ClassNK Technical Journal

Feature Articles: Digitalization

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— CONTENTS —

Business transformation using digital technology has increased in the Maritime Industry as well as other conventional industries. Keynotes on the digitalization in the Maritime Industry are stated in this article. First the history of the use of computer technologies is looked back, and then the essence of digitalization and the related digital twins are described. Furthermore the role of collaboration with domain experts in data analysis and the open platform for data sharing are described. Finally, issues of the maritime industry and the role of digitalization are described and conclusions are stated.

The risk of cyberattacks on ships is increasing. The basis of this is constant connection to the Internet via satellite communications, the promotion of the use of ship data such as ship IoT, and the use of a general-purpose OS for ship equipment. We considered anticipated cyber risks when ship systems approach the system environment on land, based on knowledge of cyberattacks on land.

The history of AI began at the Dartmouth Summer Research Project on Artificial Intelligence, which was held in 1956.Since its birth, however, AI has experienced two boom periods, followed by two winter periods, in-between.This paper will provide a broad overview of the current state of technology in AI,based upon its history.In doing so, this paper aims to relinquish unnecessary fears that the public might have towards AI,while promoting the establishment of AI into broader society, as the third AI boom is currently taking place.

In recent years, movements to digitalization and reformations of business model using digital technology, i.e. digital transformation, have progressed by leaps and bounds. From the standpoint of a classification society, ClassNK has been setting up a platform and offering services for digitalization and it is further accelerating. This article introduces ClassNK's activities for digital transformation in the maritime industry.

In the field of ships, research and development of technology related maritime autonomous surface ships (MASS) has been actively carried out in Japan and overseas. The research stage is progressing to the development stage, and the demonstration experiment of technology related MASS on an actual ship is being carried out. This paper mainly describes how to evaluate the safety of MASS from the standpoint of a classification society.

Technical Topic

According to regulation 14 of Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), from January 1st 2020, any fuel oil used on board ships will be tightened from the current requirement of 3.50% m/m to 0.50% m/m outside emission control areas (ECAs).

ClassNK identified five potential safety implications of compliant fuel oil and reviewed mitigation measures against these implications, and issued as guidance. This article introduces the outline of the guidance.

There is a good possibility that ROV (Remotely Operated Vehicles) can be more efficient for docking surveys, while in-water surveys by divers may be accepted in lieu of Surveys in dry dock on the slipway. In order to verify its effectiveness, a test trial of in-water surveys using ROVs was conducted. This paper introduces the results.

This is a report of the summary of marine casualties in 2018 (1 January to 31 December) for ships registered with ClassNK. And, as measures for strengthening regulations for SOx emissions and ballast water management system are being adopted, incidents of machinery damage estimated to be related to fuel oil and malfunction in ballast water management system are being reported. Hence, Such incidents of machinery damage are introduced.

In order to carry out reasonable fatigue strength assessments in line with the actual situation, it is necessary to use loads which act on ships actually. Therefore, the authors analyzed AIS data for about 25,000 ships over a period of about 3 years, and identified the standard route for each ship type and ship size in order to grasp the loads actually acting on ships. In addition, wave scatter tables corresponding to the specified standard routes were obtained and appropriate methods to set the design load corresponding to these wave scatter tables were examined.

Fundamental characteristics of the Ocean Energy Harvesting Vessel, that is the new conceptual idea of the sailing vessel with hydro-rotor for generation, were investigated by parametric-research method. At first, a conventional soft-ware for the basic performance of sailing phenomenon was prepared. One type of the sailing system named AIST-Rig was selected out after the comparison. Detailed parametric research was conducted with the variation of main parameters such as lift-coefficient of the aero-foil etc. Finally, we could get the result that the lift-coefficient of the aero-foil (s) and the friction-coefficient of the hull seems to be main factors according to the potential of the system.

This article introduces recent topics discussed at IMO (International Maritime Organization). At the 1st issue, a summary of the decisions taken at 74th Marine Environment Protection Committee (MEPC 74) and 101st Maritime Safety Committee (MSC 101) is provided.

ClassNK Technical Journal 1st Issue

ClassNK President & CEO Koichi Fujiwara

Welcome to the first issue of ClassNK Technical Journal.

Up until now, we had regularly issued two kinds of technical publications titled “ClassNK Technical Bulletin” in English and "Nippon Kaiji Kyokai Kaishi" in Japanese respectively.

With the remarkable development of information and communication technology (ICT), artificial intelligence (AI) and so on in recent years, we are witnessing the rise of a new society closely symbolizing Japan’s concept of “Society 5.0”. This movement is also rapidly progressing in the maritime industry as digital transformation.

On the other hand, the maritime industry is facing the global challenge of reducing GHG emissions and must carry out the necessary initiatives to halve GHG emissions in global shipping no later than the year 2050 compared to 2008 levels.

Under these circumstances, together with all other industries, the maritime industry must strive for innovative R&D and technological development that goes beyond the traditional business framework.

ClassNK is carrying out mid-long term R&D in line with its R&D Roadmap developed in 2017 from the above perspective.

In response to these environmental changes surrounding the shipbuilding and maritime industries, we have decided to integrate the previously published “Nippon Kaiji Kyokai Kaishi” and “ClassNK Technical Bulletin” into a comprehensive publication containing technical information titled “ClassNK Technical Journal”.

I sincerely hope the ClassNK Technical Journal will be useful to everyone among the new changes in the maritime industry.

In closing, I would like to express my gratitude for the continued support and feedback we receive from all of you.

About Special Feature on "Digitalization"

ClassNK Corporate officer, Director of Research Institute
Toshiyuki Matsumoto

As stated in the address of Mr. Koichi Fujiwara, President & CEO of ClassNK, we have decided to newly publish "ClassNK Technical Journal" as a comprehensive publication of technical information aiming to enhance technical information offers.

Special feature on the digitalization, which is the significant task of the maritime industry, has been set in the first issue of ClassNK Technical Journal.

We asked external knowledgeable persons to contribute the special feature. Dr. Hideyuki Ando, MTI Co., Ltd. contributed a keynote report on the digitalization in the maritime industry. Mr. Kenji Fukushima, KDDI Digital Security Inc. wrote on the cybersecurity and issues in ships. Mr. Wataru Ihara and Ms. Olivia Quek (Mizumura) contributed an article titled “The current state and potential of Artificial Intelligence”.

We would like to express our deepest gratitude for their kindness taking this occasion.

Furthermore ClassNK’s activities on the digitalization and on the maritime autonomous surface ships are also introduced in the special feature.

It would be our pleasure if the special feature could be useful for activities of digitalization in the maritime industry even just a little.

Digitalization in the Maritime Industry

Hideyuki ANDO*

1. Introduction

Interest in digitalization and business transformation using digital technology has increased, and even in conventional industries, there are companies making efforts to establish the position of a responsible person such as a CDO (Chief Digital Officer) to oversee digitalization, or to establish a digital department. Various explorations and trials are being carried out in various situations such as what digitalization strategies should be and whether the department responsible for digitization should be a new digital department or an existing business department.[1)]

As the background of the management of conventional industries focusing on digitalization, as embodied by GAFA, there will be a sense of danger of losing competitiveness in medium- to long-term business strategies.

These movements are also rushing to the maritime industry, and there are similar movements in setting up CDOs and specialized departments shipping companies and major manufacturers in Europe and in other areas, and classification societies are competing in creation of guidelines and the revisions of rules in line with the digitization of classification services.

The author has so far been involved in research and development on the application of computer technologies in the maritime field at universities, and in shipbuilding and shipping. This report first looks back on the history of the use of computer technologies that Japan has advanced, and then the essence of digitalization and the related digital twins are described, and based on the author's own experience and work, the role of collaboration with domain experts in data analysis and the open platform for data sharing are described. Finally, issues of the maritime industry and the role of digitalization are described and conclusions are stated.

2. Use of Computer Technology in the Maritime Industry

So what is the difference between this digitalization and the introduction of conventional information systems? First of all, I would like to briefly look back on the introduction of computer technologies so far in Japanese shipbuilding and shipping.

Shipbuilding and shipping have introduced the latest information technologies at an early stage compared to other industries. In shipbuilding, the mainframe was introduced in the 1970s, and advanced numerical calculation methods such as the finite element method (FEM) were applied to structural design, and in the late 1980s, design work was rationalized by detailed design using CAD on workstations and data output from there to the production system called NC machine tools.[2)]

In addition, it has also contributed to shipbuilding development and productivity improvement, such as with technology to develop ship hull forms by combining model tests in tanks and CFD (computational fluid dynamics), and the simulation of production processes using product models.

In shipping, the mainframe was introduced at the same time as shipbuilding in the 1970s, and operations such as B/L (Bill of Lading) issuance and cargo information management were rationalized[3)], and since then, operation work has been further rationalized by introducing a stowage computer for each ship type, such as container ships and car ships, and the introduction of an operation management systems for ship operations and ship management have proceeded.

In addition, with regard to ship equipment itself, the introduction[4)] of autopilots for automatic steering from the 1960s, the formulation[5)] of The M0 (Referred to as "M Zero") specification for the unmanned operation of engine rooms at night and the integrated control monitoring system were developed during the same period. Since the 1990s, along with computer technology innovation, control technology and information systems have been introduced, such as the introduction of GPS and electronic navigational charts (ECDIS) and the introduction of TCS (Track Control System) and AIS in cooperation with autopilots. In the main engine, the utilization of computer technology has proceeded as electronically controlled engines[6)] that replaced mechanical fuel injection using a conventional cam with software control, and this became popular in the 2010s.

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Looking back on history, it can be seen that both shipbuilding and shipping have incorporated the latest computer technologies from time to time into their own businesses and ships themselves for rationalization and efficiency.

3. The Essence of Digitalization

Compared with the introduction of conventional computer technology and information systems and current digitalization, of course, the use of mobile terminals and the use of convenient digital tools such as AR and VR are also important, but this point has been addressed by the introduction of conventional information systems and there is no significant difference.

Here, the purpose of digitalization is to clarify the waste inherent in conventional ways of businesses, to reduce it and promote rationalization. For this purpose, there is an idea to bring the logic of the computer world into the complex real world in a sense using digital tools such as data, simulation, and optimization. This is to promote rationalization and efficiency beyond the boundary of each company by using digital tools. Aiming for an industry that becomes leaner and meaner, the idea of creating an industrial structure that is more competitive than ever through new forms of collaboration with customers and suppliers is inherently included in the term digitalization.

By visualizing the situation with data, increasing transparency, making waste clear through analysis, and working with customers to aim for leaner situation, is it possible to change the competitiveness of a company? I think that is the point of view of managers who are actively engaged in digitalization.

4. Digital Twin

Recently, “digital twin” is a keyword that has been attracting attention. A real-world twin model is created on a computer, current data is extracted by IoT and reflected in a computer model, and an optimal solution is derived through simulation and optimization calculations on the computer and reflected in the real world, and also here, and basically the concept is to highlight and improve the waste that exists in the real world.

The digital twin concept itself was developed from the use of computers in engineering such as CAD/CAM/CAE, and the concept of PLM (Product Life Cycle Management), and is based on the idea of expanding the product model that has conventionally been kept in the manufacturing industry to the operation of products.[7)]

On the other hand, the digital twin is a very powerful concept, and in various industrial fields a part of reality is extracted from each aspect, modeled and expressed on a computer, and the current state sensed by IoT is reflected in the model, and simulation and optimization calculations are performed for the future, and after that, in the current state, companies make important decisions based on simulation predictions, which can be called almost real, as to how best to behave, and companies are always willing to take optimized options.

Taking Uber's dispatch service as an example, cars currently driving in the vicinity are displayed in the smartphone app, the estimated arrival time from each location to the current location is displayed, and the car to be dispatched is selected while referring to attribute information such as vehicle type, fee, and driver ranking. Although it seems that the same fleet management is performed not only in Uber but also in taxi company dispatch services and dispatch center systems, it provides an easy-to-use application that combines the vehicle location information obtained from the IoT, the arrival time prediction based on the optimal route calculation algorithm, and the attribute information database. In this way, users can always find the best driver according to their own standards, and drivers can also provide services only when they can work. All payments are made electronically for both users and drivers. As seen above, this is an example of digitalization in terms of eliminating various levels of waste, and tools such as the digital twin play a central role in realizing this.

Another example of a digital twin is the GE wind turbine (Figure 1). Turbine equipment for wind power generation is already connected to the network and is converted to IoT in the sense that sensor data is sent, and the operation status can be monitored remotely. Using this data, the fleet of wind turbines that make up the power plant is modeled on a computer, and in this example, by combining CFD simulation and optimization calculations, the direction that each windmill should face is optimized, and the concept of maximizing the amount of power generation under wind conditions is shown.

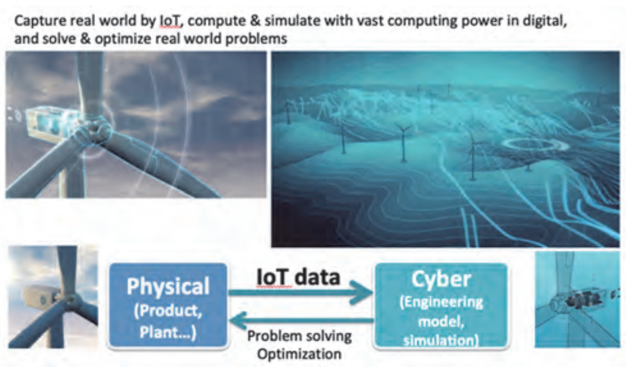

Figure 1　Example of Digital Twin in GE Wind Turbine

What seems to be important here is that engineering knowledge related to CFD is the technical knowledge that has been necessary for design and production in the past. However, in the era of IoT, the knowledge is not only necessary in design and production, but it is also needed in operations in order to optimize wind power generation. IT technology alone cannot solve optimal operation, and it is difficult to realize and utilize an actual digital twin without the cooperation of engineering and IT experts and combining each technology well.

As with the maritime industry, in digitalization in conventional industries, collaboration between domain experts such as engineering and IT experts becomes very important.

5.　Collaboration with Domain Experts

Around 2003, when I was working as a graduate school teacher, I worked with a graduate school student in the text mining analysis of problem cases in ship engine & power plants[9)]. Background of the research was an article in the Intelligent Systems magazine of IEEE about an airline company using sensor data sent from airplanes and machine learning of maintenance records to predict the replacement timing of aircraft parts from past maintenance records[10)]. At that time, with receiving a lot of guidance from the veteran chief engineer, we first conducted a study to analyze available past failure reports.

Although detailed explanations are omitted, using various natural language processing and artificial intelligence technologies, such as ontologies and several machine learning methods, we analyzed past cases of engine failure with a computer, complemented by humans, and we conducted a study to extract a fault tree used in reliability engineering with little effort.

At that time it was still not called *Big data*, but pattern discovery from such large dataset was called *data mining*. In data mining, data is generally organized and analyzed by various machine learning methods, patterns are discovered, and finally, patterns are reviewed and evaluated by domain experts, and since the purpose was to search for treasure from data, such as discovering knowledge, in that sense, we built a method to realize such a process.

However, when we explained the knowledge (in this case, the failure tree) obtained from past failure reports to NYK chief engineers, we got the response that "I see, it was well organized for amateur.", but naturally, we couldn't have such valuable knowledge that a veteran chief engineer would respect.

This was natural results., In a sense, the contents of the fault reports were simply rearranged into the appearance of the fault tree, and it is not more than what was described in the original failure reports. After all, in a normal situation, the designers of manufacturers or chief engineers drill down the root causes behind such failure reports, and valuable knowledge in the true sense can be obtained by examining the methods how to prevent its occurrence, and what to do to minimize consequences after such problems occur.

However, after that, based on the hints obtained from our research, in the department of the chief engineer who made the previous comment, made study on past accidents records, which NYK have experienced so far. At that time, the loss amount evaluated financially was added as teaching data for each trouble, narrowed down to those with large-scale losses, and detailed cause analysis was conducted. A countermeasure manual was then rationally created by repeating hypothesis testing like data mining and a method similar to machine learning with teaching. After that, I heard later that NYK achieved to reduce the number of problems and the resulting damage for targeted engine issues. After all, the concept of data mining is realized when the domain experts understand the concept and methodology of it and work with solid motivations to solve problems.

More than 15 years have passed since then, and now skilled chief engineer leads dedicated teams that use big data of engine and power plants, continuing to show valuable perspectives and judgment as a domain expert, and leading the overall activity. At the same time, I began to observe situations, where data scientists, who are skilled at handling large amounts of data and calculating numerical values, work together with the engineer to find abnormalities using sensor data from ships. This kind of domain experts and IT experts collaboration is exactly what will transform work through digitalization, and I am convinced that this is an approach that uses data to truly solve problems.

In order to create such a situation, on the other hand, it is necessary to have an IT infrastructure experts who can design, develop and operate IT infrastructure to collect sensor data, arrange it into a form that can be analyzed, and the cost of developing and maintaining such an infrastructure is also necessary. Based on these total cost effects, management support for tackling data utilization is also very important, as well as support for introducing digitalization activities into the organization, and understanding and driving by the business divisions. I think the sorts of approaches are digital transformation of companies.

Also, through digitalization, the power of computers is utilized, standardization and tool introduction are promoted so as not to take time and cost, and a cycle in which data can be used continuously with acceptable effort and cost, and the aim is to create a continuously learning organization from data. I think that is the ideal that digitalization should aim for. According to the chief engineer, who is in the story of 15 years ago, mentioned recently to me that the idea to collect data, analyze it, and make objective judgments based on it, has long been existing traditionally in the company and onboard ships. In fact, there were official instruction documents that show how to collect data, by which, every engineers had been able to collect and analyze data. This time, by automating the means of collecting data and using IoT, the amount of data is enormous and tools for analysis and machine learning have been prepared, and have become possible to create a place for data scientists to be active. I received a comment by the engineer saying, “In essence, if you explain that current IoT and abnormality detection is the same way of thinking that has been done in the field traditionally, they will understand well and be pleased.”

In a sense, when the digital twin mentioned above can be used in the field, such as in operating based on the results, there remains a need for domain experts to make comprehensive decisions, including factors that are not considered in more complex computer models and simulations, and on the other hand, we digital engineers continue to refine our skills to make full use of modern tools such as data collection, analysis and simulation. I think that there is a form of modern data utilization and digitalization that we aim for while collaborating with the domain experts responsible for business.

6. Open Platform for Data Utilization

As described so far, it is very important to use data to advance digitalization in traditional industry, and it can be said that it is important to promote the utilization of data in cooperation with domain experts.

This also leads to the importance of sharing data and using data to collaborate with professionals in each field, domain experts on ship products such as shipyards, manufacturers, classifications, and maritime business experts such as shipping, ship management, insurers, brokers, etc.

Although the author began collecting ship data to improve shipping company operations around 2008, and equipped with a data collection device to accurately grasp ship performance and operational status, for ship designers, such as for safety purposes and shipbuilding, there are many uses for such data utilization, and we thought that sharing data with them could create new value. In addition, on the other hand, if a computer for data collection was installed on the ship for each purpose, it would be too much installation work and cost, and would therefore be wasteful, and eventually data utilization would not be realized, and therefore, computers for data collection need to be generalized and integrated. To that end, we came up with the idea of standardizing the computer specifications for data collection in some way.

At that time, such discussions were held under the activities of the “Research Group of Smart Ship Aiming for Optimization for the Environment” in 2011-2012 of the Japanese Marine Equipment Association. After that, in response to these discussions, since February 2013, the Smart Ship Application Platform Project (SSAP) activity at the Japanese Marine Equipment Association was started, aiming to propose the standardization of onboard data collection servers from Japan.

The activities of the study group included the trial design of onboard data servers, prototype development and trial on domestic vessels, and concept creation of the open platform between shore and ship (Figure 2). Based on these experiences, finally, two new ISO standard proposals NP (New work item Proposals) were conducted in cooperation with the Japan Ship Technology

Research Association (JSTRA), the official secretariat of Japan's ISO/TC8.

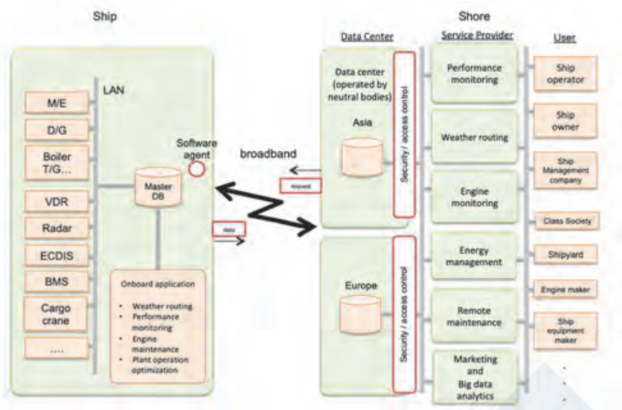

Figure 2　Conceptual Diagram of the Open Platform between Shore and Ship

After that, at the New Smart Ship Application Platform Project (SSAP2 Project) from August 2015, ISO work was promoted with JSTRA, and the draft standards were revised with the cooperation of experts including Norway and Denmark, and in October 2018, it was officially registered as ISO19847 (specification of onboard data collection server) and ISO19848 (data format used by onboard data server) [11, 12].

Although there has been an international standard called IEC61162 for navigation data[13], and it is easy to extract the IEC61162 signal output from each navigational device. On the other hand data output from integrated control and monitoring systems, which collect engine and power plant data, did not have a fixed protocol. and there are hundreds to thousands of data points in such system. Therefore, conventionally, it has been a troublesome task and costly to deal with for each individual ship to extract data about engine and power plant. However, by adopting equipment that complies with ISO19847 / ISO19848, it became possible to retrieve the list of tag names collected by the system and the time-series data of each tag in a standardized manner, and this is expected to greatly reduce the difficulty of data collection from such system.

In addition, ShipDC was established at the end of 2015 as a wholly-owned subsidiary of ClassNK as a mechanism to transfer data collected from ships to the land and share it with participants in the maritime field at a shore data center while controlling security and access authority. The IoS-OP (Internet of Ships-Open Platform) consortium, the user group of ShipDC, was established in 2018 after a preparation period in 2017. The IoS-OP discusses (1) rules for data sharing, (2) data quality, and (3) data catalogs.

Although a detailed description is omitted here, the ship data naming framework provided by ISO19847 / 19848 and ShipDC/IoS-OP provides a structured mechanism for linking data collected on ships to the final application, and theoretically, any application or sensor data on the ship, and has a very systematic structure that incorporates a mechanism for firmly connecting within this framework.(Fig.3) In the future, it is expected that the momentum of data utilization will increase in various areas such as ship performance, motion, structure, engine, auxiliaries, and cargo. However, we hope that the utilization of such data will be promoted by collaboration with various domain experts, while maintaining the same scheme that handles such wide range of IoT data collection and utilization systematically.

In this way, the international technical standard of ISO19847 / 19848 and the open platform for data sharing composed of ShipDC / IoS-OP is a platform for neutral data sharing and business consensus building regarding industrial data sharing and utilization, such as in the establishment of rules for data utilization implemented as an industry. This is a very unique and advanced example both globally and in comparison with other industries. In an effort to take advantage of the characteristics and goodness of Japan's maritime cluster, where various technical collaborations have been conducted, in the future, it is expected that the number of supporters and users will increase globally and will be established as a data sharing standard in the maritime field.

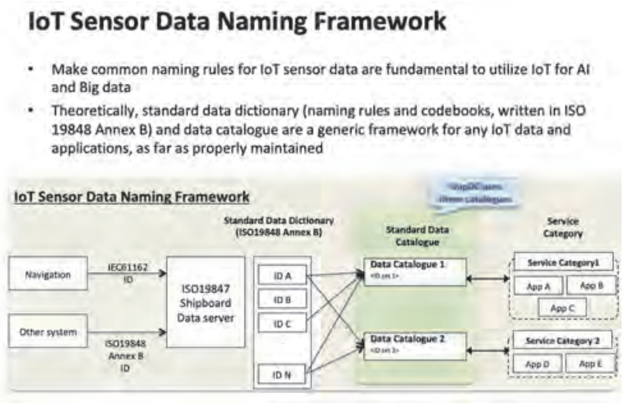

Fig.3　IoT Sensor Data Naming Framework

7.　Future Issues in Digitalization

Next, I would like to describe future issues in incorporating digitalization into the maritime industry.

First, it is thought that digitalization will proceed in relation to each business and customer from the standpoints of shippers, shipping, shipbuilding, marine, ship classification, insurance, and brokers that make up the maritime industry. As they are business issues, it might be difficult to understand latest activities from outside, however I think that improvements of actual business and operations by digitalization will evolve at very fast speeds. Here too, collaborations between business experts and IT professionals are essential.

In addition, shipping as a whole has two major challenges: technological development for zero-emission ships and saving of crew workloads of ship operations through the realization of autonomous ships.

In the field of zero emission, although I think the issues will be sorted out in the future, including further optimizing the hull form and propeller based on not only by model scale, but based on full scale by advanced combination of model scale test, full scale measurement and full scale CFD. This is an effort that can be made by using advanced computer technology and measurement technologies in cooperation with shipyards, shipping companies, and manufacturers.

Evaluation technologies for ship performance in services are also an expected field. National Maritime Research Institute of Japan (NMRI) is currently leading OCTARVIA project. It aims at to develop common measures to evaluate the performance of ships under wind and waves, and common base analysis tools.

In addition, with regard to technologies such as structural health monitoring of ships, condition diagnosis of equipment such as engines and steam turbines, and remaining life diagnosis, research is currently underway to improve the design and operation of ships more rationally, and future commercialization is awaited.

As mentioned above, there is data collected by ships as one of the keys for various future use cases. I expect that the open platform mentioned earlier will be used for these various purposes.

Another major issue is technology development for autonomous ships. The main theme here is the technical development of marine manufacturers, and the other is the operational, organizational and social issue of how to safely operate such highly sophisticated and complex systems. However, in case of Japan, with declining birthrate and coming shortage of labors, although efforts to deal with this issue are inevitable, it is necessary to cultivate seeds of these technologies and raise them to a state that is socially acceptable. Japan has historically been actively engaged in the research area of autonomous ships since the 1970s. There are also new issues such as comprehensive safety assessment, system integration, software reliability, cyber security, and many of these are extremely computer technology and software related.

In the future, maritime industry is expected to steadily advance research and development, demonstration, practical application, and operation in both hardware and software to overcome these issues. The advancement of digitalization as a whole in the maritime field while also utilizing the data sharing framework has an extremely close relationship with the movement toward solving major problems in the maritime field such as zero emissions and autonomous ships.

