based on intelligent optimization algorithm.*

5.4.5 Multi-Source Data Acquisition and Processing Network

There are three parts of the Multi-Source Data Acquisition and Processing Network.

Online monitoring and control platform for offshore ships and goods transportation. It is a multi-disciplinary platform, which contains computer, navigation, marine engineering, network and communication, software engineering, information systems, GIS (geographic information system), marine meteorology, and control technology. Its online monitoring and controlling cover the global navigation area to realize the online integration monitoring on the basis of offshore broadband network.

The offshore ship polymorphism data acquisition system. It is based on the ship polymorphism heterogeneous data acquisition unit, collecting four types of real-time data: the navigation data, engine data, goods data and video data. And it provides online analysis and early risk warning.

The broadband dynamic video transmission system for offshore ships. It builds the broadband network video surveillance system to the offshore ship. The video image of the ship can be sent to monitoring command center onshore. The monitoring center can achieve real-time video remote monitoring on the deck, the sea, the cabin, the bridge and other positions. This system can summarize the data from GPS/DGPS, VDR, SSAS, AIS, log, electric compass, sounder, wind speed instrument and autopilot.

5.4.6 Ship-Shore Information Integrated Network

If the intelligent ship wants achieve the most commercial interests, it is not only to achieve the ship itself intelligence (point), but also to achieve the connection and management with the management center of the shipping company (line), and to achieve the resource sharing in national or regional logistics network (area). The dynamic broadband information exchange and communication system developed under the E-navigation strategy, it has the characteristics of numerous types and wide distribution. How to collect, merge and display the maritime safety information onboard or onshore, establish an information exchange model, a comprehensive evaluation model, and a reliable marine traffic safety guarantee system, is the key and difficulty technology to be solved. Ship shore information integration model is shown in Figure 5.8. In the offshore dynamic broadband network system, as the basic communication link construction of the ship-shore, ship-ship, in includes the ship-shore dynamic access and broadband network, and ship-ship dynamic interconnection and broadband network. The goal of the former one is to provide a direct broadband connection with the shore based system for offshore sailing vessels, and aim of the latter one is to provide broadband interconnection among the vessels. (See Figure 5.10)

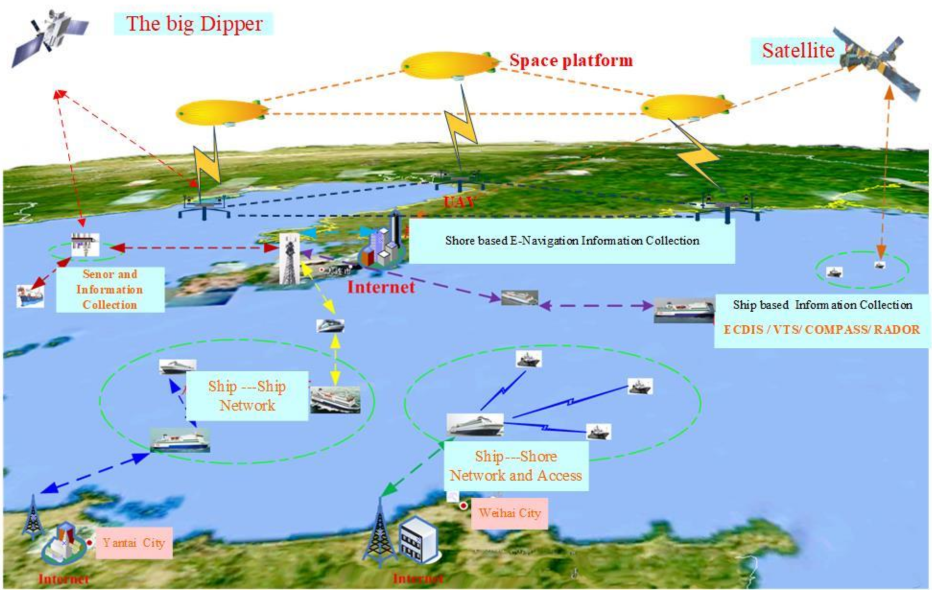


Figure 5. 10 - Ship-shore information integrated network

Source: Yang, T. L. (2015). *Research on Maritime Communication Networks under e-Navigation Strategy*

With the wide application of new technology and new equipment, the standards of the ship borne equipment and shore based facilities are not unified, resulting the information incompatibility of ship-ship or ship-shore. The e-Navigation system is an information interaction system, so the flow of information among the various components of e-Navigation is the key to the system. The standardization of information transmission and data modeling is an important research content of e-Navigation. In May 2012, in the 90th conference of MSC, the IHO S-100 was set up as a standard data model under the concept of E-Navigation, that is to say the various e-Navigation related data shall conform to S-100 data modeling mechanism, and create data access and service architecture basing on the S-100 in the range of SOLAS. Currently, the E-Navigation communications working group also recommends the IMO to consider the IHO S-100 standard as a universal data structure of maritime information.