8. Conclusions

A view on maritime digitalization is introduced. Beyond individual companies, the entire maritime industry is required to promote rationalization and efficiency through digitalization. The importance of using data, and the importance of working with domain experts and IT experts are also mentioned. In the utilization of ship data, an open platform framework has been proposed by Japan, and this utilization is expected in the future.

In the future, although it will be necessary to move toward major issues such as zero emissions and autonomous ships, I believe that digitalization is the driving force for that. We will continuously utilize data, vast computational power and domain knowledge to promote rationalization and efficiency improvement for the entire maritime industry as one of main players of global society.

References

1) Michael Wade, DX Execution Strategy; Create an organization that earns digitally, 2019
2) Masahiro Sonda, Current Status and Future Prospects of Shipbuilding Systems, collection of papers of lectures of the Society of Naval Architects of Japan, No.5, 2005
3) Hundred Years History of Nippon Yusen Kabushiki Kaisha (NYK Line), 1988
4) Diesel oil carrier (including combined use) NK-M0 Engine Department Automation Standard Specification, Japan Institute of Marine Engineering Vol.9 No.1, 1974.1
5) Takeo Koyama, Research on Optimal Automatic Steering System for Ships Sailing in the Open Sea, collection of papers of the Society of Naval Architects, 1967 122, p.18-35, 1967
6) What is an electronically controlled diesel engine?
http://www.marine-engineer.or.jp/images/denshiseigyo_diesel.pdf
7) Michael Grieves, Virtually Perfect: Driving Innovative and Lean Products through Product Lifecycle Management (English Edition), 2012
8) Tomas Kellner, Wind in the Cloud? How the Digital Wind Farm Will Make Wind Power 20 Percent More Efficient, GE Industrial Report, Sep 2015
http://www.gereports.com/post/119300678660/wind-in-the-cloud-how-the-digital-wind-farm-will/
9) Ando, Yamato, Hori, Masuda, Shiroyama, Research on failure report analysis method using text mining, collection of papers of the Society of Naval Architects of Japan, 2002 192 p. 475-483
10) S. Letourneau et.al.,: Data Mining to Predict Aircraft Component Replacement, IEEE Intelligent Systems and their Applications, Volume 14 Issue 6 Nov/Dec 1999
11) ISO 19847:2018 - Ships and marine technology — Shipboard data servers to share field data at sea
12) ISO 19848:2018 - Ships and marine technology — Standard data for shipboard machinery and equipment
13) IEC 61162-1:2016 - Maritime navigation and radio communication equipment and systems - Digital interfaces - Part 1: Single talker and multiple listeners

Current State of Cybersecurity and Issues in Ships

— Cyber Risk in Ships from the Viewpoint of Cyberattack Techniques on Land —

Kenji FUKUSHIMA*

1. Introduction

In recent years, keywords such as “ship IoT” and “smart ships” have been frequently seen. Ship IoT is a mechanism for analyzing data as big data by transmitting data such as position information, speed, and data from engines and generators to a server on land, through satellite communication from ships during the voyage. From the analysis results, it is possible to identify signs of failure, prevent large-scale failures, select efficient courses, and reduce fuel costs. In order to utilize such ship IoT, the standardization of data collection server specifications and development of data analysis methods using AI are underway. As the background of ship IoT becoming popular, there are high speed and constant connections of satellite communication services, and the ship is approaching the similar IT environment as land. As a result, the risk of threats on the Internet, such as malware, has also increased in ships.

In the shipping industry, which plays a very important role in the world’s logistics infrastructure, it will make a large impact on society if a security incident that affects ship operations occurs. In 2017, A.P. Moller-Maersk, a Danish company, experienced a cybersecurity incident due to a computer virus. According to media reports[*1], they received the damage of about 300 million dollars because of the suspension of business for 10 days, which became the largest security incident in the maritime industry.

In this paper, we consider cybersecurity risks in ships and make mention of future issues based on the knowledge of cybersecurity on land.

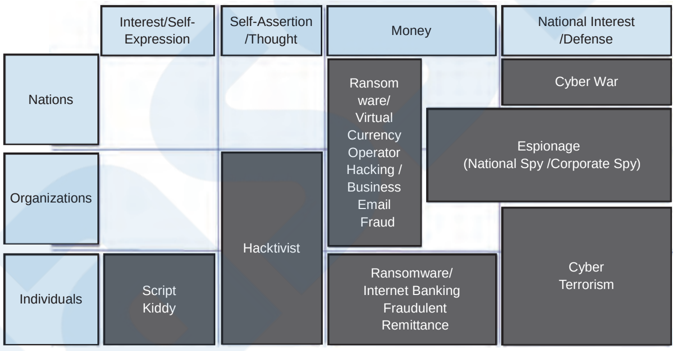

Figure 1 Cyber-Attackers and Their Motive

2. Current Status of Cyberattacks on Land

First, Figure 1 shows a summary of cyber-attackers and their motives.

Attacks around the 1990s when the Internet was generalized were mainly performed by individuals who were skilled in computer knowledge, and the purpose was to test their technical skills and satisfy self-expression. In addition, the number of “script kiddy” that imitates hackers out of curiosity increased. On the other hand, organizations and individuals who carry out website falsification and DDoS attacks[*2] in order to insist on political ideas are called “Hacktivist”, and “Anonymous” is a world-famous group of Hacktivists. Cyberattacks by hacktivists themselves have been declining since peaking in 2015[*3].

* KDDI Digital Security Inc.

*1 ZDNetJapan, “Maesk, a major shipping company, announced the serious impact of the “NotPetya” attack in 2017.” <https://japan.zdnet.com/article/35113829/>, accessed August 22, 2019.

*2 Attacks that intentionally prevent being accessed to a specific network or Web service by using many hosts connected to the Internet.

*3 ZDNetJapan, “Attacks by hacktivists have been greatly reduced. What is the reason: IBM research”, <https://japan.zdnet.com/article/35137171/>, accessed September 6, 2019.

Conversely, organizational cyberattacks which are intended to monetary purposes, intelligence activities, and destructive activities are increasing every year. For monetary purposes, there are “ransomware”, fraudulent internet banking transfers, and targeted attacks aimed at the fraudulent outflow of virtual currencies.

On the other hand, cyber wars between nations are also transforming into a reality. Cyber space is also called the “fifth battlefield” following land, sea, air, and space, and intelligence and destructive activities are being carried out against government agencies and companies in other countries behind the scenes. In addition, it is said that some countries are engaged in industrial espionage as a nation in order to give their own companies a competitive advantage. Hacking units are being organized in nations, and hackers are being trained. Cyberattacks make it hard to locate actual attackers, and the IT environment cost of attack is low, so it makes possible for the nations which lacks economic power to launch an attack without any difficulties.

3. Reasons for Increasing Cybersecurity Risks in Ships

Chapter 2 has described the current state of cyberattacks on land. By making the IT environment in ships closer to the IT environment on land, the risk of being exposed to the same threats on land is increasing even in ships. There are three main factors. The first is the evolution of the communication infrastructure of ships. The communication infrastructure of ships had been said to be 10 to 15 years behind that on the land. However, the provision of services that can always be connected to the Internet via satellite communications and services that enable large-capacity communications has started so that the network in ships is no longer isolated from the Internet. The second is that the systems on ships continue to be used for a long time. The life cycle of general IT equipment is approximately 5 to 6 years. After the period expires, the support for hardware, software, OS, etc. will end. On the other hand, systems in ships are often used continuously for more than 10 years. As a result, the OS of marine equipment is no longer supported and the vulnerabilities of the devices are remained, the risk of being infected with “malware[*4]” is increased. The third is the problem of IT equipment management in ships. Even now, malware infection incidents occur from PCs, smart devices, USB flash drives, etc. which are brought on board by crews. We can prevent the incidents by setting rules and having crews protect themselves, but it is difficult to ensure thoroughness since crews often change on every voyage.

4. Differences between Security Measures on Land and Security Measures in Ships

There are two differences between security measures on land and security measures in ships. The first is the difference the purpose of what is placed emphasis on security measures. There are three elements of information security: confidentiality, integrity, and availability. In general, the countermeasure for information leakage is valued in information security, so there is a tendency to be perceived more seriously if “confidentiality” is violated. On the other hand, “integrity” and “availability” are more important since the primary purpose of ships is to ensure safety of navigation. When implementing security measures, it is necessary to select measures that meet this objective. The second difference is the specific environment in ships. The communication environment is almost limited to via satellite communication. Although always-on connection services are becoming popular, it is impossible to have a large amount of communication as much as on land. In addition, even if an equipment failure or incident occurs on the ocean, it is not possible to rush into immediately from the land. This kind of maintainability should be considered when introducing cybersecurity measures.

5. Cybersecurity Threats on Ships Considered from Typical Cyberattack Methods

Chapter 5 considers threats to ships, focusing on typical attack techniques on land.

5.1 Ransomware

5.1.1 What is Ransomware?

Ransomware is a type of computer virus that has the function of requesting a ransom for users of infected PCs. Damage has

[*4] A generic term for malicious software and malicious code created with the intention of operating illegally and harmfully. It includes computer viruses and worms.

been increasing since around 2015, and the damage was further expanded since ransomware with a self-infecting function such as "WannaCry[*5]" came out in 2017.

5.1.2 Ransomware Mechanism

Figure 2 shows a mechanism of ransomware.

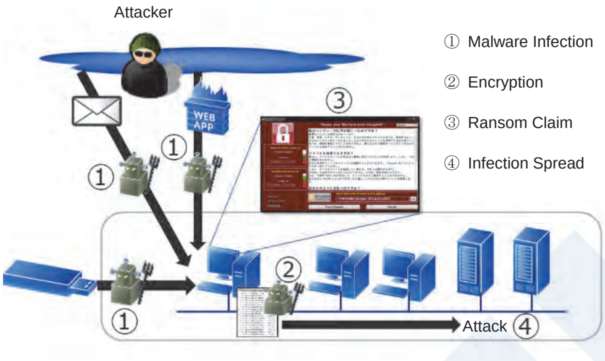

Figure 2 Mechanism of Ransomware

There are three main routes of infection for ransomware: email, downloads from websites, and USB devices. When a PC is infected with ransomware (①), files on the PC are encrypted one after another, and the user of the PC cannot open the files (②). Once encryption is executed, a screen for requesting a ransom is displayed in exchange for the key for decrypting the file (③). Furthermore, in the case of ransomware with a self-infecting function, it spreads to other PCs on the network (④).

5.1.3 Examples of Ransomware Damage

In Chapter 1, the damage of the A.P. Moller-Maersk in Denmark, which occurred in June 2017, was listed as a case of ransomware in the maritime industry. The ransomware "NotPetya" that started this case is a ransomware with a self-infecting function similar to Wannacry. NotPetya was a ransomware aimed at an unspecified number of people. However, PCs in the company's network were infected by chance. The infection spread from 45,000 PCs and 4,000 servers, and it resulted the suspension of business for 10 days.

5.1.4 The Scenario of Ransomware Damage

Any device that uses Windows may be damaged by ransomware. In a ship, the most concerned scenario is that equipment related to navigation becomes infected with ransomware and makes it impossible to navigate. Some devices such as ECDIS, run on Windows OS, in which case ECDIS itself can become infected with ransomware. If equipment related to the navigation of large ships such as container ships and tankers is infected with ransomware and stops functioning, it will be impossible to navigate and will be unavoidable that a ransom must be paid.

5.2 Targeted Cyber Attacks

5.2.1 What are Targeted cyber Attacks?

IPA (Information-technology Promotion Agency, Japan) announces "10 Major Security Threats 2019[*6]" every year. As with ransomware, "targeted cyber attacks" are one of the most popular threats in recent years. This kind of attack is literally an attack aimed at a specific target. Attackers infiltrate internal PCs by sending targeted attack malware to target companies/organizations. After that, by remotely operating the invading PC from outside, it steals confidential information in the organization and attacks internal systems.

5.2.2 Mechanism of Targeted cyber Attacks

Figure 3 shows the mechanism of targeted cyber attacks.

*5 Worm-type ransomware targeting Windows. A large-scale cyberattack began in May 2017, infected more than 230,000 computers in 150 countries, and requested cryptocurrency bitcoin as ransom for infected computers in 28 languages.

*6 IPA (2019),"10 Major Security Threats 2019",<https://www.ipa.go.jp/security/vuln/10threats2019.html>, August 7, 2019.

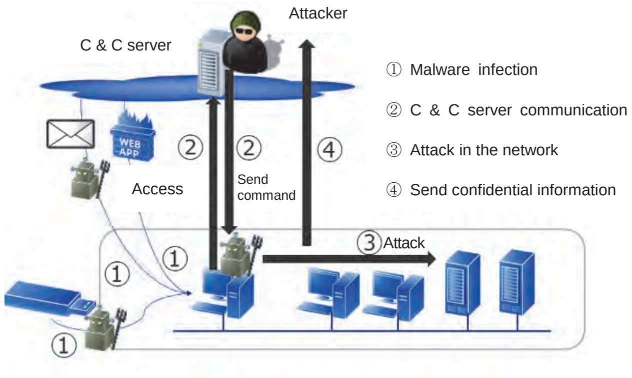

Figure 3 Mechanism of Targeted Cyber Attacks

The first step in targeted cyber attacks is to send “targeted cyber attack malware” to the target organization and infect the PC in the organization with malware. As with ransomware, downloads from websites, and USB memory, etc. are used as the infection routes (①). PCs infected with malware are connected to “C & C servers[*7]” on the Internet managed by the attackers (②). An attacker can perform various operations from the outside by sending commands from the C & C server to the target PC. Attackers take over in-house systems and higher-privileged users (③) using the invading PC as a starting point, collect confidential information, and send it to the outside(④). In addition to steal confidential information, targeted attacks are performed to steal privileged user authority within the company, to falsify system data, and to acquire information for fraudulent activity through mail eavesdropping.

5.2.3 Attack Scenarios by Targeted Cyber Attacks

In a ship, when it is invaded by a targeted cyber attack, various threats are assumed by the attacker’s remote operation. It is possible to display a position different from the actual one by disguising the position information of ECDIS and AIS.

In the future, when self-supporting ships become widespread, the steering of the ship will be controlled from the outside, and there is a risk of being guided to an unintended route. As a result, cyber terrorism may cause serious damage such as collisions of large ships with a port or collisions between large ships. In the future, if the shipping industry is targeted in a dispute between nations, there is a concern that it will cause massive damage.

5.3 Cyberattacks on IoT Devices

5.3.1 What are Cyberattacks on IoT Devices?

The number of devices connected to the Internet is expected to reach 40 billion by 2020[*8]. Office devices, automobiles, home appliances, industrial devices and other devices that have not previously had a communication function have been connected to the Internet as IoT devices. Many of these devices connected to the Internet do not take cybersecurity measures into account, and it is not uncommon for users to be able to log in from the outside using the default password. For this reason, damage has occurred, such as eavesdropping where camera images can be seen from the outside and being used as a platform for attacking other servers.

5.3.2 Attack using IoT Device Search Tool

A representative IoT device search tool is SHODAN[*9]. SHODAN is a website that publishes collected information by performing port scans[*10], banner checks[*11], etc. on IoT devices connected to the Internet. This mechanism is shown in Figure 4.

The original purpose for which SHODAN is disclosed is to allow IoT device managers to diagnose their systems. However, it is a tool for attackers to find targets. If the equipment on ships is connected to the Internet, it can be searched with SHODAN and may become an attack target. French security researchers have disclosed that attackers can easily hack systems in ships via

[*7] A server (command & control server) that remotely sends commands to a computer infected with malware.
[*8] Ministry of Internal Affairs and Communications (2018),“2018 White Paper on Information and Communication”, p.7 Diagram 1-1-2-1, <http://www.soumu.go.jp/johotsusintokei/whitepaper/ja/h30/pdf/index.html>, accessed September 6, 2019.
[*9] SHODAN, <https://www.shodan.io/>, accessed September 6, 2019.
[*10] A method to find an available port on the target device in order for an attacker to enter the system. NMAP is used as a tool.
[*11] As a preparation before an attack, a method to send data from the outside to the software running on the server and check the software type and version from the response.

the Internet[*12]. The researchers used SHODAN to search for ships equipped with VSAT systems. The researchers revealed that they were able to log in remotely after entering the default authentication information into the VSAT system on ships.

When it is possible to log in to the communication device, there is a possibility that someone could change the setting of the packet filtering and connect freely from the outside, or search the network inside the ship using communication equipment as a stepping stone. If this happens, there is a possibility of unauthorized login to the equipment on ships.

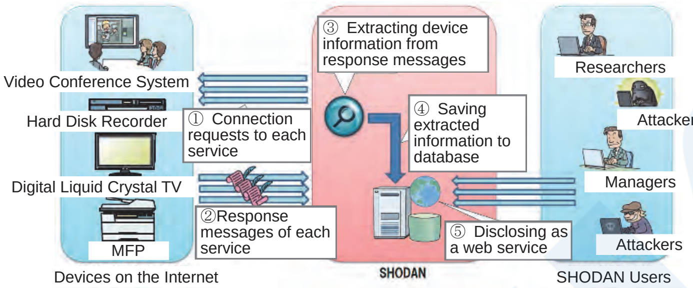

Fig. 4　Mechanism of SHODAN

(Source) IPA Technical Watch "Inappropriate information disclosure and its countermeasures for an increasing number of connected devices"

5.3.3　Malware Targeting IoT Devices

Malware targeting IoT devices has been spreading on the Internet since around 2016. A typical example of malware is "Mirai". Mirai has a self-transmissible function and automatically attacks other IoT devices on the Internet and expands the range of malware infection. A collectivity of devices infected with Mirai is called a botnet. Attackers use this botnet to launch large-scale attacks such as DDoS attacks aimed at companies and organizations. When a ship's equipment is infected with Mirai, it may result in pressure on the communication line and obstruct the communication of the business that is originally required.

5.4　Cyberattacks against GPS (GNSS)

5.4.1　What is Cyberattack against GPS?

GPS position information is indispensable for ships because it is used for important navigation equipment such as AIS and ECDIS. However, the GPS signal itself is a very weak radio wave. In addition, public information is available on how to calculate location information from GPS consumer signals. For this reason, the GPS mechanism itself is vulnerable to attacks, and attackers are targeting this vulnerability.

5.4.2　Attack Methods against GPS

Cyberattack methods against GPS include jamming, spoofing, and impersonation of location information.

Jamming is an attack that transmits a stronger radio wave than the original radio wave of GPS and interferes with regular GPS communication. As for jamming damage, there have been reports of cases where aircraft couldn't use GPS around Seoul in around 2012[*13]. Also, in the United States, a device which is capable of transmitting GPS interference called PPD (Personal Privacy Device) was sold on the Internet for about $20. It was mainly used by truck drivers for the purpose of preventing their truck's location information from being captured by the company, but it is currently illegal.

GPS spoofing is an attack that spoofs a real GPS signal by generating a GPS signal independently. Software that creates GPS signals has been released as freeware, so it is possible to make a GPS spoofing device by individuals with wireless knowledge.

Aside from attacks that impersonate GPS radio waves, there are attacks that impersonate the data signals of location information received by GPS antennas. Several cases of impersonation of this GPS location information have been reported.

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*12　Twitter (2017), "Shodan now live tracking ships via VSAT antennas exposing web services", <https://twitter.com/x0rz/status/887238046172753920/photo/1?ref_src=twsrc%5Etfw%7Ctwcamp%5Etweetembed%7Ctwterm%5E887238046172753920&ref_url=https%3A%2F%2Fmashable.com%2F2017%2F07%2F18%2Fhacking-boats-is-fun-and-easy%2F>, accessed September 6, 2019.

*13　Sankei News (2016), "GPS Failure of 1007 Aircraft over South Korea: Concludes North Korean Interference," <https://www.sankei.com/world/news/160623/wor1606230042-n1.html>, accessed September 6, 2019.

For "Pokémon GO[*14]," a smartphone game, an app that impersonates GPS location information and catches Pokémon that occur around the world has been released, and the account has been suspended by the game provider. In addition, a smartphone app provided by AEON, the shopping center, has a mechanism that adds AEON visit points from GPS location information. There have also been cases of impersonation of GPS location information, leaving a record of 2.69 million visits to AEON in various places, and being arrested for exploiting points worth 5.38 million yen[*15].

5.4.3 Cyberattack Scenario against GPS

The most frightening thing about GPS attacks is that the location information is impersonated, and it is to be guided in a different direction from the destination where it should be headed. In the case where a ship is misguided, there will be a grounding accident if there is shallow water ahead, and there is a risk of a collision if it is pointed at another ship. Such GPS hacking for cyber terrorism and piracy is quite conceivable. Technically, in 2013, at the University of Texas at Austin, experiments using a GPS spoofing device to guide to a different route from the destination by guiding to a different coordinate from the actual ship position have been successful[*16].

5.4.4 Attack Incident (Suspicion) by GPS Hacking

In June 2017, an event occurred in which the GPS position data of more than 20 ships became incorrect position data off the port of Gelendzhik in Russia[*17]. All the AIS trace data of the nearby ships showed the same wrong GPS location information (near the international airport more than 30 km away). Similarly, around the Kremlin in Russia, it was confirmed that GPS location information has been significantly incorrect since around 2016. This was also an event where the current location was skipped to an international airport more than 30 km away[*18]. It is speculated that the cause of the phenomenon of location information being impersonated at the airport is to prevent drones from flying around the Russian government building. Many commercially available drones are equipped with a "geofense function" that cannot access airports based on GPS location information. It is thought that this function may prevent suspicious drones from coming close to the Russian government building.

6. Approaches of Security Measures for Ships

At the IMO Maritime Safety Committee (MSC98), a policy to manage cybersecurity risks with the Safety Management System (SMS) was approved. In response to this, in Japan, ClassNK issued the "Cybersecurity Management System for Ships (Requirements and Controls) [First Edition][*19]" in February 2019. This guideline is mainly created with reference to ISMS (ISO27001 and ISO27002). ISMS is a mechanism which certifies that information security rules are being formulated, and security measures are implemented, reviewed, and improved continuously in companies.

In addition to the ClassNK cybersecurity approach[*20], "Cybersecurity Design Guidelines for Ships" was issued in February 2019, and "Software Security Design Guidelines" was issued in May 2019.

These two guidelines are based on the concept of Security by Design. Security by Design is the idea of incorporating security from the planning and design stage and has proposed that the security at the time of shipbuilding and the security of ship

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*14 A game for smartphones that catches and nurtures Pokémon by integrating the Pokémon world of anime with the real-world using AR technology. In the game, Pokémon is generated at a specific location in conjunction with GPS location information.

*15 Asahi Shimbun Digital (2018) "Suspects of Exploiting Visit Points from AEON: Impersonation of Location Information by PC" , <https://www.asahi.com/articles/ASLCD6R60LCDTIPE03N.html>, accessed September 3, 2019.

*16 Todd Humphreys (2013),「Secure PNT for Autonomous Systems」, <https://radionavlab.ae.utexas.edu/index.php?option=com_content&view=article&id=351:secure-pnt-for-autonomous-systems&catid=30&Itemid=37>, accessed September 6, 2019.

*17 C4ADS(2019),「ABOVE US ONLY STARS」, <https://www.arcgis.com/apps/Cascade/index.html?appid=b919c8d91b0a4f868f02acfdebc428d7&classicembedmode>, accessed September 6, 2019.

*18 CNNbusiness (2016), 「Getting lost near the Kremlin? Russia could be 'GPS spoofing'」,<https://money.cnn.com/2016/12/02/technology/kremlin-gps-signals/index.html>, accessed September 6, 2019.

*19 ClassNK (2019), "Issued Cybersecurity Management System for Ships", <http://www.classnk.or.jp/hp/ja/hp_news.aspx?id=3662&type=press_release&layout=1>, accessed September 6, 2019.

*20 ClassNK (2019), "Announced ClassNK Cybersecurity Approach", <http://www.classnk.or.jp/hp/ja/hp_news.aspx?id=3562&type=press_release&layout=1>, accessed September 6, 2019.

equipment be implemented in advance from the planning and design stage.

7. Issues in Cybersecurity for Ships

There are three major issues in cybersecurity for ships. The first issue is the peculiarity of the environment on ships. As for security measures on land, various products and services have been provided since the spread of the Internet. However, not all security products and services can be installed on ships. There are cases where the installation environment, communication environment, maintainability, operation system, etc. are not suitable. Since there are no system administrators on ships, it is difficult to deal with complicated operations. In addition, as a feature of existing security products, many of them are required to update the pattern files and satellite communication is expensive and impractical. In addition, since the ship itself has a long service life, the OS installed ship equipment may be used beyond their support years. The second issue is human resources. Although it is not limited to the shipping industry, few companies can secure enough human resources to promote cybersecurity. Another factor is that it is difficult to instill IT literacy at the site because crews working at the site are changing regularly, and the required expertise is greatly different. To that end, it is necessary to create a mechanism and to conduct continuous security awareness activities with the cooperation of cyber security experts. The third issue is investment costs. Security measures for ships are required rapidly, and there are many cases that require new investment. In addition, the target is not only new ships, but also the existing ships. Therefore, security measures are required not only for shipbuilding but also for ships in operation. In November 2019, the Ministry of Economy, Trade and Industry issued the "Cybersecurity Management Guidelines Ver2.0,[*21]" and this guideline recommends that managers themselves make investment decisions for cyber security measures as management issues.

8. Conclusions

In this article, we have organized the current status and issues of cybersecurity measures for ships from the detailed contents which we taken into account the situation we have heard from ship management companies, ship owners, shipbuilding companies, and ship equipment manufacturers based on the knowledge we have put into the cybersecurity industry for more than 15 years. Taking these issues into account, we can utilize AI and IoT with peace of mind by taking appropriate cybersecurity measures. In order to continue to develop as a shipping industry, it is desirable to work on cybersecurity measures for safety and security in parallel with the promotion of effective IT utilization.

Acknowledgment

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References

1) JPCERT (2015), "Preparing for Attacks Exploiting SHODAN - Control System Edition", June 9, 2015.
2) IPA (2014), IPA Technical Watch "Inappropriate Information Disclosure of Increasing Internet Devices and Countermeasures", February 27, 2014.
3) Takeyasu Sakai (2018), "GPS Security: Vulnerability and Countermeasures", The Institute of Electronics, Information and Communication Engineers (IEICE Technical Report), SANE2018-33, August 2018.

[*21] Ministry of Economy, Trade and Industry (2017), "Cybersecurity Management Guidelines Utilize Ver2.0", <https://www.meti.go.jp/policy/netsecurity/mng_guide.html>, accessed September 6, 2019.

The current state and potential of Artificial Intelligence

— Is AI a potential threat to humans? —

Wataru IHARA*, Olivia Quek (MIZUMURA)*

1. Introduction

The term "Artificial Intelligence" was first used by John McCarthy, at the Dartmouth Summer Research Project on Artificial Intelligence held in 1956 [1)]. This marked the beginning of the era of Artificial Intelligence (AI). Since its beginnings, however, the integration of AI into common society has been far from smooth, as evidenced by the fact that AI has undergone two "winter seasons". As this paper is being written, AI is currently experiencing its third hype, as the adoption and dissemination of its uses have come to be increasingly stable within the greater society. This paper will first review the history of AI and describe present-day technologies prevalent within the field. It will then proceed to describe various strengths and weaknesses of AI, before illuminating how the power of AI can be harnessed in an appropriate manner that can benefit society at large. The authors hope that by eliminating unnecessary fears that greater society might hold towards AI, its use in society might become even more widespread.

2. A brief history of AI

However, its dissemination into the greater society has been far from smooth. The first AI boom, which began in 1956, came to an end in the 1960s. The technologies that the first AI boom was centered upon, were mainly used for exploration and inferencing and were thus more suited for solving complex mazes and puzzles, rather than for business uses. Although it created a hype amongst academic and research circles, the use of AI was largely constrained to academic research, as computers were extremely expensive and not easily available to the greater public [2)].

The second AI boom began in the 1980s and lasted till roughly 1995. It was during this phase in AI's history, that so-called "expert systems" – systems capable of constructing and processing rules based on knowledge previously acquired by humans – were born. The use of computers by the greater society became increasingly widespread, as technology giants such as WINDOWS and Mac began to take center stage in the field. Although expert systems had their beginnings in 1965, when Lotfi Zadeh first proposed fuzzy logic, it was the sharp decline in the price of the home computer, coupled with its spread into the greater society, that helped promote the second AI boom. By the end of this period, which was around 1997, technologies in AI had developed to the extent that they were able to beat even the most adept humans in games such as Othello and Chess. Although the second AI boom experienced its demise, what differentiated the second AI boom from its predecessor, was that the adoption of AI by the greater society had become extremely widespread and stable by the end of the second boom, thanks to the introduction of rule-based processing systems. "If the value of A is 10 or above, dispatch a coupon. If no significant effects

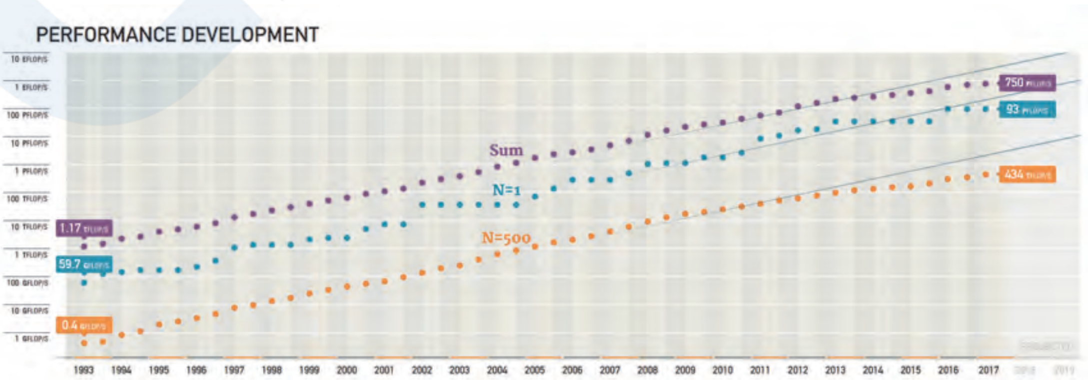

Figure 1

* Miotsukushi Analytics, Pte., Ltd.

from the coupon are observed, increase the threshold value to 11.” The processing of rules such as this used to be called “AI” during the 1980s and 1990s. Today, rule-based processing has become a cornerstone for even the most common computing programs.

The third AI boom, which began in the 2010s, is still very much alive today. Machine learning, largely centered around deep learning, has come to be prevalently used. Convolutional Neural Networks (CNN) were first used for audio classification in 1988 [3], then for (alphabetic) image classification in 1989 [4]. While theory in the field has no doubt progressed by leaps and bounds, it is the development of the internet - which has made it possible for data to be collected effortlessly -, combined with the increasing availability of big data, the widespread use of GPUs, and explosive developments in computer memory, that have helped fuel the current AI hype. Indeed, the computing power of computers has increased almost exponentially, thanks to developments in computer memory and the advent of GPUs. Figure 1 below depicts how the performance of the top 500-ranked supercomputers has evolved since 1993 [5]. The width of the vertical axis increases by 10 times, for every unit increase in memory. While the top 500-ranked supercomputer could achieve only 0.4 GFLOPs per second in 1993, it could achieve up to 434 TFLOPS per second in 2017. This marks an improvement in computing power by approximately 1,000,000 times.

Thanks to the tremendous improvement in the performance of computers and the increasing availability of big data, we now live in an age where complex computations based on large amounts of data can be performed with extreme precision. This is the dominant feature of the third AI boom.

Rule-based systems are not well-suited for solving complex problems, because they operate on human-written rules, that can very easily become too complicated for these systems to handle when the number of rules increases significantly. The advent of machine learning techniques, has, however, made it possible for rules to be automatically detected and implemented by machines. By learning from large amounts of data and performing calculations far more complicated than the rules that any human could write, machines are now able to make predictions with an ever-greater degree of accuracy. Figure 2 depicts the error rate of predictions in an international competition for visual recognition, the ImageNet Large Scale Visual Recognition Challenge (ILSVRC) [6]. To illustrate the performance of the algorithms, we have drawn a horizontal line at 5.1%, which is the human error rate. The use of deep learning began to spread in 2012, and its precision has increased by leaps and bounds ever since. As Figure 2 shows, the error rate of algorithms in the ILSVRC fell below the 5.1% mark in 2015, implying that the algorithms were now able to perform visual recognition tasks at a level of accuracy surpassing the average human.

It was in this manner that the third AI boom - an era in which machines have the ability to solve complicated problems and make predictions with a degree of accuracy as good as, or if not better, than the average human - has come to be. A characteristic of this boom that sets it apart from its two predecessors, is that AI has become increasingly adopted by businesses on a large scale. This is a reason why many people have become interested in AI.

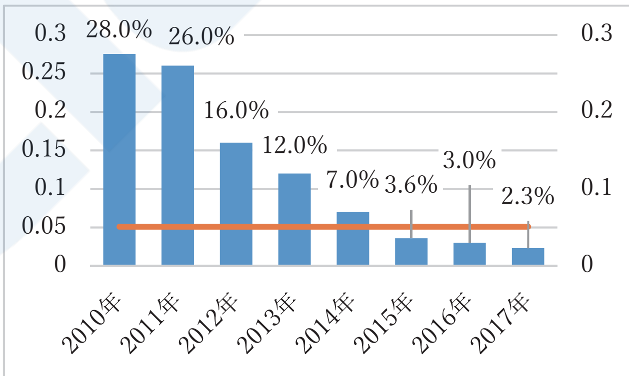

Figure 2　Error rates in the ILSVRC

3.　The achievements of AI

3.1　The strengths and weaknesses of AI

As previously explained, the third AI boom is premised on machine learning, backed by the availability of big data. For this reason, data is a crucial ingredient. Put differently, it is whether data is available or not, that determines what AI can or cannot do. For example, AI will not be able to make accurate predictions when regularities and criteria for making assessments cannot be observed in the data. Moreover, as the predictions made by AI are based on probability, it is not advisable for AI to be deployed in situations where even the smallest rate of error cannot be tolerated.

In contrast, AI performs extremely well in tasks where regular patterns can be detected in big data. One example would be instantaneous abnormally detection based on the logs of 10,000 people, conducted around the clock. Another example would be the production of the same result, based on data, regardless of external events such as the weather.

3.2 The uses of AI

3.2.1 Image recognition

Banner advertisements have become extremely prevalent on the internet. Today, the relevance and degree of engagement of particular images and videos in advertising banners can be assessed, thanks to AI. Before the advent of AI, features of advertising banners used to be decided upon by advertising directors. However, the amount of time needed for human directors to decide upon the most relevant features for ad banners increased in proportion to the number of advertisements placed on the internet. Besides, human decisions are always inevitably prone to a margin of error. These developments implied that image recognition, facilitated by AI, could outshine humans in tasks related to the selection of features for advertising. On top of that, AI even has the potential to measure the exact degree of correlation between each particular feature, and its impact on a company's growth. While even the most outstanding of all human directors will not be able to evaluate every image - given the vast quantity of images currently used in advertising - AI can do so. The use of AI for conducting image recognition in advertising has caused businesses to grow by many-fold. It has also freed human advertising directors to be able to concentrate on their main sphere of work, that is, the creation of articles and catchphrases.

Additionally, AI is currently used to recognize handwritten characters, through a technique known as Optical Character Recognition (OCR). Before the third AI boom, image processing used to be rule-based. For example, an algorithm would detect the Japanese character "パ", based on a set of specific rules – the presence of a circle on the upper right corner, and two straight lines that were narrow on top and wide below. This meant that algorithms performed well in the recognition of printed characters, but poorly in the recognition of handwritten characters, due to a large number of deviations from the rules amongst the latter. Today, thanks to the employment of machine learning, algorithms are being taught to recognize handwritten characters in the absence of rules, simply by observing large samples of handwritten characters collected from the internet. The degree of accuracy of these algorithms has surpassed 99% [7]. Machine learning algorithms come with an added advantage – the ability to learn from past errors and increase their rates of precision through self-learning and correction.

Yet another common use of image recognition would be the detection of faulty or sub-standard merchandise, with the caveat that the standards for evaluation need to be based on static images. For example, an algorithm needs to be taught explicitly that the image of the afternoon sun on an orange is not an anomaly or cause for the orange to be classified as substandard.

3.2.2 Predicting human behavior

AI is also used in the allocation of shelf space for merchandise. First, AI is taught to recognize the specific location of specific goods. Next, data on the features of customers, the shelves that they spend time at, as well as the amount of time that they spend at each shelf, is collected. Adjusting for the effects of prices and weather, the effects of shelf space allocation on merchandise sales can then be analyzed and quantified. The use of a combination of various AI algorithms has become commonly used in case studies such as the one mentioned here.

The use of AI to predict workman accidents has also become increasingly commonplace. A challenge when using AI to predict accidents, however, is that these events occur with a very low probability, implying that the data is very imbalanced. An algorithm that predicts that accidents are not going to occur may have a very high degree of precision, but will be unlikely to be of much use to businesses. To get around this problem, we first classify workman accidents into several categories and then make predictions of classified outcomes, based on the conditions of each worker on a given workday. In other words, we train the algorithm to predict which category of accidents is/are likely to occur, based on the assumption that accidents are going to occur.

The use of AI is also becoming increasingly commonplace in career change services. For example, AI is being used to ensure that the best possible match between companies seeking to hire and the job-seeking applicants recommended to them is achieved. If recommendations were to be made without much calculation, the number of applicants for relatively popular jobs would be overwhelming, and that for other jobs dismal. However, due to the limited number of job vacancies available, only a small fraction of applicants would be hired for the job they applied to and all other job-seekers would be jobless. This is where AI has tremendous potential to help. AI algorithms split samples of job-seekers evenly and recommend jobs that each job-seeker has a relatively high probability of being employed for. Such tasks used to be extremely labor-intensive, but thanks to the advent of AI, tasks which previously required approximately 40 people can now be performed with just 3 people. This frees the remaining 37 staff to concentrate on high value-added tasks that AI is not well-suited for, such as the reviewing of job applicants' resumes.

3.2.3 Analysis of information having to do with vehicles

AI is increasingly used to analyze information on things that move across space, such as cars and manufacturing equipment. For example, GE collects data on the flight conditions of airplanes via the use of IoT [8]. By analyzing such data, the aircraft company Alitalia has reduced its fuel costs by $46,000,000. The company has also been able to predict the probability of its aircraft encountering a technical problem on a given flight route, based on the actual condition of each aircraft. Of course, the detection of technical problems could take place at an even higher degree of precision, were a veteran to go through every case in detail. However, Alitalia alone operates more than 100 airplanes on a full-time basis. Given the tremendous number of logs on aircraft carrier conditions, it is simply not realistic to rely on humans to perform these checks. Thanks to the power of AI, logs on aircraft carrier conditions can now be monitored in real-time, on a 24-hour basis, allowing even the smallest of abnormalities to be detected.

In the automotive industry, users are provided with store-related recommendations based on real-time information on the mileage and usage conditions of their cars.

3.2.4 Analysis of online behavior

This sector has always been highly-compatible with AI. Throughout the third AI boom, AI has become even more prevalent within the sector. For example, Figure 3 shows the accuracy of predictions on which users of an online game application are likely to be paid users in the month following the time of analysis. Although the degree of prediction is somewhat lower in the middle ranges, it is extremely high in the upper and lower-most ranges. The variables used to conduct this forecast, such as the intervals between users' timings of purchase in the past, have a crucial role to play in accounting for the algorithm's accuracy [9]. Approximately 2,000,000 records on the online behavior of 45,408 users were used to make this prediction. Needless to say, a human cannot possibly go through such as a huge amount of data. A computer algorithm, however, requires just 7 seconds to perform the computation. Computation speed is another important feature of AI. It is important to note, however, that the selection of variables that are optimal for such an algorithm to work, has to be conducted by a human. Exactly how the results of the analysis ought to be used in improving upon the online game service must also be formulated based on human thought and reasoning.

予測確率(%)	UU数	実際の課金	課金率
100%	535	513	96%
90%～99%	1,329	1,248	94%
80%～89%	811	707	87%
70%～79%	901	771	86%
60%～69%	961	733	76%
50%～59%	1,172	886	76%
40%～49%	1,758	1,176	67%
30%～39%	2,952	1,657	56%
20%～29%	6,033	2,768	46%
10%～19%	24,152	7,069	29%
0%～9%	822,461	27,880	3%

Figure 3 Precision of paid user forecasts

3.3 The potential uses of AI

At the current time of writing, AI that is adopted by businesses requires data that is carefully selected, and variables that are painstakingly defined and handpicked by humans, in order to perform well. It also works by recreating past successes. AI, as we currently know it, is not able to collect data, nor define what is correct or wrong, in the absence of human supervision. Games such as AlphaGo and Bonanza are based on completely defined sets of rules, have finite numbers of possible strategies, and allow for experiments to be performed for an infinite number of times in completely artificial environments. AI excels when such conditions are met. However, it is crucial to remember that the rules of games such as Go and chess were created by humans, and that the environments under which they are played are constructed by humans. In Bonanza, the movement of three chess pieces are used in an equation for evaluating the effectiveness of a given strategy [10). However, the definition of the equation, as well as the particular chess pieces chosen for the equation, were based on human thought.

Compared to the second AI boom, the current AI boom has witnessed a drastic reduction in the need for humans to spell out specifically-defined rules. Nonetheless, it still remains a fact that humans have to be the ones deciding upon which data to use, and which set of rules to observe. These human-based decisions are an integral aspect in determining an algorithms precision. If less-than-optimal data were to be used in the construction of algorithms, the performance of the model would, no doubt, be greatly constrained by the data's quality. Consider the case where AI is used to make recruitment decisions based on the job resumes of applicants. If the training data consists of a large number of successful job applications by graduates from university A and a large number of unsuccessful applications by graduates from university B, the algorithm will learn to predict a high degree of success (failure) for applicants from university A (B). Through relearning, predicted success rates of university B graduates would continue to fall, while that for university A graduates would continue to rise. This case study shows that AI tends to reflect biases that are present in the data presented to it. The ability to recreate whatever is being taught to it with a high degree of precision, can be said to be a double-edged sword for AI.

4.

4.1 Steps for the implementation of AI

It is highly recommended that the following 8 steps be taken when AI is to be adopted [11).

・Step 1：Determine specific issues to be addressed.
・Step 2：Select the data to be used.
・Step 3：Select the appropriate methodology.
・Step 4：Think about how AI is to be used.
・Step 5：Create a machine learning program.
・Step 6：Adopt AI
・Step 7：Relearn.
・Step 8：Adjust the model appropriately.

As a first step, the organization should clarify and gain consensus on what exactly AI is to be used for. Next, it should collect data related to the issues at hand and verify the condition of the data. It should also construct an actual statistical model and evaluate the model's precision, as well as take note of the amount of time taken by the model to make its predictions. Based on these observations, the organization can then take note of what data it lacks. It is only after having taken these steps, that the organization will be in a good position to evaluate how AI can be used. AI can then be officially adopted, after having programmed a machine-learning algorithm and verifying that the model is indeed usable. By following the above-mentioned steps, organizations will be much better prepared to deal with problems after they have implemented AI, such as an unforeseen lack of data, a low degree of precision of the model, or a general uncertainty on how to interpret the results of the model.

4.2 How to get along with AI

Rumors that AI will be a huge disruptor to our economy, replacing jobs on a massive scale, are widespread. Research has suggested that about 47% of the working population is employed in jobs that have a risk higher than 70% of being replaced by machines within the next 10 – 20 years [12). The replacement of parts of people's jobs by AI has already begun to take place. Even so, as the authors have previously mentioned, AI that is being used today depends on the availability and quality of training data that is being presented to it. Feature-selection is based upon the data, which has to be selected and processed by humans. In other words, AI cannot beat the level of precision that a highly-experienced human can achieve through a painstaking review of every case. The tasks that it is especially well-suited towards are highly-repetitive tasks that do not require complex decision-making. AI also excels in checking huge amounts of data and making almost instantaneous decisions based on the data.

There is also another possible way for humans to work efficiently with AI, that is, by making human judgments based on data that has been processed by AI. Although AI beat humans in chess during the 1997 chess tournaments, a team comprised of amateur chess players and 5 chess computer software beat the world's strongest chess AI algorithm Hydra, as well as the chess grandmaster, in the PAL/CSS freestyle chess tournament held in 2005. The amateur players formulated their strategies based on the analytical results presented to them by the software. This case study shows how we can get along with AI, by understanding the results that AI presents to us, and making our own decisions based upon these results.

4.3 The uses of AI in shipping

Automated navigation and the detection of malfunctions based on image recognition are some of the most prevalent uses of AI in the shipping industry. However, vessels depend on highly experienced captains and pilots to run, and parts of the navigation process that can be easily automated have already been automated. Ships differ from automobiles, in the sense that car drivers have highly varying skill levels, roads intersect in a complicated manner, and sudden brakes can be applied easily in the case of the former. Ships, in contrast, require a huge degree of adaptability and experience to drive. For these reasons, it is crucial that the exact components to be automated have to be spelled out clearly. It is also difficult for AI to beat the degree of precision that trained human eyes can achieve in this field. Rules regarding the avoidance of collision between vessels are also clearly written and can be obeyed by the rule-based systems that were prevalent in the second AI boom. Having said that, there is tremendous potential for AI to play a part in this industry. For example, AI can be adopted to surveil water surfaces of open seas, detect malfunctioning of vessel components using data collected from the various sensors of ships, improve the efficiency of detection based on manuals already at hand, optimise the weight of cargo to be loaded onto ships, optimize vessel fuel usage based on real-time sea and wind conditions, surveil seas remotely using satellite images, automate the navigation of small-scale vessels, and predict the navigation routes of neighboring vessels in congested seas. A common theme of each of the above cases has to do with the fact that these tasks need to be performed around the clock, and that it is not realistic for a highly-experienced human to keep track of all data and water conditions at all times. The scale of the data involved tends to be massive, and it is difficult for highly experienced crew members to be stationed at every possible location. It is in these cases that AI has the potential to support and replace humans, and in the process of doing so, relieve a huge burden from the shoulders of crew members, AI can also help inexperienced crew members perform complex tasks which only experienced crew members could perform in the past.

Unfortunately, a method to detect the potential uses of AI in the sector has not been established. The most feasible thing to try would be to attempt to implement AI boldly, in areas that are currently being conducted by skilled crew members, but that may be improved upon through the use of data.

5. Summary and the future outlook of AI

In this paper, the authors described the state of AI as we know it at the present time of writing. While there is certainly a lot of hype regarding AI, the third AI boom is closely related to businesses. Cases where AI has been used to facilitate the growth of businesses, using huge amounts of accumulated and stored data, are widespread. We need only to look at giants in the tech industry, GAFA, in order to see examples of these. On the other hand, AI has also come to be perceived as a potential threat, which is difficult to prevent. In the midst of these developments, it is apt to note that AI is far from omnipotent and that we ought not to raise our expectations for AI too high. A more sensible way to deal with AI would be to recognize the strengths and weaknesses of AI and to delegate tasks that AI excels in while specializing in tasks that humans are far more able to perform.

Humans have already experienced such a revolution when computers first emerged in the market. The advent of the home computer used to be perceived as a threat, where humans dreamed that computers would one day evolve to such a superior state that they would replace humans in terms of job performance. What we know, today, however, is that computers are simply tools that are used to aid, not replace, humans.

Similar to computers, there will come a day when AI becomes firmly rooted in greater society. The authors hope that members of the shipping industry will foresee such a day, and make use of AI in a way that will be of the greatest benefit to them.

References

1) J. McCarthy, M. L. Minsky, N. Rochester, C.E. Shannon：A PROPOSAL FOR THE DARTMOUTH SUMMER RESEARCH PROJECT ON ARTIFICIAL INTELLIGENCE
2) 松尾豊：人工知能は人間を超えるか
3) Toshiteru Homma,Les E. Atlas,Robert J. Marks II：AN ARTIFICIAL NEURAL NETWORK FOR SPATIOTEMPORAL BIPOLAR PATTERNS
4) Yann Le Cun：Generalization and Network Design Strategies
5) https://www.hpcwire.jp/archives/12646/20170619-june-2017-top500-performance-development
6) http://image-net.org/
7) https://dx-suite.com/
8) https://www.forbes.com/sites/ptc/2014/06/23/will-the-internet-of-things-revolutionize-the-aircraft-industry/#47c2b1dc3a75
9) Yuta Kaneko,Katsutoshi Yada,Wataru Ihara,Ryunosuke Odagiri：　How Game Users Consume Virtual Currency
10) Hoki Kunihito：Optimal control of minimax search results to learn positional evaluation
11) 井原渉：ＡＩ導入の教科書
12) Frey&Osborne：Frey&Osborne research 2013

ClassNK’s approach to digitalization

Yoshimichi SASAKI*

1. Introduction

It is no exaggeration to say that in recent years one can see and hear words such as “digital” and “digitalization” being used by mass media (e.g. TV and newspapers) practically every day. The digitization of data and its utilization have been aggressively implemented by many industries such as automobile, aircraft, wind power generation, and so on.

Since this field is making steady progress and rapidly changing, and is sometimes used with differing significance, the definitions of important terms are clarified at the outset in this report.

・“Digitization” is the conversion of analog data such as data on paper to digital data.
・“Digitalization” is the conversion of processes to digital form to increase efficiency.
・“Digital transformation” (abbreviated as “DX”) is the reformation of management and business model using digital technology.

Especially in the case of the business-to-business (B-to-B) industry, digitalization and digital transformation are difficult to promote independently, and these are being promoted nationally or by the industry as a whole. In Japan, the Ministry of Economy, Trade and Industry has been the primary body promoting digital transformation and issuing relevant guidelines.[1)]

With respect to issues such as the communication environment, and the robustness of machinery and equipment during voyage, it is difficult to state that the maritime industry is ahead of other industries in its approach to digitalization. However, from the viewpoints of advances in information technology, environmental protection, improved safety and efficiency, movements to effectively utilize data generated on ships have progressed by leaps and bounds.

2. Current activities by ClassNK

2.1 Approach related to digitalization

Nippon Kaiji Kyokai has a 120-years history as a classification society, and is recognized as a “Regulator” because of its history of developing classification society rules and implementing regulatory inspections. On the other hand, there are increasing demands being placed on ClassNK in recent years to contribute more to the industry from the standpoint of using data effectively over the lifetime of a ship, that is, from the design and construction to the operation of a ship, and from the standpoint of an “Innovator” using data or supporting “Innovation”.

For this reason, ClassNK has been working to speed up various activities such as preparing standards and guidelines related to digitalization and providing an “Infrastructure” or platform for offering services under the policy for contributing to digitalization of the marine industry.

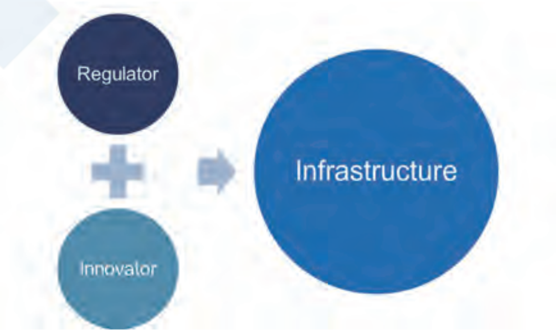

Fig. 1　ClassNK’s approach

* Digital Transformation Center, ClassNK

2.2 Examples of activities

Fig. 2 shows a summary of the platform, services, and guidelines related to digitalization in timeline form offered by ClassNK since 2010.

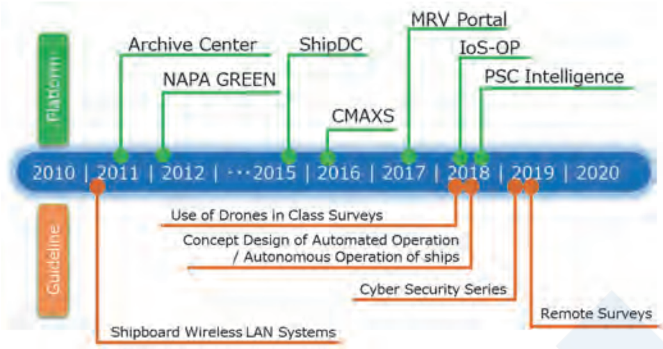

Fig. 2 ClassNK's digitalization activities

Typical examples are introduced below.

2.2.1 IoS-OP

The Internet of Ships Open Platform (IoS-OP) is the data distribution platform of shipboard data and the like. As shown in Fig. 3, shipboard data is collected, transmitted to shore, and distributed to users based on the common rules of data stored on shore. This helps realize impartial and transparent ownership from the stage of generation to utilization of data, and each company can participate freely in its field of expertise. The objective is to enhance data collection and transmit the data to shore efficiently, and also to develop new solutions using enormous amounts of big data accumulated on shore.