CHAPTER 6

THE IMPACT OF UNMANNED SHIP

ON FUTURE MARITIME MANAGEMENT

6.1 The Significance of Taking Unmanned Ships as the Subject of Discussion

The development of the ship intelligence can be divided into two stages. In the first stage, the number of crew becomes less and less, and in the second stage, the crew will completely disappear. These two cases are essentially different. As long as human existence on the ship, even if there is only one person, then the ship design for personnel safety and living environment are required to meet the human needs. The situation of no crew is entirely different. All of the human related facilities can be completely omitted, and the design concept of human centered will be totally abandoned. From conventional ship to intelligent ship which only needs few crews, and finally to unmanned ship without any crew, the number of crew is gradually decreased during this period of development. We only need to consider the two extremes, which is current rules and standards designed for the conventional ship, and the changes need to be made to adapt to the unmanned ship. In the development stage of intelligent ships which the manning is reducing, the two extremes can be treated as a reference, the relevant administrations can adjust the rules appropriately within this range.

6.2 The Impact of Unmanned ship on International Conventions

Obviously, the essential difference between an unmanned ship and a conventional ship is that there is no crew. So, the first and fundamental question to be resolved is whether ships without a crew on board are ‘ships’ or ‘vessels’ within the meaning of the convention at all. Therefore, redefining ship from the legal sense will be the first and significant task. The IMO has adopted more than 50 international conventions and protocols aimed at harmonizing rules for international shipping. Among them, there are some main conventions closely related to the crew, such as The International Convention for the Safety of Life at Sea (SOLAS), International Convention for the Prevention of Pollution from Ships (MARPOL), International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) and Maritime Labor Convention (MLC), which was developed by the International Labor Organization (ILO) in 2006. The author would like to discuss one by one, the impacts on the conventions if unmanned ships are widely used.

Firstly, the SOLAS. There is a word – life in the name of this convention, so we could imagine that if there is no life onboard, it will be not applicable in many cases. Some regulations in SOLAS provides the requirements which cover construction, equipment and materials on board. For most of the structures, an unmanned ship is basically the same as a conventional ship, for instance, the double bottoms. However, the regulations relating to information procedures and communication for the crew, alarms, monitoring mechanisms etc., are obviously difficult to apply on a completely unmanned ship. Different from the way in which the warning devices need to be reminded of the duty officer in time, many monitoring techniques will be implemented by means of remote control. And the lifesaving equipment and structure is not necessary anymore. Therefore, the layout of many equipment on board will be made considerable change.

Another interesting problem is whether there is any need to issue a Minimum Safe Manning Certificate if there is no crew on an unmanned ship. If issued, then the minimum number of safe manning is zero, then the certificate does not have any practical significance. However, if not issued, the operation of remote control personnel onshore also meets all the requirements of the ship's daily sailing safety. Furthermore, do workers on shore need to bear the same safety responsibilities as those on board? All the current international and national rules on safe manning are drafted on the understanding that the crew is based on board the ship, hence, the related concepts may need to be adjusted more precisely for unmanned ships. In SOLAS, the requirements of safe operation are also made clearly. ISM Code proposed requirements for the crews and the captain in the terms of responsibilities and obligations, with the change of the subject of management, the specific operation process needs to change.

Secondly, the MARPOL. The main content of the MARPOL convention is to prevent ships from causing various forms of pollution. These specific requirements for pollution are based on external ecological considerations, and it will not change when there is no crew on board. Among them, the specific work that involves the crew is the filling of all kinds of record book, of course, the form of electronic records may also be recognized, and it is more convenient for inspection. One thing we should pay attention to is that it is necessary to make clear specifications for dealing with the pollution accidents of ships, that is, the response capability of pollution of unmanned ships in emergency and liability of it.

Thirdly, the STCW. In accordance with the ideas of the requirements of the traditional STCW Convention, it is evident that a corresponding training regime will eventually have to be developed for persons operating ships remotely. Moreover, the examination and certification of these personnel is also a problem, which needs to be solved even before the wide application of unmanned ship. Because of the remote control, the staffing and watchkeeping system need to be changed. The regulations on the job setting, working hours and time off should also be adjusted. The decision of whether a particular manning suffices for maintaining a safe lookout and watchkeeping on the ship will have to be addressed through the process of safe manning where all such factors will have to be taken into account.

Fourthly, the COLREGs. The provisions of the COLREGs, such as safe speed, signals, lights, etc. are mostly still applicable to unmanned ships, but the navigational tasks of the crew, such as situation, awareness and operational decision-making when it comes to collision avoidance, priorities, speed etc. need to be changed accordingly for unmanned ships. The various types of cameras, radar, audio technology and other technical solutions replaced the traditional human lookout. It was necessary to make specific requirements for the AI before it completely replaces human. The way which the signal is transmitted may need to be changed because the subject of recognition is changed from human to machine. In this case, the electronic signal must be more effective than the acousto-optic signal. There is a question that if the operational decisions are automated without any controller, who is the decision-maker. A program? Or the programmer?