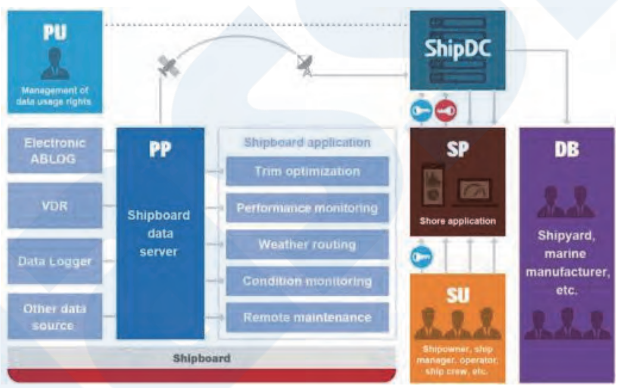

Fig. 3 Data flow in IoS-OP

The IoS-OP consortium was established for promoting data distribution while maintaining the profits of data providers. Activities such as technical studies on the provision of common rules (IoS-OP Rules) and security, offer of business space, etc., are being implemented. There are 58 companies and associations mainly within Japan participating in the consortium, and overseas expansiont of the consortium is being promoted aggressively. The IoS-OP activity has been recognized as an innovative data distribution approach in business. This data sharing project has been approved as the first business entitled to take advantage of the System for Permitting Business to Request Piblic Data by the Ministry of Internal Affairs and Communications (MIC), the Ministry of Economy, Trade and Industry (METI) as well as the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

2.2.2 Monitoring

Safety and reliability are demanded in ship operations. For this purpose, monitoring technology for collecting and analyzing ship conditions becomes very important.

Within Japan, major operators are taking the initiative, and many R&D projects related to monitoring are in progress. Some of the projects are already in the stage of realization. Overseas, major main engine manufacturers and system integrators are speeding up activities for utilizing the monitored data. Under these circumstances, ClassNK has been participating appropriately in R&D projects and actively exchanging opinions with industry professionals so as to assist the activities of top runners in the industry.

ClassNK is also developing the "ClassNK CMAXS" system as a monitoring solution for shipboard machinery and equipment for supporting appropriate maintenance management and monitoring of various shipboard machinery and equipment by forming alliances with several equipment manufacturers. The system broadly consists of two groups: "Condition monitoring system of equipment" and "Maintenance management system." Data of maintenance work implemented on board and condition monitoring of various equipment is stored in the cloud database "CMAXS Database" through various shipboard systems, and this database can be browsed from anywhere in the world. Especially, the "Condition monitoring system of equipment" is provided with troubleshooting functions in addition to automatic condition diagnosis and automatic anomaly level analysis of equipment shown in Fig. 4. Moreover, depending on the equipment, big data can be analyzed including navigation data, weather data and sensor data, and a quick anomaly level analysis of equipment can be performed.

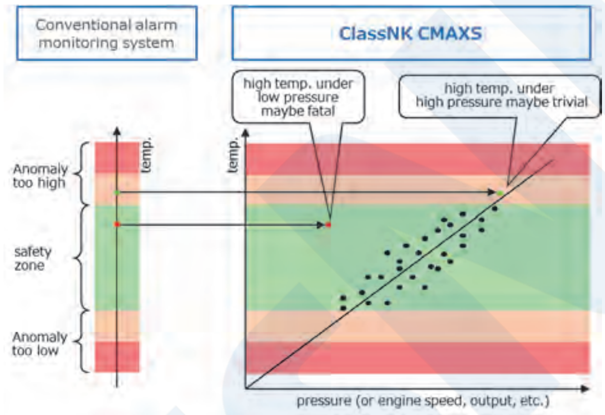

Fig. 4　Example of CMAXS

On the other hand, studies are in progress for realizing "hull monitoring" technology to analyze remaining fatigue life of the hull structure after estimating stresses on the hull from operation data such as ship speed and ship position data, cargo deadweight, and weather and sea condition data in actual plying areas.

2.2.3　ClassNK MRV Portal

With the establishment of regulations of the EU regulation on monitoring, reporting and verification of carbon dioxide (CO2) emissions (EU MRV) [3] and the amendments to MARPOL Annex VI,[4] the submission of Emission Report after collecting data such as fuel consumption data in each ship became mandatory. ClassNK has offered the "ClassNK MRV Portal" system for support, in response to such requirements. As shown in Fig. 5, monitored data and authentic documents (Bunker Delivery Notes, etc.) are being sent to the server from the ship or from shore, support is being given to preparation of Emission Report through collected data, and sensing functions for gaps in received data are also being offered.

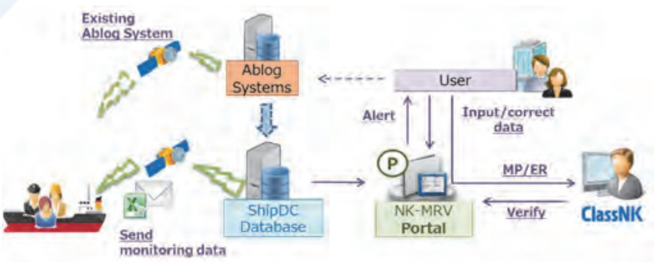

Fig. 5　ClassNK MRV Portal(Outline)

2.2.4　PrimeShip-PSC Intelligence

PrimeShip-PSC intelligence is a data system that supports the improvement of Port State Control (PSC) performance and ship management system. This system enables analysis of trends on number of detentions and deficiencies recorded at each port or country, output of PSC checklists at each port or country based on the trends, and sorting of deficiencies recorded frequently on managed ships along with the ability to review them. Fig. 6 shows the conceptual sketch of PSC Intelligence.

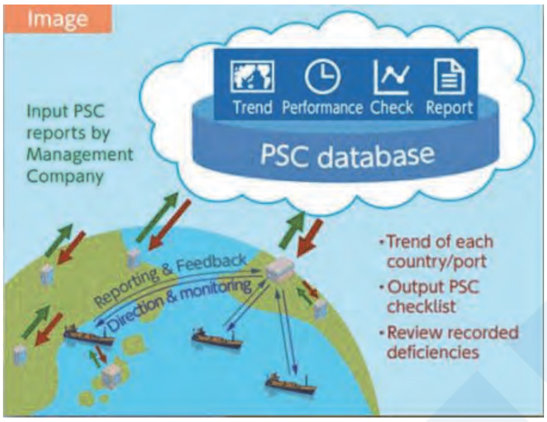

Fig. 6 Conceptual sketch of PrimeShip-PSC Intelligence

2.2.5 Data Driven Regulation

Until now, feedback of the results of research based on results of surveys of ships in service was the main constituent for making amendments to classification rules. Presently however, rules can be amended using data generated over the lifetime of a ship through the design, construction and operation stages in addition to the results of classification surveys.

Fig. 7 shows the concept related to studies on design waves used for strength assessment in the structural rules. To ensure the safety of a ship structure, studies are carried out based on the severest weather and sea conditions encountered by the ship. Conventionally, however, the ship generally adopts maneuvers to avoid rough weather and sea conditions. Presently, operation data can be obtained from an Automatic Identification System (AIS), enabling actual route information of every ship to be collected. By coupling this information with global weather and sea data, the actual ship speed under wave heights, wave directions and rough weather and sea conditions actually encountered by the ship can be estimated. ClassNK is currently working on the development of rules for design waves referring to the actual operations of tens of thousands of ships, which could not have been done until now.

2.2.6 Cyber Security

With the progress of digitalization and sharing of data, cyber risks such as wiretapping and data falsification increase; thus, measures against such risks or ensuring cyber security becomes very important. In the marine industry, civilian organizations (e.g. BIMCO) have published guidelines on cyber security.[5)] The IMO has also published guidelines on cyber security[6)] and non-mandatory resolution,[7)] while the International Association of Classification Societies (IACS) has published recommendations related to cyber security.[8)]

ClassNK has announced the “ClassNK’s Cyber Security Approach” which gives the basic concepts of cyber security, referring to the trends of international organizations and marine organizations mentioned above.

“Ensuring navigational safety” was regarded the most important goal of onboard cyber security and the cyber security measures were arranged in a five-stage hierarchy, as shown in Fig. 8, with “the role of each person” being clearly specified. Furthermore, it has been decided to analyze the latest cyber security information and suggest the best practice at that point.

Based on this concept, three guidelines indicating the agent implementing the cyber security measures and the description of the measures were published as the “ClassNK Cyber Security Series.”

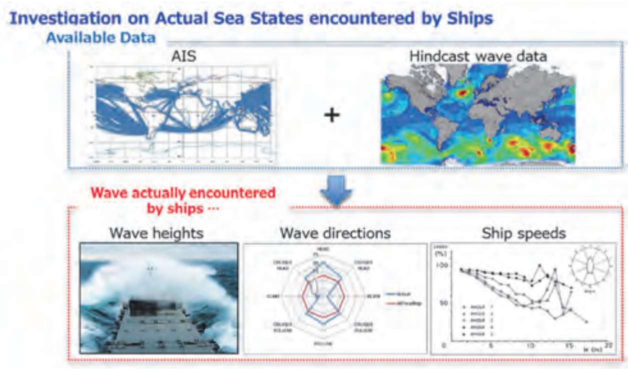

Fig. 7 Example of rule amendment using data

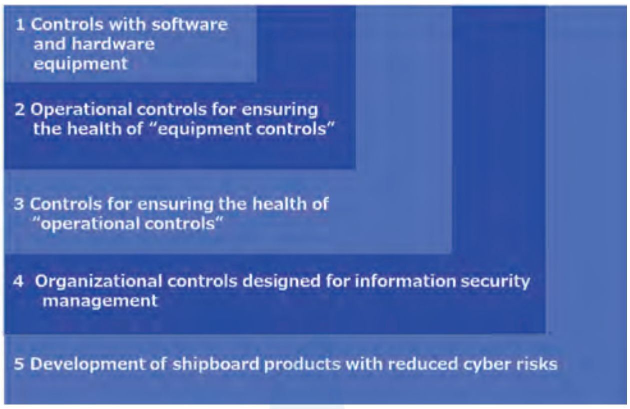

Fig. 8 Hierarchy of cyber security measures

2.2.7 CBM

Condition Based Maintenance (CBM) for performing the necessary maintenance and inspection based on the results obtained from conditioning monitoring of equipme (see Sec. 2.2.2), was incorporated into the ClassNK "Rules for Preventive Machinery Maintenance Systems" from 1994. In 1997, the ClassNK "Rules for the Survey and Construction of Steel Ships" clearly stated that survey system based on condition diagnosis results could be employed for Class Maintenance Surveys. Presently, amendments to rules for reviewing the rules system related to surveys are being considered to promote the utilization of CBM along with the development of techniques for measurement in recent years. More specifically, the same survey method had been required for all equipment in each ship until now; however, the plan now is to employ CBM only in a part of the equipment and enable selection of Continuous Machinery Survey (CMS)* in the rest of the equipment, that is, to enable selection of survey method by equipment.

3. Digital Transformation in the future

Until now, we have introduced ClassNK's approach to digitalization. However, digitalization of business is one of the means and is not an objective. ClassNK is considering digital transformation (DX) of business using digital technology, which is the future of digitalization of the industry, and hopes to contribute to increased efficiency and to further enhance safety of the marine industry as a whole.

3.1 Establishment of the DX Center

For studying the digital transformation of the entire industry, business topics over a wide range of vision, and not just the scope of each business, should be studied and connected to future plans. For this reason, ClassNK set up a dedicated department for digital transformation independent from the business head office called the Digital Transformation Center (abbreviated to DX Center) in January 2019.

This DX Center has been promoting activities aiming for digital transformation of ClassNK within and outside the company through provision of rules and guidelines for digitalization of the marine society and development of technical services related to reforms and the upgrading of surveys.

3.2 Formulating the "Digital Grand Design" action plan

"Presenting the vision" has been raised as one of the items to be constrained by the guidelines for promoting DX by METI as mentioned initially, for going ahead with digital transformation. ClassNK has been progressing with the preparation of "ClassNK Digital Grand Design," an action plan for digital transformation, by clarifying topics considering environmental changes such as the society and technology that surround the marine industry, while reviewing the approach to digitalization of ClassNK until now. Although ClassNK is presently working on it, since the study of various trends is necessary, it plans to publish in the near future.

* Refers to "Continuous Machinery Survey", a survey method by which open-up inspections are performed sequentially in accordance with a survey plan approved by ClassNK for the relevant equipment so that the open-up inspection period for each type of equipment does not exceed five years.

3.3 Digital Transformation of surveys

Reforms, as shown in Fig. 9, of surveys of ships in service, are one example of digital transformation.

Sensor data and operational data of equipment collected on board the ship are sent to the onshore data center and stored there. These data including weather and sea data are processed by monitoring techniques. The results are stored along in the Digital Twin database and linked to design data and construction data. The Digital Twin system simulates events of the real world in cyberspace; that is, it reproduces the present status of the ship on a PC. ClassNK's "Integrated Survey Support System" analyzes this Digital Twin data and determines the survey items according to the conditions of the individual ships. Studies are also underway to propose prospective survey locations and survey dates after adding information on these survey items and operational data to the ship management companies.

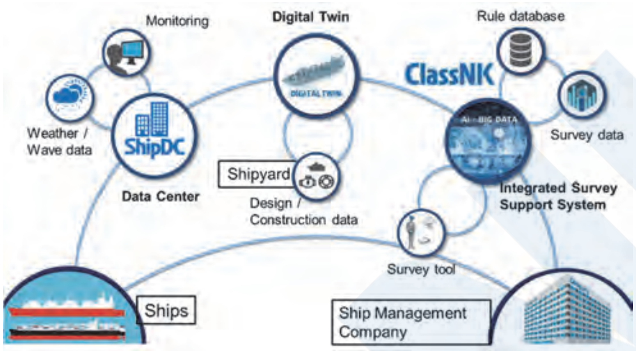

Fig. 9 Data Driven Survey Scheme

In the current rules, the survey items are specified by ship particulars such as age, size and ship type. However, technical studies are being carried out anticipating reforms in the future leading to the "Data Driven Survey Scheme" for specifying survey items according to the results of condition diagnosis based on the data of individual ships.

3.4 Digital Transformation of design

On the other hand, the digital transformation of design, as shown in Fig. 10, is being studied even in design work carried out in shipyards.

A cloud-based "Rule assessment system" linked to the CAD system of the shipyard will be offered, and an environment will be provided to assess design data seamlessly. The said system will analyze the objects of CAD data, and automatically identify and asses the requirements needed from the rules stored in the database.

The designer after completing design studies, will send a request to start approval of the CAD data. ClassNK's staff-in-charge will check the assessment conditions, perform sampling assessment, and confirm that appropriate assessment has been performed in the design study stages. After confirmation, approval status will be granted to the CAD data, and if comments are necessary, they will be given directly at the relevant locations of the CAD data.

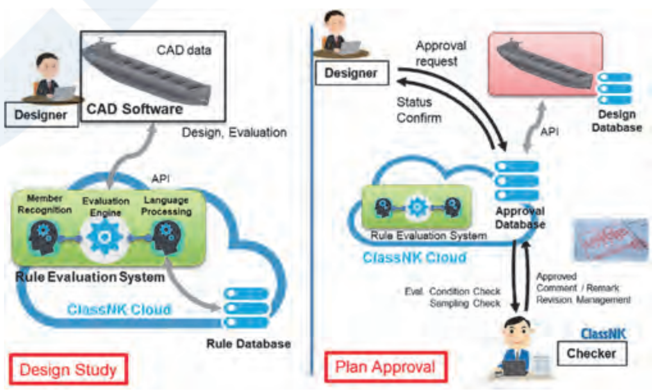

Fig. 10 Data approval concept

For approval of paper drawings up until now, CAD data was processed to suit submission of drawings on paper, separate assessment models were used, and comments added to the drawings on paper were reflected manually in the CAD models. That is, the design data and data for approval were separate; manual intervention was necessary to proceed with the work. ClassNK is anticipating seamless processing of design data and approval data with the data approval. To realize such a system, many issues remain to be resolved, but ClassNK has been proceeding step by step in its technical studies toward the goal.

4. Conclusions

Digitalization of the marine industry by ClassNK has been introduced in this report. From the standpoint of a classification society, ClassNK has been setting up a platform for digitalization, offering services and preparing guidelines, and at the same time studying business reformation using digital techniques (digital transformation).

On the other hand, since the data created by the classification society by itself is only a part of the data of a ship over its lifetime, ClassNK is aiming to work together with a large number of stakeholders in the marine industry, merge their needs with its needs, and realize digital transformation of the entire industry.

ClassNK will continue with activities aiming for digital transformation of the entire marine industry henceforth with the cooperation of all related personnel, enhancing safety and increasing efficiency to higher levels.

References

1) Ministry of Economy, Trade and Industry (METI) : "Guidelines for promoting digital transformation", 2018
2) Information and Communications Bureau, the Ministry of Internal Affairs and Communications MIC): Press Release "Data sharing business that can utilize the System for Permitting Businesses to Request Public Data" approved for the first time on 24 June 2019.
3) Regulation (EU) 2015/757 of the European Parliament and of the Council: "On the monitoring, reporting and verification of carbon dioxide emission from maritime transport, and amending". Directive 2009/16/EC, 2015
4) IMO: Amendments to MARPOL Annex VI (Data collection system for fuel oil consumption of ships), Resolution MEPC.278(70), 2016
5) BIMCO et al: "The Guidelines on Cyber Security Onboard Ships"
6) IMO : "Guidelines on Maritime Cyber Risk Management", MSC-FAL.1/Circ.3
7) IMO : "Maritime Cyber Risk Management in Safety Management Systems", RESOLUTION MSC.428(98), 2017
8) IACS : Recommendations, REC153 "Recommended procedures for software maintenance of computer-based systems on board" to REC164 "Communication and Interfaces", 2018

ClassNK's activities for Maritime Autonomous Surface Ships

Tomoaki YAMADA*

1. INTRODUCTION

1.1 Background

In recent years, technologies such as sensing technology, AI and IoT have made rapid progress and are used in various fields. In the automobile field, research and development of automatic driving technology and demonstration experiments have been actively carried out by utilizing these technologies, and automatic driving technology for some functions such as brakes, accelerators, and steering has already been put into practical use.

In the field of ships, research and development of technology related maritime autonomous surface ships (MASS) has been actively carried out in Japan and overseas with the aim of improving safety by preventing human error and improving working conditions by reducing the work load on crew members.

Overseas, the research stage is progressing to the development stage, and the demonstration experiment of technology related MASS is being carried out mainly in Northern Europe. In Japan, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) formulated a roadmap for the practical application of MASS in June 2018, as well as support projects to promote the development of elemental technologies necessary for MASS Demonstration projects to promote practical use and projects aiming at the concept construction of MASS have been launched, aiming for their practical application by 2025 together with the industry, academia and government.

1.2 Social issues

While their technological development is steadily advancing, in order to realize MASS, it is necessary to develop legislation to ensure that they can be safely operated. MASS have been taken up in the agenda at MSC98 held in June 2017 at the IMO, and issues regarding IMO regulations related to MASS are currently being organized. In addition, at the MSC101 held in June 2019, the IMO approved the Interim Guidelines for MASS Trials, and compiled basic policies to be considered when conducting trials of systems and infrastructures related to MASS.

While the work on legal development is underway, the current situation is that it has not yet caught up to the speed of technological development. In particular, careful discussion is necessary for items that have a very large impact on MASS operations, such as responsibility in an accident.

1.3 Technical issue

The IMO defines the following four degrees of MASS.

Degree one: Ship with automated processes and decision support

Degree two: Remotely controlled ship with seafarers on board

Degree three: Remotely controlled ship without seafarers on board

Degree four: Fully autonomous ship

In the case of Degree one, the main focus of development is to reduce the work burden on the crew. Humans make decisions through processes such as recognition, judgment, and response. The same is true for seafarers, who maintain the safety of their ship by correctly recognizing the situation in an ever-changing environment, making the best judgment under that situation, and then responding to it. In the decision-making process, recognition and judgment are difficult to automate.

For example, in order to automate the lookout (recognition) performed by a crew member, it is necessary to develop a technology capable of sensing equivalent to a human being's ability. There are methodologies existent such as developing ultra-high-performance radars capable of detecting boats and fishing gear that cannot be found by existing radars, sophisticating sensor fusion technology, or providing support from land. However, considerably high technology is required to truly realize "human equivalence".

For the automation of judgment, there is the idea of utilizing AI technology, but the actual situation is that the person who

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uses it cannot honestly trust the judgment of the machine if the basis of its judgment is not clear. When we casually try to automate what people do, we are reminded of how advanced we are.

In Degree two, the first technical hurdle to be cleared is the establishment of a communication environment in which correct information can be provided to the remote operator on an appropriate time axis. It is possible to lower this hurdle by limiting the navigation area, but it is also necessary to technically establish countermeasures when communication is interrupted and to establish protection measures against cyber attacks from the outside.

In addition, in the case of Degree three and Degree four aiming for complete unmanned operation, further technological development in elemental technology units is required, including the development of support systems from land. In particular, how to design the Operational Design Domain (ODD) and fallback are important points.

It is thought that the realization of MASS will progress in steps, and the state in which MASS and conventional ships (non-automatically operated ships) coexist will naturally occur in the process. The technical hurdle is raised by having to deal with the situation of where ships with various characteristics are mixed.

2. WHAT IS REQUIRED OF A CLASSIFICATION SOCIETY

As a completely independent third party, Classification Societies have fulfilled their roles by developing rules and technical standards for conventional ships, checking the quality of both design and construction, and confirming that the minimum necessary operational capability is maintained after the ship is put into service through inspection and survey. The principle remains unchanged in the case of MASS.

In the development of the rules and technical standards for MASS, it is important that sound discussions are held at the IMO. The role of the Society is to provide technical support, sometimes as a Japanese classification society, and sometimes as an IACS member. In particular, international agreements must be the minimum content necessary to ensure security. Although it is absolutely absurd to assume that accidents will occur due to failure of the rules, it is possible that excessively setting the regulations on the safety side may hinder the progress of the technology. A Classification Society is required to have a sense of balance from such a viewpoint.

In order to develop appropriate rules and technical standards, the Classification Society itself must be familiar with MASS. This requires R&D in cooperation with the industry as well as by the Society itself. Fortunately, in the case of this Society, a number of projects for MASS have already been launched in Japan, and the Society is also participating in these projects from the standpoints of collaborator or evaluator. The knowledge obtained from actual projects is extremely valuable, and the Society would like to develop rational rules while listening to the direct opinions of participants from shipping companies, shipyards, marine equipment manufacturers, universities, and research institutes. Japan's strong position is that all relevant parties in the industry are present.

The knowledge gained through these activities will be summarized in rules or guidelines, and the procedures for implementation will be clarified for developers of technologies related to MASS. The Society will serve to assist technological development in the industry.

3. ClassNK’S ACTIVITIES

3.1 Publication of Guidelines for concept design of MASS

In March 2018, the Society issued the “Guidelines for Concept Design of Automated Operation/Autonomous Operation of Ships (Provisional Version).” These guidelines summarize the requirements to be considered for ensuring the safety of MASS, assuming that the design and development of automated operation of ships are carried out under various forms and concepts. These guidelines are intended for a system that handles part or all of the human decision-making process such as recognition, judgment, and response (hereinafter referred to as an automated operation system) in order to distinguish from a system that handles simple automation such as ON / OFF of alarms.

In the design of an automated operation system, it is important to clarify the basic elements for ensuring safety shown below as much as possible from the conceptual design stage, and to verify the safety of the design based on appropriate risk evaluation methods.

(1) Object of automated operation of a ship
(2) Division of roles between human and automated operation system
(3) Operational deign domain (ODD)
(4) Fallback
(5) Human-Machine Interface (HMI)
(6) Cyber security
(7) Reliability of computer systems

In particular, the following three areas are technical points in verifying the safety of the automated operation system: "Prerequisite" which is a prerequisite for the use of the automated operation system and which is also one of design conditions; "ODD" which is a design range within which the system functions properly; and a "fallback" which is performed in order to minimize a risk when the system deviates from the ODD. If these three areas can be expanded, higher-level work automation will progress.

3.2 Participation in demonstration projects

As mentioned in 1.1, the MLIT started demonstration projects in July 2018 for automatic maneuvering, remote maneuvering, and automatic berthing functions, which are the core of MASS, as an effort for the practical application of MASS by 2025. The Society has participated in these demonstration projects from the standpoint of collaborator and/or evaluator. In addition to focusing on ensuring that the demonstration project is carried out safely, by entering the project from the development stage of the automated operation system, efforts are made to establish evaluation technology for three functions (automatic maneuvering, remote maneuvering, and automatic berthing) that will be realized in the near future.

3.3 Development of guidelines for development of automated operation systems and onboard ships

3.3.1 Basic concept

In addition to the conceptual design described in 3.1, the safety of the automated operation system must be confirmed at each stage of the design and development, manufacturing, and installation onboard ships. Methods and procedures for maintenance and management during operation must be clarified as well. Based on this concept, the Society plans to publish guidelines that summarize the requirements for each stage of design and development, manufacturing, installation onboard ships, and maintenance management during operation by the end of 2019. This section provides a summary of the representative contents planned to be described in the guidelines.

3.3.2 Verification of safety during design and development of automated operation systems

It is very important to clarify "how much (range)" to automate "which part (object)" of a wide variety of onboard operations in MASS. For example, the meaning differs greatly when automating the evacuation maneuvering by the system and when automating simple temperature management such as an air conditioner. The automated operation system assumed by the Society automates the operations directly involved in vessel maneuvering, engine control, power management, cargo management, etc. In order to confirm the safety of such a system that automates considerably complicated operations, the following two items are examined at the stage of system development.

(1) Framework and process for design and development of automated operation system
(2) Functions of the automated operation system

The validity of the design is evaluated in above (1). The main focus is to confirm that the developer of the automated operation system has the appropriate ability and that the design and development is performed in an appropriate process. For example, it is required for developers to have the ability to verify the reliability and validity of software and hardware constituting the system by themselves.

It is necessary to conduct a function confirmation test to verify that the developed automated operation system satisfies the required specifications created at the time of design in above (2). This functional verification test is assumed to be conducted by two types of tests: the test method specified by the system developer itself and the test method specified by the Society.

As a function confirmation test, for example, when it is necessary to verify that the automated operation system supports a wide variety of scenarios, such as an automated maneuvering system, evaluation by simulation is effective. Based on the simulation results conducted by the developer, the Society will evaluate the completeness of the test scenarios and the validity of the test results.

When evaluating the safety of an automated operation system at the development stage, it may be necessary to make an expert judgment to examine its effectiveness depending on the function of the automation system. In particular, in order to confirm the safety of automation systems including human involvement (for example, relative distance to other ships at the time of evacuation operation, the start time of evacuation, and handing over to the crew from the automatic evacuation function), evaluation based on actual experience is considered effective. For this reason, it is considered to be an effective method to verify the validity of the automated operation system in various scenarios using a ship handling simulator.

3.3.3 Verification at installation onboard ships

As described in 3.3.2, if the safety of the automated system itself has been confirmed at the stage of design, development, and manufacturing, it will be confirmed by document examination and on-board tests that the connection and integration of related equipment and sensors with the automated operation system are properly carried out when the automated operation system is installed onboard.

The following procedure is assumed as the flow of the automated operation system up to the installation to the ship.

(1) Drawing examination for individual ship design

(2) Implementation of system integration test on board

(3) Implementation of confirmation tests in actual operation

3.3.4 Training of crews

No matter how sophisticated the automated operation system is, it is human beings that can master it. In particular, in the case of an automated operation system based on manned autonomy, it is important that a crew member onboard can correctly understand and use it. For example, when the fallback is implemented by a crew, it is necessary for the crew to understand correctly the ODD of the automated operation system and to understand the fallback procedure and the time required for execution. Overconfidence in automated operation systems also poses a significant risk.

Therefore, it is important to prepare explanatory materials on the automated operation system (including manuals, outlines of the automated operation system, and explanations of its functions) for the people involved in the operation of MASS, including onboard crews, and to install them onboard the ship so that onboard crews can utilize them as necessary. At the same time, it is also important to train the crews for operational familiarity.

3.3.5 Risk assessment

In MASS, sufficient consideration must be given to avoid possible foreseeable malfunctions. From that perspective, risk assessment is very effective as a method for assessing the safety of automated operation systems.

There are three timings for risk assessment of automated operation systems: conceptual design of automated operation system (3.3.1), development of automated operation system (3.3.2), and automated operation system installation onboard (3.3.3). Risk assessment performed at the time of conceptual design may be performed at the same time as risk assessment performed at the time of automation system development.

(1) Risk assessment performed during the conceptual design and development of automated operation systems

In situations where the specifications of the ship are not finalized, it is impractical to perform risk assessment assuming all situations during operation. Therefore, it is recommended that the risk assessment performed during system development should be conducted with a focus on hazards for the system itself. When the risk control measures for these hazards are affected by the specifications of the ship, only the hazard is extracted during system development. It is important to take specific risk control measures during the risk assessment that is carried out on board the ship.

(2) Risk assessment to be performed when an automated system is installed onboard

Since the risk caused by the automated operation system itself has been verified at the time of system development, it is recommended that the risk assessment to be performed when an automated system is installed onboard should be conducted with a focus on hazards related to the cooperation between the ship and the automated operation system.

In particular, it is important to identify hazards that should be assumed for the following items and to take necessary risk control measures so that the safety of MASS can be ensured.

a) Risks arising from the human-machine interface

b) Malfunction of sensors and control devices connected to the automated operation system

c) Impact of the automated operation system on other systems of onboard vessels

d) Cyber security

e) The event of an emergency such as a fire or the intrusion of a pirate

3.3.6 Automation and remote control

In MASS, automation and remote control are often discussed together, but originally automation and remote control are completely different technologies. For example, in the case of an automated operation system, the validity of an algorithm is a main object of evaluation, but in the case of a remote control system, the stability of communication between a ship and a remote control center is most important.

When we imagine a use case for ship maneuvering, it is assumed that remote control is used in coastal areas where a stable communication infrastructure can be maintained, remote support and automated maneuvering systems are used in congested areas, and automated maneuvering systems are used in voyages in open seas. Also in a bay, it is possible to use the automated operation system or remote control for berthing operations. In either case, however, either automation or remote control is selected. In theory, it is conceivable that the fallback of the automated operation system is performed by remote control, but with current technology, it can be established only under a very limited environment, and it is considered that it will take a considerable amount of time for technology development to advance to a general-purpose level.

On the other hand, some concepts can be applied to both automation and remote control technologies, such as prerequisite, ODD, fallback, etc.

In order to correctly evaluate the safety of MASS, it is necessary to evaluate the system focusing on prerequisite, ODD, and fallback method while recognizing the difference between automation and remote control and understanding which technology is applied to which on-board operation.

4. CONCLUSION

This paper mainly describes how to evaluate the safety of MASS from the standpoint of a classification society. Details will be published as guidelines at the end of 2019. We hope this guideline can contribute to the development and commercialization of technology related to autonomous ships.

REFERENCES

ClassNK : Guidelines for Concept Design of Automated Operation/Autonomous Operation of ships (Provisional Version)
ClassNK : Cyber Security Management System for Ships (Requirements and Controls) (First Edition)
ClassNK : Guidelines for Designing Cyber Security Onboard Ships (First Edition)
ClassNK : Risk Assessment Guidelines

Outline of Guidance for onboard use of compliant fuel oil with SOx Regulation from 2020

Research Institute, ClassNK

1. INTRODUCTION

In order to prevent adverse effects on human health and air pollution caused by ship' exhaust gas, regulation 14 of Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) sets forth control measures to reduce emissions of Sulphur Oxides (SOx) and Particulate Matter (PM) from ships. From January 1st, 2020, any fuel oil used on board ships will be tightened from the current requirement of 3.50% m/m to 0.50% m/m outside emission control areas (ECAs).

According to the Final report on the Assessment of Fuel Oil Availability (hereinafter, the IMO study) [1)], which was carried out by IMO, it would not be possible to supply sufficient amount of distillate fuel oil and desulphurized residual fuel oil to correspond SOx global cap in 2020. Therefore, the IMO study assumed that most of fuel oil compliant with SOx global cap (hereinafter, compliant fuel oil) would consist of blended oil (a blend of various intermediate materials with <0.50% sulphur content). Also, compliant fuel oil to be supplied after 2020 is expected to consist of various low-sulphur blendstocks other than light distillates more than current heavy fuel oil, and the ratio of blendstocks in fuel oil may vary widely among the region compared to current heavy fuel oil. According to the various blend ratios of such lower sulphur blendstocks, it is expected that the range of properties of the fuel oil would be more widely spread than that of the current fuel oil. It is pointed out by IMO and ISO working group on petroleum and related products and fuels that further mitigation measures and implications will be needed to mitigate such varied properties.

Under this circumstance, ClassNK reviewed the current mitigation measures and implications when using compliant fuel oil from 2020 and issued the results as "Guidance for onboard use of compliant fuel oil with SOx Regulation from 2020" in March 2019. This article introduces the outline of this guidance.

2. COMPLIANT FUEL OIL FROM 2020

2.1 Classification and production process of compliant fuel oil with SOx regulation

In discussing the use of the compliant fuel oil, ClassNK considers that it is important to take into account the possible future changes on the blending for marine fuel oil and the changes in the properties. ISO 8217:2017 specified the properties of marine fuels, in the standard the marine fuel is classified as shown in the table 1[*1]. As classification in the table is not directly link to the sulphur contents, the compliant fuel oil after 2020 is defined in Table 2. The definition in Table 2.2 is consistent with the IMO guideline adopted in May 2019 [2)]. Fuel oils generally referred to Marine Gas Oil (MGO) or Marine Diesel Oil (MDO) are classified as ULSFO-DM or VLSFO-DM in Table 2.

For readers' information, Publicly Available Specification (PAS) 23263 [3)] was issued in September 2019 as supplemental information on ISO 8217:2017. The PAS explains future changes of the following characteristics as technical considerations when using compliant fuel oil: stability, compatibility, kinematic viscosity, cold flow properties, Cat-fines and ignition characteristic. However, The PAS does not introduce new specifications nor an additional table for 0.50% sulphur fuels.

[*1] Classification of the marine fuel in ISO 8217:2017 is defined in ISO 8216-1:2017.

Table 1　Classification of marine fuel oil in ISO 8217:2017

Abbreviation	Classification of marine fuel	Description
DM	Distillate Marine Fuels	Fuel oils which the specifications of Distillate Oil required in ISO 8217:2017 are applied to (e.g. DMX, DMA, DMZ, DMB)
RM	Residual Marine Fuels	Fuel oils which specifications of Residual Oil required in ISO 8217:2017 are applied to (e.g. RMD80, RMG180)

Table 2　Fuel oil defined in accordance with their sulphur contents

Abbreviation	Generic term	Description
ULSFO	Ultra-Low Sulphur Fuel Oil	Fuel oils compliant with 0.10% sulphur limit required inside ECAs. It is subdivided into ULSFO-DM and ULSFO-RM depending on the production process.
VLSFO	Very Low Sulphur Fuel Oil	Fuel oils compliant with 0.50% sulphur limit required outside of ECAs. It is subdivided into VLSFO-DM and VLSFO-RM depending on the production process.
HSHFO	High Sulphur Heavy Fuel Oil	Fuel oils with a sulphur content of more than 0.50%. Ships which do not install SOx scrubber are prohibited to use such fuel oil from January 1, 2020. Furthermore, these ships should not carry such fuel oil from March 1, 2020.

Figure 1 shows the blending process to produce marine fuel oils (include compliant fuel oil) and dotted lines show possible blending process for VLSFO-RM after 2020. The compliant fuel oil may mainly consist of light distillates as low-sulphur blendstocks (for example, process 5 and 6 in the figure), but ClassNK considered that the supply capability of such fuel is limited from an economic perspective. In other words, ClassNK expected that most ships will use VLSFO-RM, which contains some amount of residuals.

With respect to methods for producing VLSFO-RM, three representative methods are expected; these three are shown as 7a, 7b and 7c in Figure 2.1. Regarding 7a, the supply amount will be limited by the low sulphur crude oil production. Regarding 7b, the supply amount will be limited by the insufficient capacity of desulphurization process in some refineries. Therefore, ClassNK considers that the major source of VLSFO-RM should be 7c.

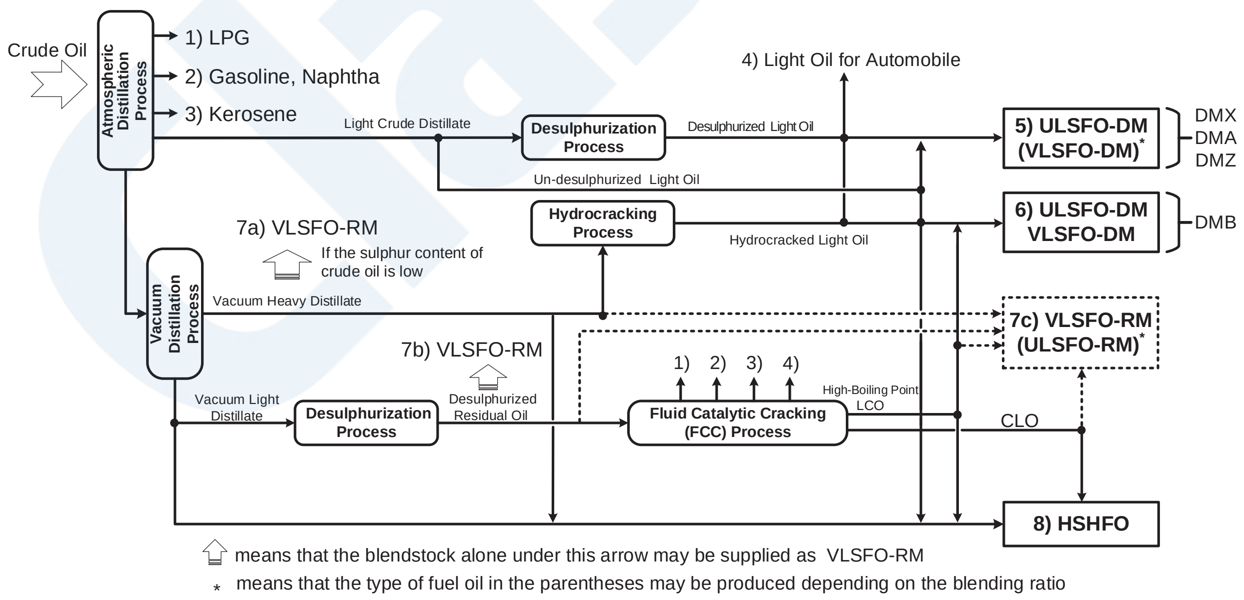

Figure 1　The possible blending process to produce marine fuel oils [4)]

ClassNK considers that candidates for low sulphur blendstocks for 7c are light cycle oil (LCO) and clarified oil (CLO). LCO is one of the products from fluid catalytic cracking (FCC) process, and CLO is made up from by removing Cat-fines from slurry oil, which is also one of the FCC productions. FCC is an important reforming process in current refineries, and is widely used to increase the yield of lighter components such as gasoline and gas oil from crude oil. Since the lighter products (the process 1 and 2 in Figure 1) which contain many paraffinic hydrocarbons (straight-chained hydrocarbon) are produced from distillation after FCC process, the residual component, that is LCO and CLO, contains rich aromatics hydrocarbons. The FCC process requires low-sulphur materials, such as desulphurized vacuum gas oil, desulphurized atmospheric residue and vacuum residue without desulphurization (if the fewer sulphur contents in crude oil), as a result, the sulphur content of both LCO and CLO are much lower than that of crude oil. Therefore, ClassNK considered that these two blendstocks would be more blended than in current HSHFO. It should be noted that the mixing ratio among the 4 possible blendstocks would be widely varied depends on the varied capacity of FCC process among refineries, and on the properties of the Crude Oil, they use.

2.2 Paraffin and Aromatics

Hydrocarbons contained in the heavy fuel oil are classified into two types; paraffin and polycyclic aromatic. With the variation of the process for producing VLSFO-RM described in 2.1, it is expected that both paraffin-rich fuel oil and polycyclic-aromatic-rich fuel oil are commercially supplied after 2020. Both types of fuel oil are considered to have contrasting properties as shown in Table 3.

Table 3 Characteristics of paraffin-rich fuel oil and Polycyclic-aromatic-rich fuel oil

	Paraffin-rich	Polycyclic-aromatic-rich
Typical molecular structure	Icosane (an alkene whose number of carbon atoms is 20)	 Naphthalene
Ignition and combustion quality	Good	Poor
Cold flow properties	Poor	Good
Compatibility	Poor if these two types are mixed	

3. HOW TO USE COMPLIANT FUEL OIL ON BOARD IN SAFE

3.1 General

3.1.1 General mitigation measures to use low sulphur fuel oil

When using low sulphur fuel oil, it is necessary to use appropriate cylinder oil with BN (Base Number: hereinafter BN4) matched to the sulphur content of the fuel oil. In global sea area where HSHFO is currently used, cylinder oil of about 70 to 100 BN is used at 2 stroke engines, but from 2020, it is necessary to use cylinder oil with a lower BN corresponding to fuel oil with a sulphur content of 0.50% or less. It is recommended to check with the engine manufacturer beforehand about the selection of cylinder oil. Also, it is recommended to check with the engine manufacturer beforehand about the selection of trunk piston engine oil.

3.1.2 General mitigation measures to use the wide variation of compliant fuel oil

ClassNK reviewed the current mitigation measures and implications related to using compliant fuel oil from 2020. ClassNK has identified five properties of VLSFO-RM that should be taken into consideration with its use: Compatibility, Low viscosity, Cold flow properties, Cat-fines, and Ignition/Combustion quality. These five properties are recognized as technical considerations in the PAS 23263. Even with VLSFO-RM meets the ISO 8217:2017 specification, the broader range of fuel properties than current fuel oils may lead the situation that a ship should handle with VLSFO-RM with properties that have not been used. Therefore, it is important to recognize the potential safety implications depending on the properties of the fuel oil. To mitigate those implications, it is not necessary to prepare completely new knowledge, but it is important to select the best mitigation measures among the existing knowledge accumulated so far. From this point of view, this guidance addresses five notable factors related to fuel oil properties.

Since the purpose of this article is an introduction of the outline of the guideline, these properties and mitigation measures are explained briefly. The guidance is available free of charge on ClassNK website. Therefore if readers are interested in more detailed information, it would be appreciated if readers could refer to the guidance.

3.2 Mitigation measures for five potential implications

3.2.1 Compatibility

In general, when two different fuel oils are mixed, the stability of fuel that was maintained degrades, and asphaltene sludge and/or other substances may deposit. The capacity of fuel oil resists its deposition is generally defined as fuel compatibility. In the PAS 23263, the definition of compatibility is added and additional test methods and indicators to evaluate compatibility are introduced for reference. However, limit value is not specified.

Asphaltene in heavy fuel oil forms stable micelle after adsorbing aromatic polymer from maltene (continuous phase) in multiple layers as shown in Figure 2, and is dispersed in a colloidal state in maltene formed from hydrocarbon in a liquid state [5].

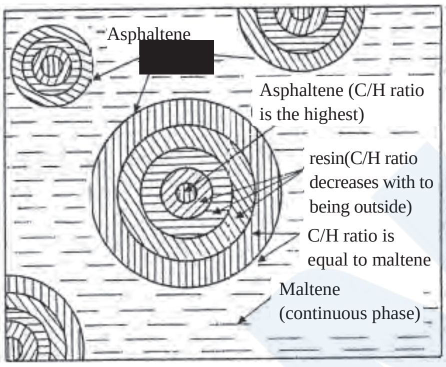

Figure 2 Schematic structure of asphaltene micelle [5]

As shown in Figure 2, an asphaltene micelle can be considered to have a structure in which aromatic hydrocarbons adsorbed in the surroundings of asphaltene, therefore the C/H ratio gradually decreases from centre to the end of the micelle C/H, the equilibrium of asphaltene dispersed efficiently in the colloidal state is lost when the fuel is mixed with other fuel oils, and/or by thermal shock or when the fuel is oxidised. When the discontinuous changes in the C/H ratio from asphaltene to maltene, asphaltene will start to aggregate and the particles will grow from fine to coarse, and finally will deposit as asphaltene sludge. In general, High C/H ratio means high aromaticity [5].

(1) Potential risks

As described above, it is expected that the composition of VLSFO-RM has more variation of blendstocks compared to that in current HSHFO. Therefore, the possibility of receiving a compliant fuel with different composition depending on the oil-supplement site, even if the two fuel oils are clarified as the same oil category.

In general, the mitigation measure has been already implicated that the fuel oil in each storage tank should be used up as much as possible before bunkering. However, there are some cases which fuel oil with different blending ratio may be bunkered and topped up in one storage tank where fuel oil is inevitably left. Even if the storage tanks are separated, it can happen that the fuel oils having different blending ratios are mixed in the settling tank, the service tank, or the piping lines. In these cases, for example, if aromatic VLSFO-RM and paraffinic VLSFO-RM are mixed, it leads to deposition of the asphaltene sludge in the mixed fuel oil due to degrade the stability of fuel oil caused by the significant change of fuel oil composition.

(2) Potential troubles on equipment

- ➢ Asphaltene sludge deposition in fuel oil tanks
- ➢ Clogging of the filter in fuel oil piping
- ➢ Sludge precipitation in a purifier

(3) Mitigation measures

- ➢ Refill new fuel oil after using up the previous fuel in a storage tank as much as possible and avoid top-up.
- ➢ If it is unavoidable to mix fuel oil in the storage tank, add a sludge dispersant to remaining fuel oils in the storage tank before bunkering, and use up the mixed fuel oil as soon as possible.
- ➢ When switching fuel oil, the risk of sludge deposition due to fuel oil mixing in the settling/service tanks and the piping is inevitable, but mitigation measures such as not switching VLSFO-RM in areas with operational risks such as congested sea areas can be considered to avoid the adverse effects on the safe operation.

3.2.2 Low Viscosity

Since the sulphur content of VLSFO is 0.50% or less, the blending ratio of the vacuum residue, especially the vacuum residue without desulphurization, will consequently be lower than HSHFO. Also, as described in 2.1, it is expected that LCO and CLO will be more blended as low-sulphur blendstocks, and their viscosity compared to the vacuum residue are much lower. Therefore, it is predicted that the viscosity of VLSFO-RM supplied from 2020 will be lower than current HSHFO. In general, lower viscosity fuel has lower lubricity, therefore when using low viscosity fuel, damage may occur to some engine parts that lubricated by fuel oil.

(1) Potential risks

When 0.10% Sulphur regulation in the ECAs started in 2015, some adverse effects on the fuel injection system when using ECA compliant fuel oil (classified as ULSFO-DM in this guidance) were observed. An example case is shown in Figure 3. If VLSFO-RM with low viscosity comes to be used instead of HSHFO, and its viscosity becomes equal to or lower than that of ECA compliant fuel oil such as MGO (Marine Gas Oil), similar troubles can be expected.

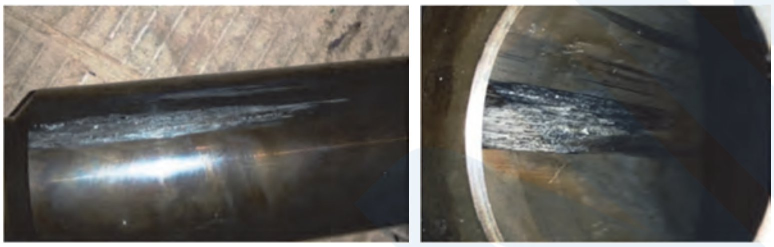

Figure 3 Scratches on the plunger and barrel in the fuel injection pump

(2) Potential troubles on engines and equipment

The similar troubles that occurred when using ECA compliant fuel oil may occur, but the low-temperature corrosion around the fuel valve in a four-stroke diesel engine shown in (1)(c) may be considered as a new risk.

(i) Diesel engine

- ➢ Sticking of the fuel injection pump (caused by lower lubricity) and start-up failure or difficulty to increase rotational speed (load) (caused by leakage increase of the internal sliding parts)
- ➢ Difficulty to increase rotational speed (load), due to the insufficient fuel supply from the fuel supply pump (caused by lower viscosity)
- ➢ Low-temperature corrosion on fuel valves and including related components

(ii) Fuel supply pump / Fuel transfer pump / Purifier supply pump

- ➢ Sticking, Gear wear, Leakage from pump seal (caused by lower lubricity)
- ➢ Insufficient supply due to leakage of the sliding part inside the pump, Leakage from pump seal (caused by lower viscosity)

(3) Mitigation measures

It is important to confirm whether the engines and equipment are suitable for the viscosity of the fuel oil that assumed to be used, and thoroughly control the temperature to adjust the viscosity. For example, it is recommended to confirm the related specifications of the fuel pump with the manufacturers in advance to the actual use of the compliant fuel, and ensure the manufacturer's recommended viscosity at the engine inlet. Many engine manufacturers have set the minimum viscosity of fuel oil at the engine inlet to 2 cSt.

3.2.3 Cold flow properties

The cold flow properties of fuel oil which contains a large amount of wax can make adverse effects on ship operation.

(1) Potential risks

As described above, VLSFO-RM is expected to have lower kinetic viscosity than that of current HSHFO. There is a possibility that viscosity of some VLSFO-RM will be similar to that of distillate to distribute. In this case, fuel heating for transfer from the fuel oil tanks is not necessary.

On the other hand, some types of low sulphur blend-stocks contain a large amount of paraffin. Hence VLSFO-RM mainly consists of these stocks may have low viscosity and a rich concentration of paraffin (this VLSFO-RM has poor cold flow properties). In this type of fuel oil, when the temperature of the fuel drops, paraffin in the fuel oil may crystallize and precipitates as wax. If fuel oil containing grown wax is transferred, it will deposit on the filter placed in the fuel oil line leading to reduce the fuel flow to the engine plant. In the worst case, the filter may be completely clogged.

Also, once wax deposited in fuel oil pipe or tanks, there is a possibility that troubles cannot be solved by fuel heating because solid wax has poor thermal conductivity and significant thermal energy may be needed for transforming the wax back to liquid.

(2) Potential troubles on equipment

- Impossible to transfer fuel oil from the storage tank
- Filter clogging in the fuel oil piping
- Deposition of wax in the purifier

(3) Mitigation measures

Even when VLSFO-RM with a higher concentration of paraffin is used on board, the risk of wax formation can be mitigated by heating in the same way as the current HSHFO. Therefore, proper heating of the fuel is useful as a precautionary measure. For example, as an indicator of fuel temperature management, it is recommended that fuel temperature should be kept approximately 10 °C above the Pour Point reported.

3.2.4 Cat-fines (contents of Aluminium and Silicon)

Cat-fines are originated from catalyst particles used in the fluid catalytic cracking (FCC) process. In the FCC process, these catalyst particles break up into smaller particle and can remain in the fuel cat-fines. It is a very hard particle composed of alumina (Al_2O_3) and silica (SiO_2) as a component.

The catalyst particles are continuously used and recycling in the FCC process, but the cat-fines remain in the slurry oil. The slurry oil is generally not used as the blendstock for marine fuel oil. Moreover, only after separating cat-fines from slurry oil, it can be used as CLO, but parts of the catalyst particles still may remain in CLO.

For representing the total amount of cat-fines in fuel oil, the total mass of aluminium (Al), and silicon (Si) are usually measured instead of directly measuring the number of alumina and silica particles. In ISO 8217:2017, the maximum Al + Si limit is specified.

If cat-fines remain in fuel oil without being properly removed on board, they may enter into the equipment and physically damage the sliding part. Figure 4 and 5 show cat-fines embedded in the piston ring and the cylinder liner.

Figure 4 Cat-fines embedded in the cylinder liner and trace of abrasive wear

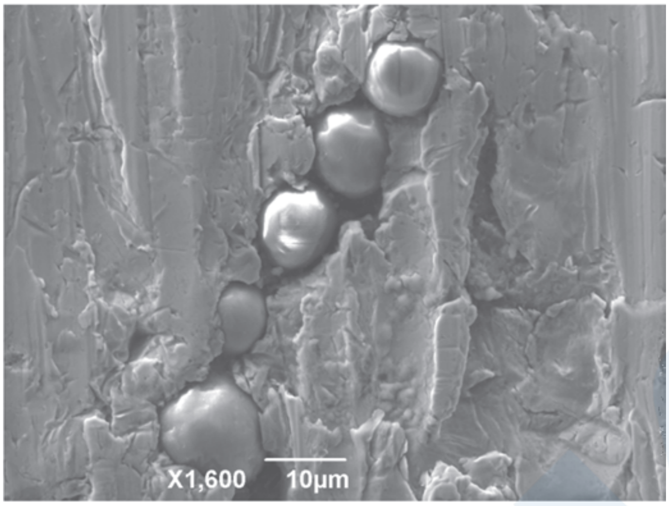

Figure 5　Cat-fines embedded in the piston ring

(1) Potential risks

There is a possibility that VLSFO-RM with a rich CLO blending has total content of Al and Si close to the upper limit of 60ppm specified in ISO 8217:2017 (60ppm is specified for RMG category). When using such VLSFO-RM, there is a risk that the burden of the purifier may increase more than now.