Lastly, the MLC. The original intention of this Convention was to protect the basic rights of the crew. From this point of view, the unmanned ship was not subject to any of the rules of the MLC, and its content was meaningless. The protection of the rights of land personnel should be based on land related regulations

6.3 The Impact of Unmanned ship on Maritime Supervision in China

First of all, it will affect the formulation of rules and regulations.

This is easy to understand. In China, the vast majority of rules and regulations refer to maritime supervision are based on the relevant requirements and standards of the international conventions. As discussed above, the widespread application of unmanned ship will inevitably bring about the revision of international conventions, and the corresponding maritime rules and regulations will naturally change with them. When the new technologies are applied to the shipping industry, the maritime authorities need to formulate uniform standards in time. For example, the regulation and supervision of remote control operations onshore is a blank.

Furthermore, it will affect the administrative approval.

For the unmanned ship, the crews and many devices will no longer exist, such as sewage treatment equipment, the lifeboat and raft and the emergency escape equipment, the relevant administrative examination and approval will be canceled and the corresponding certificates will not be issued anymore. e.g. Certificate of Competency (COC) and Certificate of Proficiency (COP) for seafarers, the International Sewage Pollution Prevention Certificate (ISPPC) for ship. Due to changes in responsibility, some of the content of the approval need to change. For instance, the safe operation of the ship depends on the remote control onshore, the review of the company's Safety Management System (SMS) should be adjusted accordingly.

Thirdly, it will affect the inspection onboard and related law enforcement work.

The unmanned ship enters and departs the port under automatic operation, and has its own intelligent computing system, it puts forward new requirements for the watchkeeping of traditional maritime Vessel Traffic System (VTS). For the site inspection onboard, if there is no crew and relevant safety equipment, the significance and necessity of PSC and FSC need to be discussed. In previous inspections, there were many inspection items that required direct communication with the captain. In the case of unmanned ship, it is a question to consider how to communicate with the person who is responsible for the whole ship. Moreover, it is apparently no longer need to consider the inspection of with operating ability and the emergency drill of the personnel. One of the most important items of routine inspection, the lifesaving equipment, has been ceased to exist, and the other equipment relates to the safety of navigation all have the detailed status data, which can be remotely check anytime.

Lastly, the cyber security will become an important aspect of maritime supervision

Because the control of unmanned ship is completed on the basis of the data exchange between ship and shore, it is necessary to ensure the security of information. The previous article has discussed the safe network for shipping, but, like the Internet on land, technology cannot thoroughly avoid malicious attacks by criminals. Such as, the interception of data, which can change the navigation routes and plans; the tampering with data, which may deceive relevant department during the inspection, etc. The MSA should strengthen the cultivation of professional forces of information security, and establish a cooperation mechanism with the relevant departments (in China, it is network police subordinate to the Ministry of Public Security). These issues should be carried out gradually with the development of intelligent ship, to avoid supervision lagging behind technological progress.

CHAPTER 7

CONCLUSIONS

The main objective of this research paper is to review the drawbacks of the conventional ship, emphasize the importance of developing intelligent ships for shipping industry in China, and discuss the changes in future maritime management. **Foremost,** this paper listed the latest developing trend of intelligent ship to demonstrate the AI technology will redefined the shipping industry soon. Then analyzed the drawbacks of the conventional ship from the two main aspects of safety and environment, introduced the improvement of intelligent ship. **Additionally**, the author summarized the key technology of intelligent ship, and discussed emphatically the communication technology for realization of intelligent ship in the context of e-Navigation strategy. **Subsequently**, the author reflected on what changes would be made by unmanned shipping to existing international conventions, discussed the implications of these changes for maritime management. **Finally,** the summary was made.

There were still some regrets and shortcomings in this research paper, the author listed them and offered sincere hope for further research. **First of all,** limited by the time of the research, the author cannot make further exploration in detail. **Secondly,** due to the topic of intelligent ship has become so popular in recent years, there are few systematic books on the subject. Technical research is mainly conducted by several large groups in the world, and the available technical data are relatively limited. Therefore, there is a lack of more accurate quantitative analysis in this paper. **Lastly,** for the large-scale use of unmanned ships, it is now in ideal condition. When it comes to reality, there may be a dramatic change in society. Changes in society will also profoundly affect maritime management. This article ignores the implications of these changes.

If further research can be carried out, the author hopes that more data can be obtained from relevant research institutions to prove the benefits of intelligent ships for China's development by more precise calculations. In this paper, the communication technologies have been listed for realization of intelligent ship in the context of e-Navigation strategy. The relevant departments can formulate more detailed implementation plans according to the data of the ports. Finally, China MSA can set up specialized research institution which focuses on the actual problem of intelligent ship from the experiment to operation stages. The aim is to bring together more experts from various professions, to provide more comprehensive and professional thinking, and also to provide strong support for the development of intelligent ships in China.

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