(2) Potential troubles on engines and equipment

- ➢ Stick and wear on fuel injection parts
- ➢ Stick, wear and nozzle hole defect on the fuel injection valve
- ➢ Excessive wear and breaking on piston ring
- ➢ Excessive wear on piston ring groove
- ➢ Excessive wear and scuffing on cylinder liner, etc.

(3) Mitigation measures

Even if VLSFO-RM contains Al and Si at the maximum limit specified in ISO 8217:2017, content of Al and Si can be efficiently removed at the engine inlet to the recommended value by each engine manufacturer, as long as appropriate pre-treatment in the settling tank and maintenance of the purifier are appropriately performed. For this reason, it is considered that further mitigation measures on the hardware are not necessary.

It is considered that the effective mitigation measure is to carry out the proper operation at the purifier and appropriate pretreatment of VLSFO-RM in the settling tank. Specific examples are shown as follows.

- ➢ To improve separation efficiency, reduce the rate of oil by proper operation at the purifier. Also, keep oil temperature at purifier to prevent degrading separation efficiency.
- ➢ Check fuel oil sample measure Al + Si content at a laboratory for every bunkering or regularly.
- ➢ Remove drain water and sludge from settling tank. etc.

3.2.5　Ignition and combustion quality

In this guidance, ignition and combustion quality are considered separately. The ignition quality is a characteristic of fuel showing the ease of self-ignition and is generally expressed as time duration from the starting injection of fuel oil into the combustion chamber to ignition (i.e. ignition delay).

Cetane number and Cetane index are used as ignition property of diesel oil. However, these cannot be measured or calculated for marine heavy fuel oil. Therefore, CCAI (Calculated Carbon Aromaticity Index) is mainly used as practical indicators for evaluating ignition delay. CCAI is an empirical index calculated from the density and viscosity of marine residual fuel developed for simply evaluating ignition delay. CCAI was developed in the 1980s, and the higher it is, the higher the aromaticity is said to be. In ISO 8217:2017, the maximum CCAI limit is specified in RM grade.

In this guidance, the combustion quality is defined as representing the extended combustion period, the flame length and the proportion of unburned components such as black smoke and deposits in the combustion chamber. That is, while the ignition quality represents the characteristic of the start of combustion, the combustion quality means the characteristic from the second half to the end of combustion.

Combustion quality is not defined and no test method is introduced in PAS 23263, but it is identified as a potential risk in the IMO guideline.

(1) Potential risks

Fuel oils with high aromaticity may have problems with ignition and combustion quality. As mentioned above, it is also considered that LCO and CLO are blended more as low-sulphur blendstocks in VLSFO-RM. LCO which mainly consist of 2-rings aromatics may especially give adverse effect to ignition quality of fuel oil. Also, CLO which mainly consist of 4-rings and more polycyclic aromatics may especially give adverse effects to combustion quality of fuel oil.

(2) Potential troubles on engines

<Low-speed 2-stroke engine>

Typical examples of damage include the followings.

- Excessive wear and breaking on piston ring
- Excessive wear and scuffing on cylinder liner
- Excessive wear, scuffing and excessive leakage on the piston rod and gland packing due to unburnt deposits
- Wear and burn-out of the fire-exposed surface on exhaust valve, etc.

<Medium or high-speed 4-stroke engine>

The higher the engine speed, the greater the adverse effect of the increase in ignition delay. Due to ignition delay, especially at low load where both atmospheric temperature and pressure in cylinder are low, irregular combustion caused by diesel knock may happen, and PM and black smoke emissions may increase. Also, it may be considered that the engine troubles mentioned for low-speed 2-stroke engines can also occur in a medium or high-speed 4-stroke engine.

(3) Mitigation measures

Enhancing the engine condition monitoring as described below is mainly the mitigation measure.

(i) For 2-stroke diesel engines

- Proper maintenance of the fuel valve, securing the valve opening pressure to atomize fuel oil properly.
- Enhance engine condition monitoring. (e.g. monitoring exhaust gas temperature, rpm of the turbocharger (surging), specific fuel consumption, the concentration of iron in drain oil sampled from the bottom of the cylinder liner, etc.)
- Continuous monitoring on cylinder liner temperature with the sensor, if possible
- Continuous monitoring on combustion condition using cylinder pressure measured by the sensor, if possible. If not possible, monitoring on combustion condition using mechanical indicator may be considered as an alternative.

(ii) For 4-stroke diesel engines

- Proper maintenance of the fuel valve, securing the valve opening pressure to atomize fuel oil well.
- Enhance engine condition monitoring. (e.g. monitoring exhaust gas temperature, rpm of the turbocharger (surging), specific fuel consumption, etc.)
- To improve startability, carry out preheating of cylinder cooling water if possible.

The guidance also provides temporary measures which can be considered to mitigate potential troubles when the sign of abnormal combustion is detected in the cylinder liner, piston ring, etc. during the engine condition monitoring.

4. SUMMARY

In this guidance, ClassNK has summarized the possible mitigation measures against all five potential implications based on the current findings. ClassNK trusts that this guidance contributes to the safe use of compliant fuel oil.

REFERENCES

1) IMO, Assessment of Fuel Oil Availability - final report, MEPC70/5/3 (Executive summary) and MEPC 70/INF.6, (2016).
2) IMO, 2019 Guidelines for consistent implementation of the 0.50% sulphur limit under MARPOL Annex VI, MEPC Resolution MEPC.320 (74), (2019).
3) ISO/PAS 23263:2019, Petroleum products — Fuels (class F) — Considerations for fuel suppliers and users regarding

marine fuel quality in view of the implementation of maximum 0,50 % sulfur in 2020.
4) Nippon Kaiji Kyokai, “Guidance for onboard use of compliant fuel oil with SOx Regulation from 2020”, (2019).
5) Awai, N., et al., “Fuel oil for land/marine medium and large diesel engines”, Sankaido, 173-176, (1994) (in Japanese).

Utilization of ROV for In-Water Surveys

Takahiro YAMAMOTO*

1. INTRODUCTION

In recent years, robotics development has attracted a great deal of attention in order to promote next-generation industries [1)-2)], R&D and commercialization have been promoted in various fields such as industrial robot [3)], servicing robot [4)], drone [5)-7)], and unmanned submersible [1),8)].

As with drones, unmanned submersibles have been widely developed, ranging from research aircraft to hobby aircraft, and the number of aircraft available on the market has increased. The remotely operated unmanned submersibles are called by various names such as underwater drones, underwater robots, and remotely operated unmanned explorers, but the name of ROV (Remotely Operated Vehicles), which is the most common name, is used in this paper. Unmanned submersible vehicles which are a stand-alone and autonomously active are distinguished as an AUV (Autonomous Underwater Vehicles).

ROVs can be operated with the same feeling as a radio controlled car, and there is a good possibility that they can be more efficient for docking surveys, while in-water surveys by divers may be accepted in lieu of Surveys in dry dock on the slipway (Chapter 6, Part B of the Rules for the Survey and Construction of Steel Ships [9)]). In order to verify its effectiveness, a test trial of in-water surveys using ROVs was conducted in March 2019. This paper introduces the results.

2. TRIAL OVERVIEW

2.1 Purpose

This trial has been carried out to confirm whether ROV could be used as a substitute for a diver, and in-water survey using ROVs for PCC (Pure Car Carrier) is assumed in this trial.

2.2 Equipment

The following two ROV models were used.

- BlueROV2 [Blue Robotics]
- CCROV [Vxfly]

The used equipment are shown in Photo 1 and 2, and the size of each equipment is shown in Photo 3.

Photo 1 BlueROV2

Photo 2 CCROV

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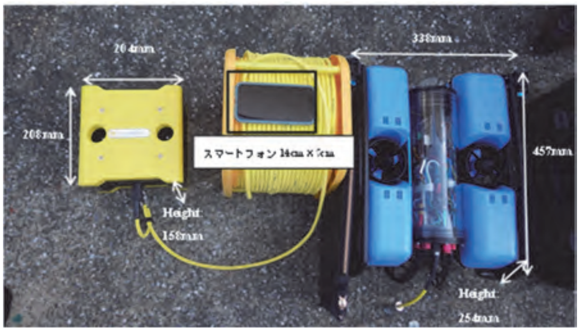

Photo 3　Size of ROVs

The ROVs were used according to the following purposes.

- BlueROV2: photographing the ship's bottom
- CCROV: photographing situations that the BlueROV2 is moving/shooting

The controllers and monitors required for the operation are shown in Photo 4 and Photo 5.

In Photo 4, specific PC software receives signals from the controller (commercially available for games) and transmits signals to ROV through LAN cables. The flight controller *1, which is frequently used in drones, is installed to ROV in order to calculate and provide appropriate thrust to propellers based on the received signals. Internal wiring is the same system as the drones. On the other hand, CCROV has a dedicated controller, and a smartphone is connected as a monitor as shown in Photo 5.

Photo 4　BlueROV2 Controller/Monitor

Photo 5　CCROV Controller/Monitor

Here, it is explained the structure of the BlueROV2 body [10], which is used to take images of the ship's bottom.

Fig. 1 shows the position of the Enclosures and Buoyancy, Fig. 2 shows the position and facing direction of the motor, and Fig. 3 shows some of the electronic devices which are installed into BlueROV2.

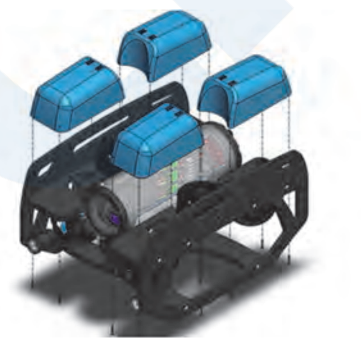

Figure 1　Position of the Enclosures and Buoyancy

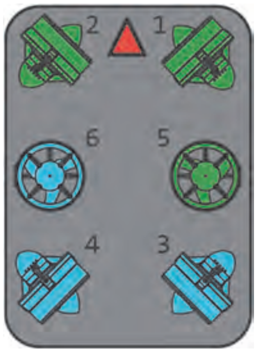

Figure 2　Motor Position and Facing direction

*1　This is a computer mounted on the airframe, not on the controller at hand, and the purpose of use is diverse like for attitude control, various calculations, signal input/output, etc..

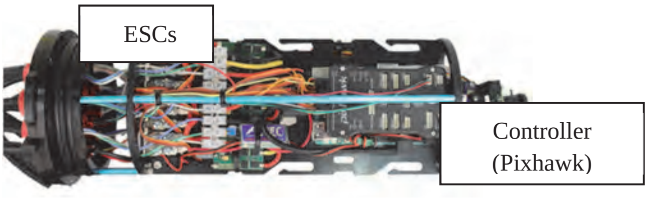

Figure 3　Electronic devices

Features of the BlueROV2 are as follows.

- Transfer on live 1080p HD video
- The camera can be tilted (zoom and pan are not applicable).
- Weight: Approx. 10kg
- Design considering use in surveys, inspections, and research (it has the payload enough to install various types of equipment.)
- Automatic adjustment and holding of heading and depth (using magnetometer and pressure sensor)
- Standard 100m depth rating and up to 300m tether available.
- Maximum forward speed : 3.7km/h
- Secure high visibility with 1500 lumens × 4 lights (illuminance can be adjusted by controller)
- Battery powered with quick-swappable batteries (lithium-polymer batteries; 4S [14.8V], 18000mAh)
- Flight controllers, which are commonly used in drones (ArduSUB [12)] are adopted as firmware.))
- In addition to up/down/left/right movement, the attitude can be changed in the roll and yaw direction. Moving in the pitch direction is difficult for this ROV, but it is compatible by installing two additional motors.

2.3　Shooting area

Shooting area and route using the BlueROV2 is shown as follows.

FORE

(1) Bow thruster (S→P)

(2) 1W/2WS/2WP marks *2

(3) 1W mark *2 + THR *3 (P) bottom plug

(4) 1W/2WS/2WP marking *2 (+bottom plug)

Move in stern direction along the keel line from here and take movies up to the 2WS/2WP/3WS/3WP.

(5) Bottom plugs of the 2WS

(6) 3SW/3W mark → 3SW mark → 2W mark

MIDDLE

(7) Draft marks (S)

(8) 5SW/FBS/5W/3W mark *2

(9) Bilge keel head (P)

AFT

(10) Inspection hole & Cover plate

(11) Gap between Rudder and Rudder Stock (near Inspection hole)

(12) Rudder Fin (S)

(13) Bottom plug

(14) Propeller cap

(15) Blade (tip + root)

(16) Sea chest (P/S)

2.4　In-water surveys using BlueROV2

Photos 6 to 10 show the state of the in-water surveys using BlueROV2.

The ROV gradually dropped to the water surface while holding the cable and landed on the water. The safety was considered

*2　IWS mark
*3　Thruster room

to the utmost, and measures such as wearing a life jacket were taken in case of falling water. A total of two people, one ROV operator and one assistant who took care to prevent the cable from wrapping, was implemented (Photo 6). The approach from the quay to the hull was performed based on direct visual observation by the ROV operator and voice information from the assistant (in charge of cable) (Photo 7).

Usually, it is possible to steer while watching the image displayed on the PC monitor, but this time, the PC monitor screen used was mirror-finished and the visibility was not excellent, so a Head-Mounted Display (HMD) such as Photo 8 was used for the purpose of further improving the visibility. The image displayed in the HMD (Photo 9) is the same as the screen of the PC monitor because it is output from the PC via HDMI. The attitude angle of the ROV was displayed in the screen, and the operator grasped its own position while looking at the figure.

Photo 6　Lowering the ROV

Photo 7　ROV Transfer

Photo 8　Use of HMD

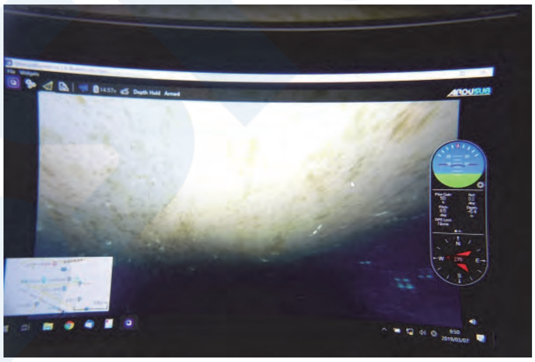

Photo 9　HMD screen

Photo 10 shows how BlueROV2 is shooting the target (taken with CCROV).

Photo 10　BlueROV2 Shooting (taken with CCROV)

2.5　Shooting results

Photo 11 - Photo 16 shows the image captured by the ROV. For the sake of convenience, this section introduces the images extracted from the shooting points listed in 2.3.

(1) Bow thruster (refer to 2.3(1))

Photo 11(a) shows an image captured by the ROV under water, and Photo 11(b) shows an image photographed in the dry dock (using Apple iPhone 7).

Taking into account the fact that this is a trial, shooting from the entrance of bow thruster was carried out in order to avoid the risk of ROV entanglement due to excessive approach. Since there was a distance from the ROV until the bow thruster, visibility is lacking as shown in Photo 11(a). Although the turbidity effect is one of the causes, it can be understood that in the case of using the ROV, it is necessary to shoot the image at least some distance from the subject.

Photo 11(a)　Bow thruster (ROV shooting)

Photo 11(b)　Bow thruster (dock shot)

(2) 1W/2WS/2WP mark (refer to 2.3(2))

It can be seen that Photo 12 is clearly seen even in underwater shooting.

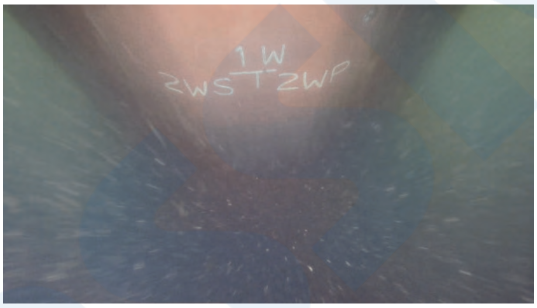

Photo 12　1W/2WS/2WP (ROV shooting)

(3) Draft mark (S) (refer to 2.3(7))

In Photo 13, the ROV can get close to the target by taking its advantage, and the number can be accurately visually recognized.

Photo 13　Draft Mark (S) (ROV shooting)

(4) 5SW/FBS/5W/3W mark (refer to 2.3(8))

The photograph 14 (a) is captured as clearly as compared with the photograph 14 (b).

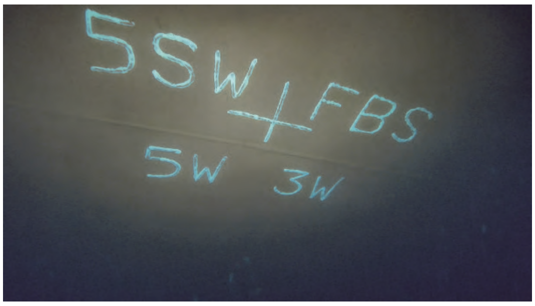

Photo 14(a) 5SW/FBS/5W/3W mark (ROV shooting)

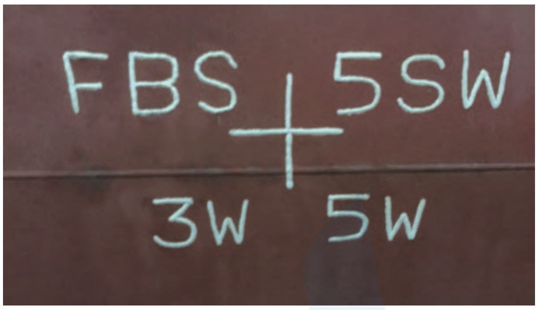

Photo 14(b) 5SW/FBS/5W/3W mark (docking)

(5) Bilge keel head (P) (refer to 2.3(9))

Both Photo 15(a) and Photo 15(b) show the bilge keel head. In Photo 15(a), the bilge keel appears straight, while in Photo 15(b) it appears curved. This is a phenomenon caused by the direction of photographing because a wide-angle (fisheye) camera is used. It is possible to cope with this problem by using a camera capable of shooting with a center projection system.

Photo 15(a) Bilge keel head (ROV shooting)

Photo 15(b) Bilge keel head (ROV shooting)

(6) Sea chest (P) (refer to 2.3(16))

Photo 16(a) is the sea chest, and photo 16(b) is the image taken close to the sea chest. In the Photo 16(b), it can be understood that the internal parts are also confirmed.

Photo 16(a) Sea chest (P) (ROV shooting)

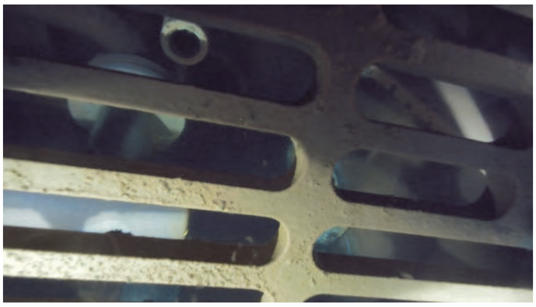

Photo 16(b) Sea chest (P) [Proximity] (ROV shooting)

2.6 Consideration

As a result of photographing using the ROV “BlueROV2”, the followings were confirmed.

- Basically, the turbidity influence can be neglected to some extent by approaching, and the object can be clearly photographed.
- Lighting is essential. If there is a distance, there arises a problem that the illumination does not reach and the object cannot be visually recognized.
- Using a wide angle (fisheye) camera may distort the image.

- The operation technique is important, but it is fundamentally safe (static stability) compared with the drone, and even if a trouble such as a failure occurs, it can be recovered by pulling up the cable.
- According to ROV operators, the tidal current effect was not perceived in this trial, but the upward and downward movements due to waviness could not be ignored. The ROV used this time had some influence even though the depth holding control was effective by the pressure sensor.
- Images taken in close proximity in-water can be taken with a quality that is not significantly different from that in the dry dock.
- The bow thruster, sea chest, etc. were photographed using the zoom function at the time of dry docking, but can only be confirmed at an angle of looking up from below. This is not the case when a cherry picker or a checking scaffold is prepared, but the advantage of ROVs is that it can easily approach and shoot.
- In addition, the area hidden by boards at the time of dry docking could not be visually confirmed, as a matter of course. It is also one of advantages of ROVs that the entire bottom can be confirmed without such constraints.

3. SUMMARY

In this trial, it was possible to confirm the effectiveness of ROV utilization in in-water survey, because it was possible to clearly photograph basically all objects by close-up shooting.

Since the actual feeling that the burden on the operator is light compared with the drone is obtained, it is considered that the requirement for the operator may be reduced compared with the drone.

On the other hand, in ROVs at the present time, it is not possible to measure the clearance of each bearing portion of the rudder and to open and close the gratings, which are required in-water surveys. In addition, it is not possible to remove deposits on the hull, such as sea lettuces and barnacles. From this point of view, it is not immediately available for in-water surveys as a substitute for a diver. When ROVs are actually used, it is considered important to match well with the in-water surveys method by divers based on the actual situation.

ACKNOWLEDGEMENT

ClassNK would like to express its deepest gratitude to all parties involved in conducting the trials, including Mitsui O.S.K. Lines, Ltd., Sekido Co., Ltd., MINAMINIPPON SHIPBUILDING Co., Ltd., and Japan Marine United Corporation.

REFERENCE

1) Japan Science and Technology Agency, Center for Research and Development Strategy: Systems and Information-Science and Technology (2019) (https://www.jst.go.jp/crds/pdf/2018/FR/CRDS-FY2018-FR-02/CRDS-FY2018-FR-02_07.pdf))
2) Japan Machinery Federation, 2017 Research and Development Report on the Promotion of Robotics Industry and Technologies (http://www.jmf.or.jp/content/files/houkokusho/29nendo/20180327-045211.pdf))
3) IFR, Executive Summary World Robotics 2018 Industrial Robots, (https://ifr.org/downloads/press2018/Executive_Summary_WR_2018_Industrial_Robots.pdf)
4) Ministry of Internal Affairs and Communications, Japan: 2016 White Paper on Information and Communications in Japan (http://www.soumu.go.jp/johotsusintokei/whitepaper/ja/h28/html/nc131520.html))
5) FAA, “Aerospace Forecast Report Fiscal Years 2016 to 2036”, 2016.3, (https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/fy2016-36_faa_aerospace_forecast.pdf)
6) Hisanori Sunohara, Impress Research Institute, “Drone Business Survey Report 2017”, Impress Crporation.
7) Goldman Sachs, “Drones Reporting for Work”, (https://www.goldmansachs.com/insights/technology-driving-innovation/drones/)
8) COMPASS November 2017, p20-27, “Undersea robots with increasing expectations for commercial use”
9) ClassNK: “Chapter 6 Docking Surveys”, Part B, Rules for the Survey and Construction of Steel Ships

10) Blue Robotics “BlueROV2”, (https://bluerobotics.com/store/rov/bluerov2/bluerov2/)
11) Vxfly “CCROV”, (https://www.ccrov.com/ccrov/en/ccrov.html)
12) ArduSub, (https://www.ardusub.com)

Summary of damage in 2018

— Trend of marine casualties and damage examples —

Research Institute, ClassNK

1. Introduction

This is a report of the summary of marine casualties in 2018 (1 January to 31 December) for ships registered with ClassNK (hereafter referred to as "registered ships"). And, as measures for strengthening regulations for SOx emissions and ballast water management system are being adopted, incidents of machinery damage estimated to be related to fuel oil and malfunction in ballast water management system are being reported. Such incidents of machinery damage are introduced here.

2. Marine casualties in 2018

2.1 Total loss casualties

One incident of total loss casualty was reported in registered ships in 2018. Table 1 shows an overview of casualties and types of ships in which total loss casualties occurred. The overview of casualties is mainly based on the information in the casualty information distribution service "Lloyd's List Intelligence Casualty Alert" (hereafter referred to as "LLI CA") mentioned later in this report.

Fig. 1 shows the changes in the number of registered ships that suffered total loss, and the gross tonnage of the total loss ships during the 10-year period from 2009 to 2018. The declining trend in the number of total loss casualties and gross tonnage has continued from 2015 to 2018. ClassNK is committed to bring the number of occurrences of total loss casualties to zero.

Table 1 Overview of total loss casualties of registered ships in 2018

Type of ship		Gross tonnage	Overview
Ship A	Asphalt tanker	999	After heeling to a large angle, the ship capsized. Subsequently, it sank. A naval ship in the vicinity that received the distress signal dispatched a helicopter and rescued all crew members near the capsized ship.

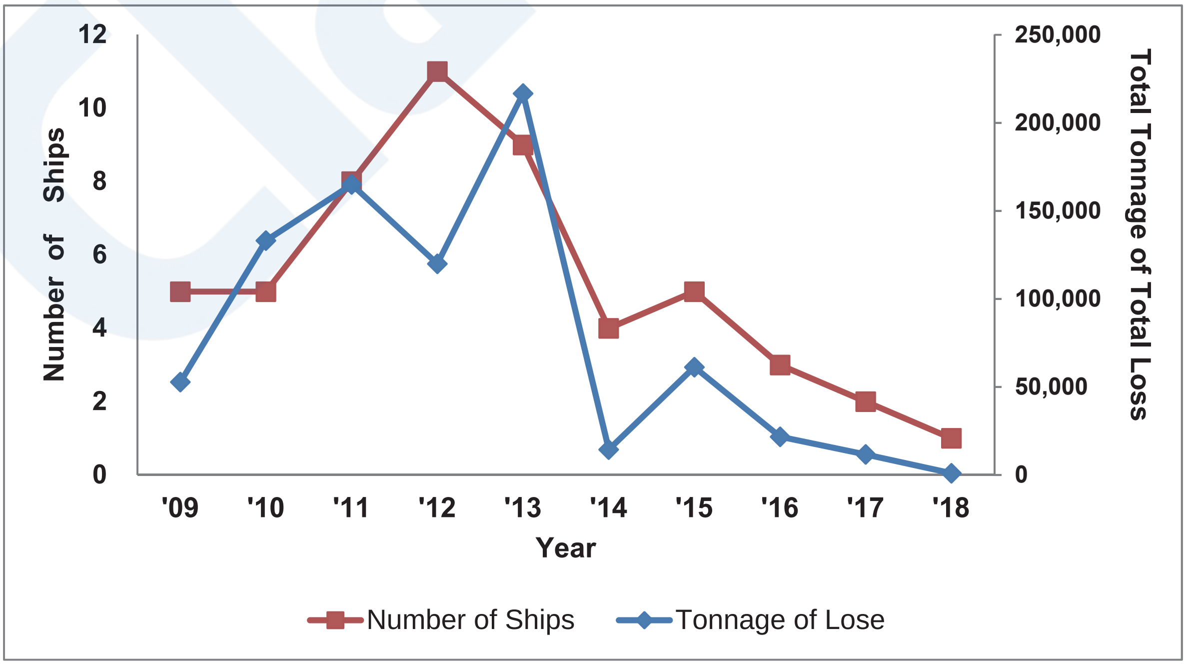

Fig. 1 Changes in the number of ships and total loss gross tonnage of total loss casualties by year

2.2 Overview of total loss casualties

ClassNK has been continuously collecting information on marine casualties of registered ships using the casualty information distribution service LLI CA. An overview of the marine casualties of registered ships reported in 2018 is given here.

The number of cases and the number of registered ships in which marine casualties occurred and which were reported in 2018 were 152 cases and 156 ships respectively, and this figure corresponds to about 1.7% of the total number of registered ships. Compared to the previous year, both the number of cases and number of ships in which marine casualties occurred have reduced by about 24%, and the trend shows a decline after 2015. The marine casualties referred to here, do not include detentions by Port State Control (PSC), damage due to piracy, and constraints of port or harbor authorities related to labor environment. Table 2 shows the causes of marine casualties of these 152 cases and 156 ships, divided into 8 cases. The results are shown in Table 2 and Fig. 2.

Table 2 Number of cases and number of registered ships in marine casualties in 2018 (Based on LLI CA)

	No. of ships	No. of cases of casualties
Collision, stranding and grounding	72	68
Engine problems	43	43
Fire and explosion	9	9
Steering system problems	1	1
Propulsion system problems	4	4
Holes and flooding	2	2
Cargo shift	4	4
Others	21	21
Total	156	152

Note: Since collisions between registered ships are included in “Collision, stranding and grounding,” the number of ships does not match the number of cases. “Engine problems” include problems in machinery equipment other than main diesel engine and auxiliary diesel engines.

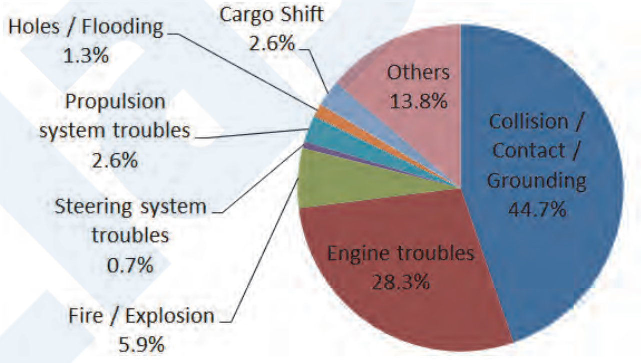

Table 2 Breakdown of causes of marine casualties of registered ships in 2018

Out of the causes of occurrences of marine casualties based on Table 2 and Fig. 2, “Collison, stranding and grounding” accounts for the maximum percentage, and is approximately 44.7% of the total casualties. “Engine problems” accounts for about 28.3%, and the percentages of these two categories account for about 70% of the total marine casualties. This trend is almost same as previous year. At least 27 of the 43 cases of “Engine problems” reported are main diesel engine problems, of which 7 cases are “Not Under Command” condition.

On the other hand, of the 152 cases of marine casualties reported, the percentages of casualties leading to accidents resulting in injury or death (such as fatalities and missing persons) and casualties leading to capsizing or sinking of the ship (major marine casualties) are shown in Table 3. Overview of “total loss” casualties from the major marine casualties is already given in Sec. 2.1. Marine casualties resulting in injury or death is summarized in Table 4.

Table 3 Percentages and number of cases of major marine casualties in registered ships in 2018

	No. of cases	Percentage of the total loss casualties (%)
Casualties resulting in injury or death	5	3.3
Total loss	1	0.7
Total	6	4.0

Table 4 Marine casualties resulting in injury or death

	Overview
Ship B	Ship collided with a fishing vessel. The fishing vessel sank, and 6 crew members were missing.
Ship C	Explosion and fire occurred in the cargo hold of the ship loaded with coal while underway. Later, the ship anchored. The fire was extinguished by the crew, but one person died, and one person was injured.
Ship D	The ship collided with another ship while navigating a river. The result was that the hull of the ship was damaged, and it sank. The Coast Guard rescued 9 persons from the capsized ship, but 3 persons were missing.
Ship E	While the ship was moored, one of the mooring ropes broke, and snapped back between dock and ship. Two of the workers died because of this accident.
Ship F	Ship collided with a fishing vessel and the fishing vessel capsized. Of the two crews on the fishing vessel, one was rescued, and one died.

From Table 4, it can be observed that most of the causes of cases related to accident resulting in injury or death from the marine casualties that occurred in 2018, are due to collision and fire. However, death due to breakage of mooring ropes has also been reported.

As mentioned above, marine casualties in ClassNK ships are on a declining trend from 2015 onward. Moreover, most of the causes of marine casualties are attributed to “collision, stranding, and grounding” and “engine problems”. ClassNK will continue to formulate provide the appropriate feedback and measures, to prevent the occurrence of marine casualties henceforth, based on the findings in this report.

3. Introducing damage example of ballast water management system and of machinery damage predicted to be related to fuel oil

3.1 Damage and malfunction in the ballast water management system

The International Convention for The Control and Management of Ship’s Ballast Water and Sediment, 2004” (Ballast Water Management Convention) entered into force in September 2017 and the ballast water management system (hereafter “BWMS”) is being installed on ships. This report introduces damage examples and damage rate of BWMS based on the survey reports issued during surveys by ClassNK from January 2017 to August 2019.

3.1.1 Breakdown of damaged BWMS by process

Table 5 shows the category of damaged BWMS by process discussed in this report. As shown in Fig. 3, the breakdown of damaged BWMS by process are 34% for combination of electrolysis and filter, 22% for combination of chemicals and filter, 22% for electrolysis alone, and 11% each for ozone system and for combination of UV and filter.

Table 5　Category of damaged BWMS by process

Electrolysis + Filter
Chemicals + Filter
UV + Filter
Electrolysis
Ozone

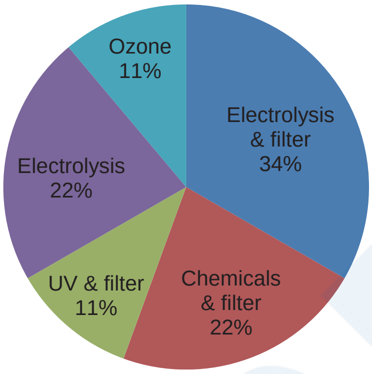

Fig. 3　Breakdown of damaged BWMS by process

3.1.2　Breakdown of damaged components for BWMS

Fig. 4 shows the breakdown of damaged components for BWMS.

The damage rate of components are 37% for electrical and control systems, 21% for main process unit and 20% for sensors. This figure shows that most of the damaged components is the electrical and control systems.

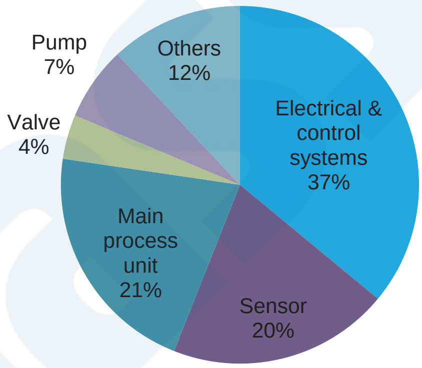

Fig. 4　Breakdown of damaged components

The main process unit means main parts of equipment and related equipment for handling of ballast water treatment as described below.

① Breakdown of damaged BWMS by main process unit

Fig. 5 shows the breakdown of damaged BWMS by main process unit. Each BWMS treated ballast water at main process unit. As shown in Table 5, some BWMS are composed combinations of multiple main process units. For this reason, Fig.5 is classified by each main process unit in case the BWMS has multiple process units. For instance, in case of BWMS using combination of chemicals and filter, the main process unit is classified into two main process units, the filter unit and the chemicals unit. As seen in Fig. 5, damage to main process unit has been reported in all type of units except the ozone unit.

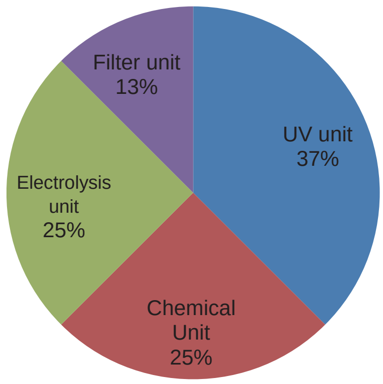

Fig. 5　Breakdown of damaged main process unit

② Breakdown of damaged parts in electrical and control systems

Fig. 6 shows the breakdown of damaged parts in the electrical and control systems. In particular, damage to control parts accounts for the majority of this figure, 74%. When seen together with Fig. 4, it is evident that the majority of damaged parts is controller among the overall damaged parts of BWMS.

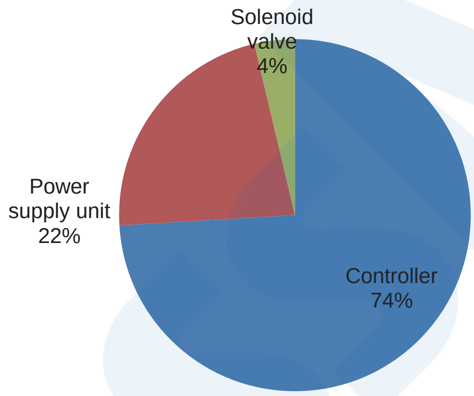

Fig. 6　Breakdown of damaged parts in the electrical and control systems

3.1.3 Damage example of BWMS

Two damage example and malfunction of BWMS are introduced in this section.

① Explosion of chemicals storage tank in chemical process unit due to backflow of supply water

Several ships have reported explosion of the chemical unit of BWMS having a combination of chemicals and filter process unit.

As shown in fig. 7, the chemical unit composes of chemical storage tank, mixing tank, flesh water level switch and flesh water supply valve. This chemical unit provides chemical from the chemical storage tank via a chemical supply valve and supplies fresh water through a fresh water supply valve into the mixing tank. The mixing tank is provided with a float-type fresh water level switch. Flow rate of fresh water is controlled by this fresh water level switch when fresh water is supplied to the mixing tank. Mixed chemicals and fresh water in mixing rank is injected to ballast water.

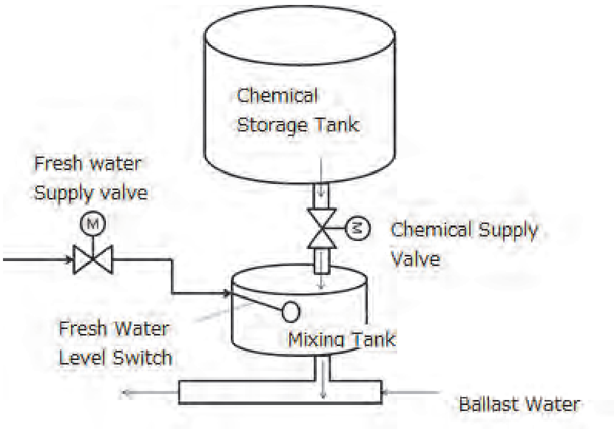

Fig. 7 Outline of chemical unit

Photo 1 Burn-out of chemicals storage tank

Photo 2 Upper part of burned-out chemicals storage tank

Burn-out of chemicals storage tank (Photos 1 and 2) and deformation of internal part of fresh-water level switch (Photo 3) were reported. The damage occurred as described below. The fresh water level switch seized due to deformation of its internal part and could not control the flow rate of supplied fresh water into the mixing tank. For this reason, fresh water continued to be supplied to the mixing tank. As a result, the water level in the mixing tank increased and the fresh water in the mixing tank flowed back into the chemicals storage tank. The chemicals used in this system are known to generate heat during dissolution and further generate gases at high temperatures. The chemicals reacted with flowed back water in the chemicals storage tank. Finally, explosion occurred in the chemicals storage tank.

As a preventive measure, an overflow pipe was additionally installed in the mixing tank to prevent the backflow of fresh water into the chemicals storage tank.

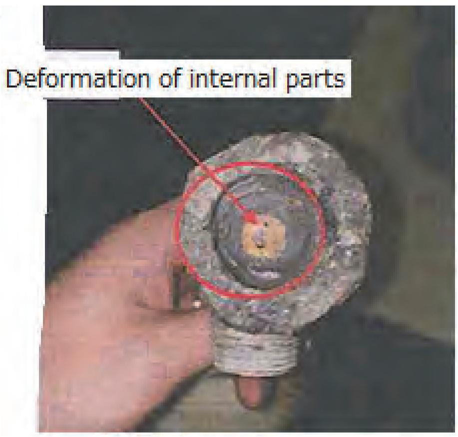

Photo 3 Fresh-water level switch with deformed internal part

② Malfunction due to lack of understanding of how to use of BWMS

Although mechanical parts to BWMS by itself were not damaged, several ships have reported malfunction of BWMS. Examples of malfunctions are for displayed error and could not be re-started of BWMS. The cause of most case is that the users are not familiar with its usage. Other examples of malfunctions were inadequate calibration of sensors, not performing of alarm reset and unknown of the alarm reset method.

3.1.4 Conclusions

Damage examples of BWMS have been introduced based on the survey reports by the Society over a period of two and a half years from 2017 to the first half of 2019.

BWMS is a newly installed system based on Convention requirements. Users are expected to be familiar with its usage before operating it. On the other hands, further improvements of BWMS system are expected to prevent and to mitigate damage.

3.2 Machinery damage and malfunction due to fuel oil

The number of survey reports issued by the Society related to damage and presumed to be caused by fuel oil has been increasing. This report introduces breakdown of machinery damage and damage examples of machinery due to fuel oil based on survey reports issued from 2018 to August 2019.

3.2.1 Breakdown of damaged machinery and components

Fig 8 shows the breakdown of damaged machinery due to fuel oil. The damage rate is 74% for diesel engines used for main propulsion (hereafter “main diesel engine”), followed by 22% for diesel engines for generators (hereafter “generator diesel engine”). Damage and malfunctions have also been reported in auxiliary boiler and other auxiliary equipment (purifiers, filters, etc.).

When damage and malfunctions of the main diesel engine were found, most cases were reported that many main diesel engines were automatically reduced the speed or emergency stopped in ECA. In many cases, this condition was reported to Port State Control (PSC) and the surveyor carried out classification survey to confirm the condition of ships and the main diesel engine. That is why number of damaged and malfunctioned reports for main diesel engine was increasing recently.

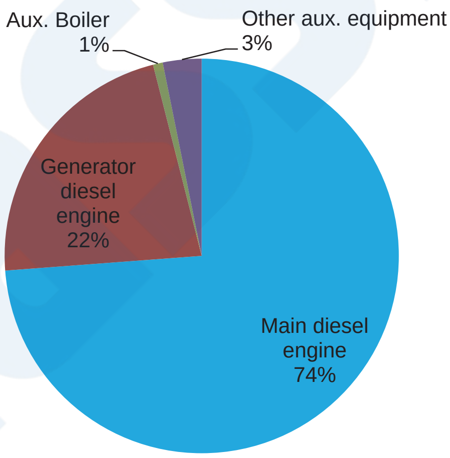

Fig. 8 Breakdown of damaged machinery

Diesel engines (main diesel engines and generator diesel engines) account for a large number in damaged machinery.Fig.9 shows the breakdown of damaged components of diesel engines. The damage rate are 37% for fuel injection system, and 30% for piston, followed by 13% for cylinder liner. The sum of the damage rate in fuel injection system, piston and cylinder liner is 80% of the overall damage in the diesel engines.

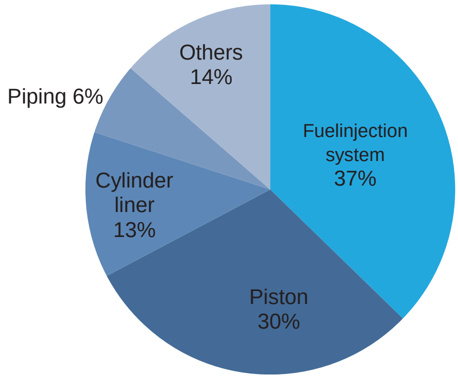

Fig. 9 Breakdown of damaged components of diesel engines

3.2.2 Breakdown of damaged parts of fuel injection system in diesel engines

Fig. 10 shows the breakdown of damaged parts of the fuel injection system, which accounts for 37% of the overall damage to diesel engines in Fig. 9.

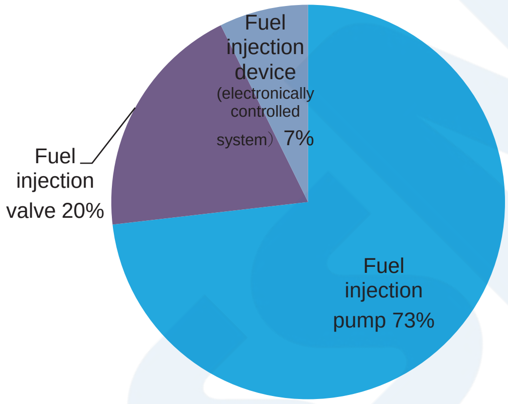

Fig. 10 Breakdown of damaged parts of the fuel injection system in diesel engines

Fig. 10 shows that the fuel injection pump is for 73% in the damaged parts of the fuel injection system. For electronically controlled diesel engine used for main propulsion (hereafter "electronically controlled diesel engine") which is increasingly being installed on ships in recent years, the damaged fuel injection device which is a specialized part of electronically controlled diesel engine is for 7 %. Common parts as fuel injection valves, etc. in electronically controlled diesel engines and conventional diesel engines (diesel engine with cam) are not included in the category of "fuel injection device (electronically controlled system)" in Fig. 10.

The breakdown of type of damage for each parts Fig. 10, are shown in Figures 11 to 13.

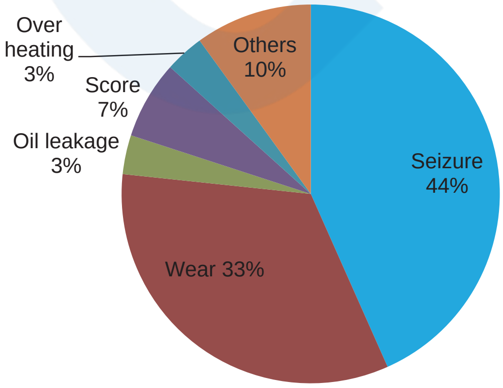

Fig. 11 Breakdown of type of damage for fuel injection pump

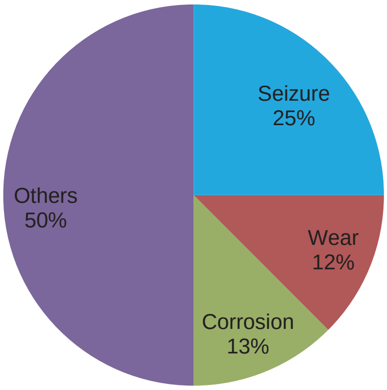

Fig. 12 Breakdown of type of damage for fuel injection valve

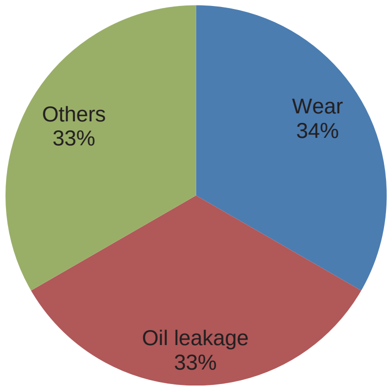

Fig. 13 Breakdown of type of damage for fuel injection device (electronically controlled system)

Wear has been reported as common damage in fuel injection pump (33%), fuel injection valve (12%) and fuel injection device of electronically controlled system (34%). For fuel injection pumps, damage rate due to wear and seizure together account for 77%, while fuel injection valves has been reported corrosion (13%) in addition to wear (12%) and seizure(25%). Fig 13 shows that a large number of oil leakage (33%) has been reported in addition to wear (34%) from fuel injection devices (electronically controlled system).

3.2.3 Breakdown of damaged parts of piston and cylinder liner in diesel engines

Fig. 14 shows the breakdown of damaged parts of piston in diesel engines.

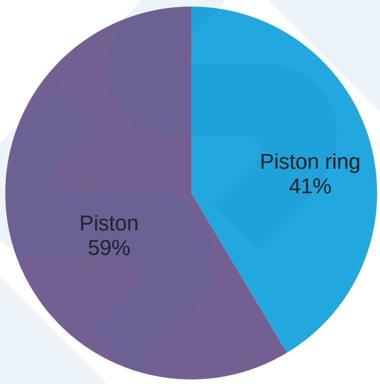

Fig. 14 Breakdown of damaged parts of piston

As shown in fig 14, damage to piston ring and piston has been reported. In this report, the piston includes piston crown, piston skirt and ring groove. Fig. 15 and Fig. 16 show the breakdown of type of damage for piston and piston ring.

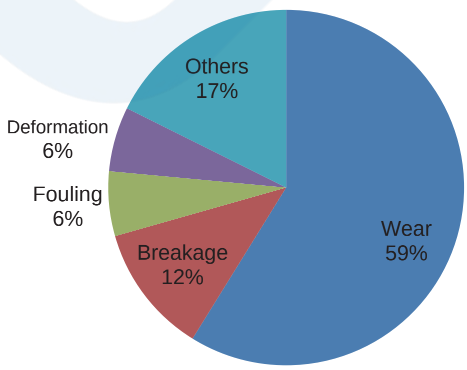

Fig. 15 Breakdown of type of damage for piston

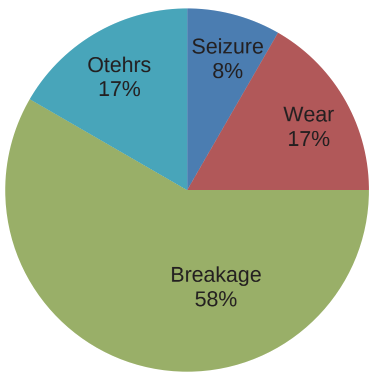

Fig. 16 Breakdown of type of damage for piston ring

As shown in Fig. 15, wear as type of damage for the piston accounts for more than half of the overall damage (59%). Most wear has been found at the piston groove, however, wear of the piston skirt is also included as piston in this figure. Breakage and deformation of ring land of piston, fouling of the fire side and side of the piston crown have also been reported.

With regard to type of damage for piston ring shown in Fig. 16, breakage (58%), wear (17%), and seizure (8%) have been reported.

Fig. 17 shows the breakdown of type of damage for cylinder liner. The wear accounts for half of the overall damage to cylinder liner (50%). The damage rate of wear of cylinder line is mostly same as piston. In particular, crack of the cylinder liner has also been reported as 22%.

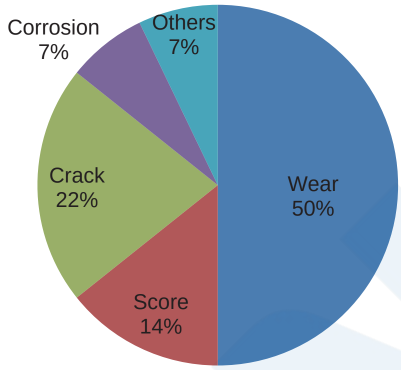

Fig. 17　Breakdown of type of damage for cylinder liner

3.2.4　Breakdown of damaged parts of the piping system

Fig. 18 shows the breakdown of damaged parts of piping system. It can be observed that fouling and clogging of FO filter or purifier account for 71%, fouling of piping on diesel engines and piping in the engine room account for 29%.

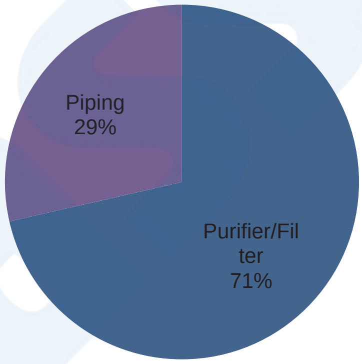

Fig. 18　Breakdown of damaged parts of the piping system

3.2.5　Breakdown of other damaged components

Breakdown of diesel engines and piping systems were introduced in Sections 3.2.2 to 3.2.4. In particularly, this section introduces the breakdown of secondary damage due to fuel oil and malfunction due to improper fuel oil handling.

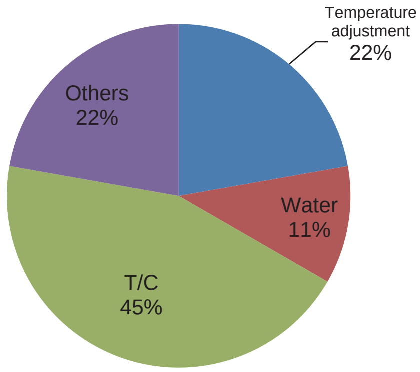

Fig. 19 Breakdown of secondary damage due to fuel oil and malfunction due to improper handling of fuel oil

Fig. 19 shows the damage rate of turbocharger as secondary damage and the malfunction due to improper handling of fuel oil.

Although no machinery damage was reported, malfunction occurred due to improper handling of fuel oil is for 33%. Malfunction due to the handling of fuel oil includes error in temperature adjustment at 22%, and improper separation of water in fuel oil at 11%. These malfunctions could have been prevented if the handling of fuel oil had been performed properly.

Secondary damage to turbocharger is for 45% in Fig 19. For the example of secondary damage to turbocharger, piston ring on diesel engine was broken caused by fuel oil and broken pieces of piston ring coming in contact with turbine blade and nozzle have been reported a lot.

In the category “Others” accounting for 22% in Fig.19, damage to lubrication parts of trunk-piston typed diesel engines due to cat-fines in fuel oil is included.

3.2.6 Damage examples due to fuel oil

Four damage examples caused by fuel oil are introduced in this section.

① Seizure of fuel injection pump due to ULSFO

Ultra-low sulfur fuel oil (fuel oil compliant with 0.1% sulfur limits, hereafter “ULSFO”) is being used in ships plying in sea areas specified as ECA. Much damage to the fuel injection pump has been reported in ships during sailing in the North American, Canadian coasts and the Caribbean Sea with ULSFO. One example is introduced below.

When the main diesel engine was tried to increase the speed after fuel oil was changed over to ULSFO, the exhaust gas temperature of main diesel engine was dropped and knocking sound occurred from main diesel engine. Finally, the main diesel engine could not be increased at starting speed.

When the main diesel engine was inspected, some seizure of the plunger and barrel of the No. 3 fuel injection pump were found (see Photo 4).

Photo 4　Seizure of plunger and barrel

In generally, the kinematic viscosity of ULSFO is low and it is well known that lubricity decreases at lowering kinematic viscosity. The cause of damaged fuel injection pump shown in Photo 4 is low lubricity with the decrease in the kinematic viscosity of ULSFO, resulting in seizure of the sliding parts, plunger and barrel of fuel pump.

②　Malfunctioned fuel injection control device in electronically controlled diesel engine

Malfunction caused by fuel oil have been reported in the fuel injection control device (see Photo 5) for controlling injection volume and injection timing of fuel.

During changeover of fuel oil to ULSFO and supply to electronically controlled diesel engine, alarm for fuel injection control device and pre-warning for automatic slow down of main diesel engine were activated. After overhauling all fuel injection control devices and cleaning all fuel injection valves, the electronically controlled diesel engine tried to start again. But alarm for the fuel rail low pressure was activated and the main engine could not be started. The cause of this malfunction is because ULSFO excessively leaked from the control valve on the fuel injection control device and the fuel pressure in fuel rail could not hold sufficient pressure.

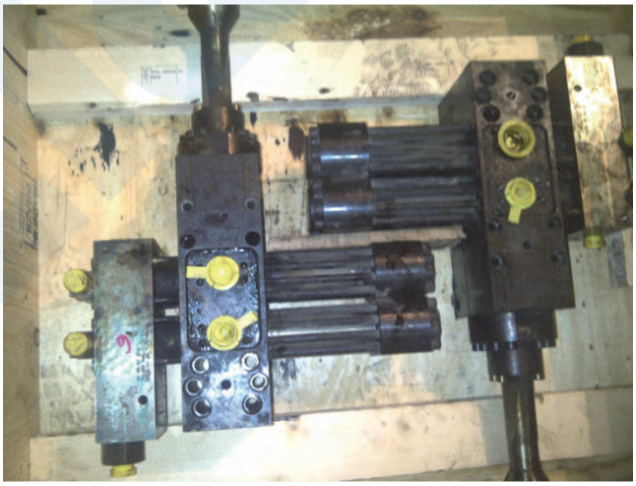

Photo 5　Fuel injection control device from which fuel oil leaked

In case the fuel injection device was used until the maintenance date recommended by the manufacturer and maintenance of the fuel injection device has not been performed properly, sliding parts of fuel injection control device has severely worm and oil leakage from the fuel injection control device tends to increase excessively. Oil leakage from injection control device has been reported a lot at the usage of ULSFO.

The engine manufacturer has issued service reports. These reports should be adhered to and the user should take an appropriate action for fuel injection control device when ULSFO is used.

③ Malfunction of main diesel engine due to improper handling of ULSFO

Generally, the kinematic viscosity of ULSFO is low. When ULSFO is used on ships, its viscosity has to be adjusted to an appropriate value for main diesel engine or generator diesel engine by controlling the ULSFO temperature appropriately. For this reason, installation of cooling equipment for ULSFO (called “ULSFO cooler” hereafter) was increased in recent years.

Some malfunctioned examples are introduced due to improper handling of ULSFO cooler.

When main diesel engine has been tried to start using ULSFO which was controlling the temperature by ULSFO cooler, the main diesel engine could not start. The cause of this malfunction was because fuel oil before the changeover ULSFO was had remained in the ULSFO cooler and pipes, and the appropriated cooled ULSFO could not be supplied to the main engine. After the ULSFO cooler and connected pipes were flushed by appropriate cooled ULSFO, the main diesel engine could start.

For other malfunctioned example, it was reported that the main diesel engine with ULSFO has slow down suddenly without no alarm. On investigation shows that the ULSFO in fuel oil tank found to be included 0.45% water and the fuel oil purifier have not operated during running the main diesel engine. The cause of this malfunction was that ULSFO without proper removed water had been supplied to the main diesel engine because the fuel oil purifier stopped working.

④ Damaged lubrication part of generator diesel engine due to cat-fines in the fuel oil

In this case, LO low level alarms activated frequently in multiple general diesel engines. It was found that the cylinder liners, journal bearings, crank journals and camshaft bearings of the generator diesel engines had suffered abnormal wear. Analysis result of LO used in the generator diesel engines showed the presence of cat-fines (Al+Si). The density of cat-fines in LO was higher than one in supplied fuel oil.

The damaged generator diesel engines were trunk-piston type. The type of diesel engine is not separated between the combustion chamber and crankcase by stuffing box in contrast to crosshead type diesel engine. For this reason, combustion residues and unburnt fuel oil injected into the combustion chamber dropped off into the sump tank which is located below the crankcase. The dropped combustion residues and unburnt fuel oil were mixed into the LO in the sump tank. The LO mixed with combustion residues and unburnt fuel oil was supplied to lubricating parts as the journal bearings, crankpin bearings, camshaft bearings, fuel injection pump, gears and the turbocharger by the LO pump which attached to the generator diesel engine. In other words, the cat-fines in the fuel oil have been supplied to bearing parts with LO. As the result, not only the parts of the combustion chamber such as cylinder liners, pistons, piston rings but also LO supplied parts were damaged by the cat-fines in the fuel oil.

3.2.7 Conclusions

Example of machinery damage related to fuel oil has been introduced based on the survey reports by the Society over approximately a one-and-a-half-year period from 2018 to the first half of 2019.

Regulation limited the sulfur content of marine fuels for ships (the so-called SOx emission regulations) will be strengthened from January 2020. The properties of complied fuel oil to regulation (hereafter “compliant fuel”) will be varied than that of the current fuel oil. In this regards, machinery damage and malfunction have a possibility to occur at the use of compliant fuel also. However, proper handling of compliant fuel and proper use of pre-treatment systems will be able to prevent and mitigate machinery damage and malfunction.

ClassNK has issued the “Guidelines for the use of fuel oil compliant with SOx emission regulations from 2020” in the spring of 2019. This guideline summarized for safe use of compliant fuel and its properties. Please refer to this guideline also.

4. Conclusions

Marine casualties in 2018, damage and malfunctions in ballast water management system and machinery due to fuel oil have been introduced in this report. The authors will be obliged if these damage information serves, even to just a slight degree, as reference for the design, construction, operation, maintenance and management of ships.

ClassNK will make more effort to reduce marine casualties and damage through effective and appropriate feedback of damage information on registered ships, such as the information introduced in this report.

Study on Design Loads for Fatigue Strength Assessments Using Automatic Identification System (AIS) Data

Norio YAMAMOTO*, Tomohiro SUGIMOTO* and Kinya ISHIBASHI*

1. INTRODUCTION

In order to accurately assess the fatigue strength of a hull structure, it is essential to have a good understanding of the cyclic loads acting upon it. Moreover, more rational fatigue strength assessments of the hull structures of a ship in line with the actual situation can be made by taking into account the specific route in which the ship is intended to navigate throughout its service life because cyclic loads are deeply related to the wave environment where ships navigate.

International Association of Classification Societies (IACS), on the other hand, has specified in its “Common Structural Rules for Bulk Carriers and Oil Tankers” (CSR-BC&OT) [1] that loads corresponding to the wave conditions experienced in the North Atlantic are to be used as the design loads for fatigue strength assessments. These loads include safety margins for various uncertain factors related to fatigue evaluation including the uncertain factor for the actual navigating routes. Therefore, if the uncertain factors are reduced by improving the fatigue evaluation techniques, an excessive safety margin is given.

Up until recently, indirect information obtained from trade statistics and interview with ship owners has been used to identify the operating routes of ships. However, almost all ships are now required by recent amendments made to the International Convention for the Safety of Life at Sea [2] to be installed with Automatic Identification Systems (AIS), thus making available a new source of data about ship navigation to help better understand the actual operating routes of ships through AIS data analysis [3)-7)].

This paper presents the results of analysis of big data obtained by AIS from 24,349 ships during over a period of two years and ten months beginning in January 2015 and ending in October 2017. Data were collected and analysed in order to identify the standard operating route for each ship, and wave scatter tables corresponding to each standard operating route were then derived using the wave scatter tables of each sea area specified in the Global Wave Statistics (GWS) of the British Maritime Technology (BMT) [8]. Using such a wave scatter table for each standard operating route, long-term predictions of stress ranges can be obtained, which in turn makes possible more realistic fatigue strength assessments. A simple load modification factor for converting loads based on North Atlantic route into those based on standard operating routes was examined because loads based on the North Atlantic wave environment is usually used as the design loads in the ship design fields.

IACS CSR-BC&OT specifies that the operating ratio of ships is 0.85. This operating ratio is used when calculating the number of cycles needed for fatigue strength assessments. In this paper, the authors have used their analysis of AIS data to obtain the operating ratio based upon actual ship navigation.

2. AUTOMATIC IDENTIFICATION SYSTEM (AIS) DATA

AIS automatically provides appropriately equipped shore stations, other ships and aircraft with information about a particular ship, including its identity, type, position, course, speed, navigational status and other safety-related information. The provision of AIS on ships was made mandatory by an amendment to Chapter V of SOLAS for the following ships whose construction contracts are dated on or after 1 July 2002 (existing ships were given from 1 July 2002 until 1 July 2008 to have an AIS installed on board according to their respective type and size):

- all ships of 300 gross tonnage and upwards engaged on international voyages;
- all cargo ships of 500 tonnage and upwards not engaged on international voyages; and
- all passenger ships irrespective of size.

* Hull Rules Development Department, ClassNK

3. IDENTIFICATION OF STANDARD OPERATING ROUTE

The 24,349 ships used in this paper were classified according to ship type and size as shown in Table 1 because operating routes are generally categorised by cargo type, cargo loading/unloading location and ship size. The reasons why ship size was used is because it, especially ship breadth, determines whether a ship can navigate major canals, and large ships tend to engage in transportation using particular routes based on long-term contracts; while small ships tend to engage in transportation using various routes based on spot contracts. The standard operating route for each ship was identified through analysis according to the following (1) to (4):

(1) If a ship navigates at speed not greater than 1 m/sec, ship speed is regarded as zero and the ship is judged to be stopping (i.e., at anchor).

(2) Ship track, distance and navigation time were calculated for unit navigation which is defined as the period between the point where ship speed is zero and the next point where ship speed is zero. Total of navigation time for the sea areas defined in the BMT GWS shown in Figure 1 was calculated for each ship type.

(3) Relative frequency of navigating time for each sea area per ship type was calculated by standardising the navigating time for each area by using the total navigation time for each ship type. Then the standard operating route was obtained.

(4) In addition, the sea areas with very low relative frequencies were eliminated in order to clearly identify the standard operating route.

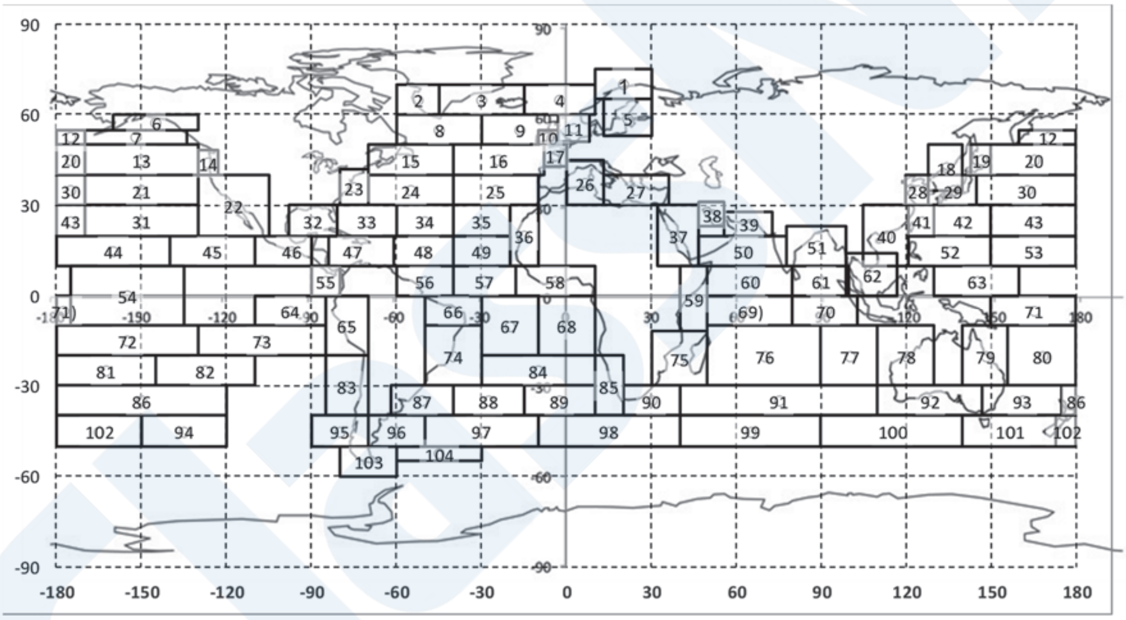

Figure 1　Sea areas defined in the BMT GWS (2000)

Table 1 Ship classification and number
(Bulk carriers, container ships and oil tankers are classified by size)

Ships	classification	number	Size
Bulk	Baby, Handy	2974	DWT<50,000
Carrier (BC)	Handymax	2171	DWT<65,000
	Panamax, Overpanamax	1442	DWT<130,000
	Capesize	1452	130,000≦DWT
Chemical tanker		2538	
Container ship (CT)	Feeder	2793	TEU<4000
	Panamax	935	TEU<6000
	Over panamax	829	TEU<12,000
	Mega	358	12,000≦TEU
General cargo ship		598	
LNG carrier		399	
LPG carrier		778	
Multipurpose ship		2229	
Oil	Small, Middle Range	1863	DET<60,000
Tanker (OT)	Large Range, Aframax	644	DWT<120,000
	Suezmax	516	DWT<170,000
	VLCC, ULCC	715	170,000≦DWT
Ore carrier		237	
Reefer		26	
Vehicle carrier		733	
Wood chip carrier		119	

4. STANDARD OPERATING ROUTE OF VERY LARGE CRUDE OIL CARRIERS

The results of an examination of Very Large Crude Oil Carriers (VLCCs) are presented in this paper as an example. Ship track data obtained from AIS data are plotted on the world map shown in Figure 2 and relative frequency of the navigating time corresponding to each sea area of the BMT GWS is shown in Table 2. Sea area 105 is the total area where wave scatter table is not provided in BMT GWS. Therefore, Sea area 105 is excluded when identifying the standard operating route. For the purpose of comparing the operating routes between different sizes of oil tankers, the world map on which AIS data of large range (LR) oil tankers and Aframax oil tankers are plotted is shown in Figure 3. Analysis of AIS data shows LR and Aframax oil tankers navigate the North Atlantic route in a higher frequency than VLCC. Moreover, this analysis shows that the service routes for LR and Aframax oil tankers are typically more varied than those of VLCCs. This result corresponds to the fact that VLCCs tend to navigate the specific route based on long-term contracts and LR and Aframax oil tankers tend not to navigate the various routes based on spot contracts.

The standard operating route of VLCCs is shown in Figure 4 by contours. The contour colours of Figure 4 depend upon the value of relative frequency of navigation time. The highest relative frequency of navigation time for VLCCs was Sea Area 61 (the sea area in Indian Ocean between Indonesia and India). VLCCs navigated within this sea area for about 12.19% in total of the data measurement period of two years and ten months. In comparison, the relative frequency of navigation time for VLCCs in the North Atlantic sea areas (Sea Areas 8, 9, 15 and 16) was only 0.36 %.

Wave scatter table corresponding to the standard operating route were then calculated from the expected values for wave scattering of each sea area obtained from the BMT GWS using each relative frequency rate of navigation time shown in Table 2.

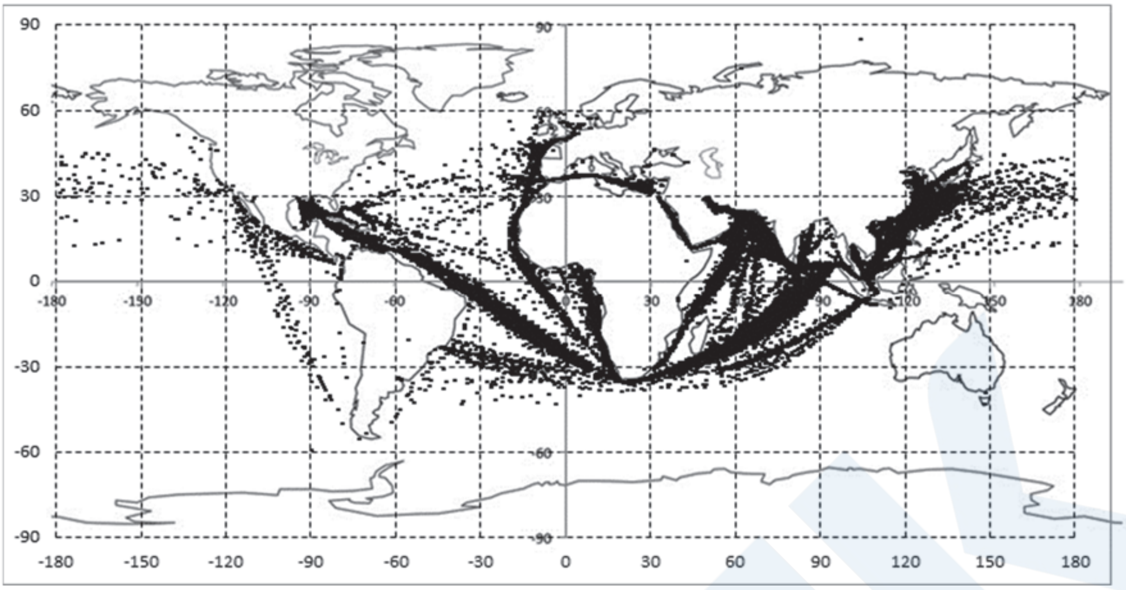

Figure 2　World map of plotted AIS data of VLCCs

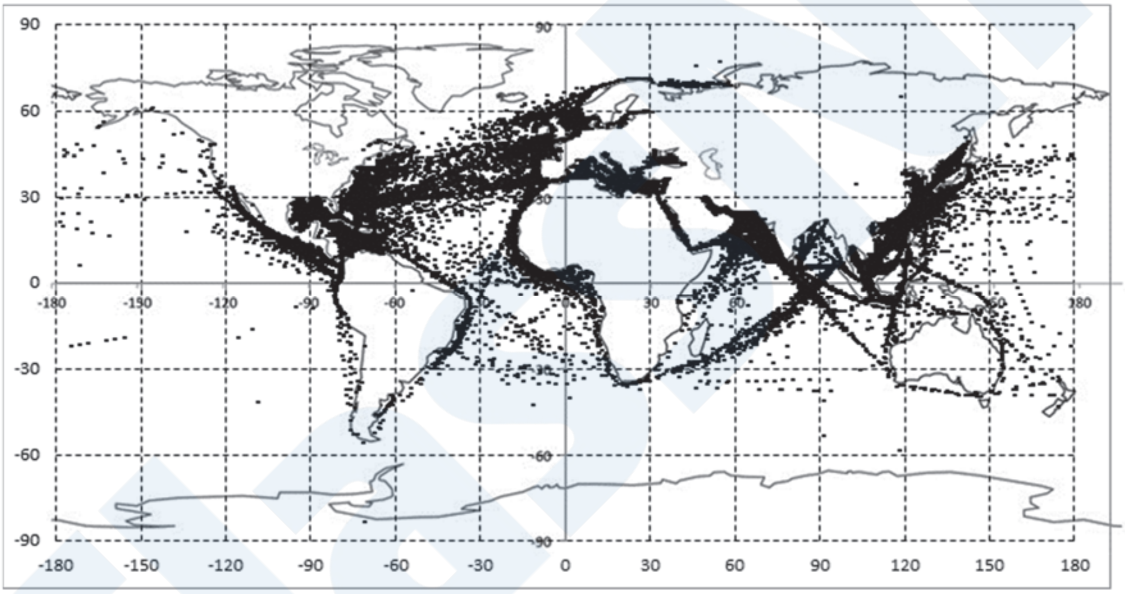

Figure 3　World map of plotted AIS data of LR and Aframax oil tankers

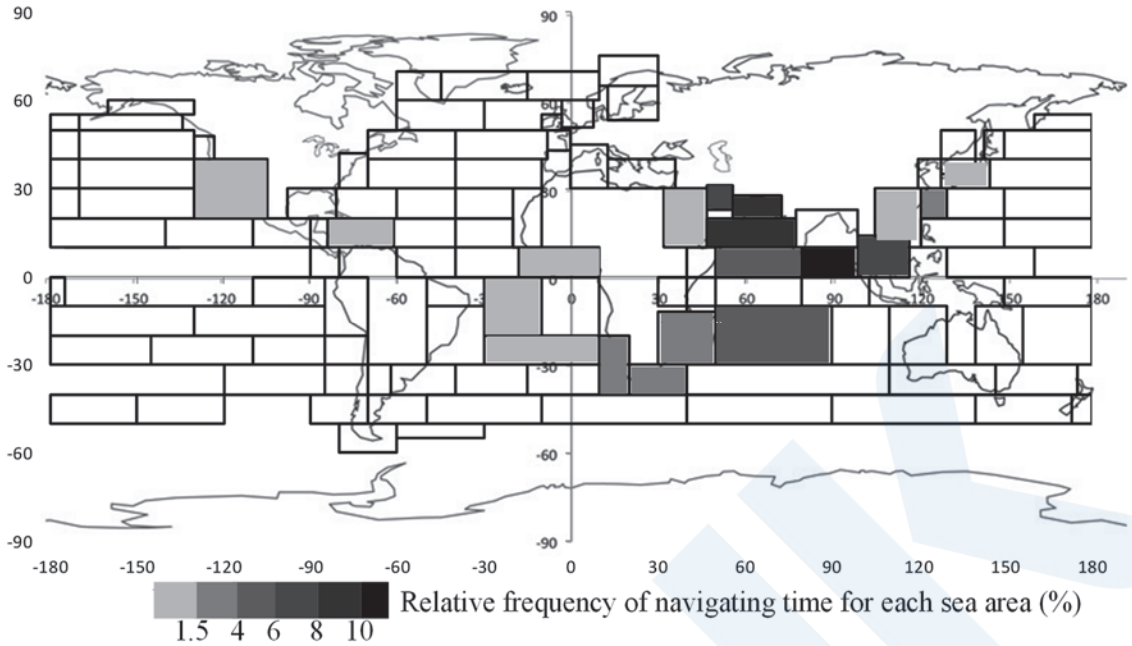

Figure 4 Standard operating route of VLCCs classified in BMT GWS sea areas

Table 2 Relative frequency of navigation time corresponding to each sea area specified in the BMT GWS (%) for VLCCs

Area	Frequency	Area	Frequency	Area	Frequency	Area	Frequency
1	0.00	28	1.43	55	0.11	82	0.00
2	0.00	29	1.78	56	1.18	83	0.05
3	0.00	30	0.29	57	0.27	84	1.66
4	0.00	31	0.09	58	1.63	85	3.13
5	0.01	32	0.87	59	0.48	86	0.00
6	0.12	33	0.35	60	4.77	87	0.36
7	0.15	34	0.12	61	12.19	88	0.16
8	0.00	35	0.05	62	6.86	89	0.50
9	0.01	36	0.49	63	0.02	90	3.54
10	0.02	37	1.62	64	0.05	91	0.46
11	0.24	38	6.01	65	0.01	92	0.00
12	0.00	39	9.39	66	0.75	93	0.00
13	0.13	40	1.85	67	1.59	94	0.00
14	0.25	41	2.90	68	1.43	95	0.06
15	0.04	42	0.31	69	1.06	96	0.06
16	0.31	43	0.13	70	1.28	97	0.03
17	0.24	44	0.10	71	0.00	98	0.02
18	0.01	45	0.07	72	0.00	99	0.00
19	0.03	46	0.19	73	0.05	100	0.00
20	0.08	47	1.67	74	1.15	101	0.00
21	0.33	48	0.49	75	2.52	102	0.00
22	1.66	49	0.08	76	4.63	103	0.09
23	0.01	50	8.87	77	0.21	104	0.01
24	0.19	51	0.23	78	0.27	105	2.30
25	0.82	52	0.08	79	0.00		
26	0.29	53	0.05	80	0.00		
27	0.60	54	0.00	81	0.00		

5. WAVE SCATTER TABLE FOR STANDARD OPERATING ROUTE OF VLCCs

A wave scatter table corresponding to the standard operating route of VLCCs can be obtained as shown in Table 3 by taking into account the relative frequency of each sea area of the standard operating route obtained as Figure 4, and the all-year wave scatter tables of the BMT GWS. This table shows the wave frequency for each significant wave height (H_S) and each zero-up-crossing wave period (T_Z).

Table 3 Wave scatter table for the standard operating route of VLCCs

		Hs															
		1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5
Tz	0.5	0	5	1219	9710	9789	3856	1071	232	40	6	1	0	0	0	0	0
	1.5	0	2	491	5651	11348	9547	5114	1955	556	124	23	4	0	0	0	0
	2.5	0	1	128	1662	4589	5763	4695	2709	1126	351	87	18	3	1	0	0
	3.5	0	0	36	481	1540	2349	2456	1898	1053	427	134	34	7	1	0	0
	4.5	0	0	10	141	499	833	996	947	659	329	123	37	9	2	0	0
	5.5	0	0	3	42	165	289	363	393	325	192	83	28	8	2	0	0
	6.5	0	0	1	13	56	103	129	149	139	94	46	17	5	1	0	0
	7.5	0	0	0	4	20	38	47	54	55	41	22	9	3	1	0	0
	8.5	0	0	0	1	7	14	17	19	21	17	10	4	1	0	0	0
	9.5	0	0	0	1	3	6	7	7	8	7	4	2	1	0	0	0
	10.5	0	0	0	0	1	2	3	3	3	3	2	1	0	0	0	0
	11.5	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0
	12.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

6. DESIGN LOAD CONCEPT USED IN THE FATIGUE STRENGTH ASESSMENTS OF SHIPS

Although fatigue strength can be assessed through a spectrum fatigue strength assessment which uses a wave scatter table and the response amplitude operator (RAO) of stress, classification society rules, including the IACS CSR-BC&OT, specify a fatigue strength assessment method using design loads which are set in advance for the sake of design efficiency.

More specifically, the long-term distributions of stress ranges obtained through approximation using a Weibull distribution whose shape parameter is one (i.e., an exponential distribution) with a 10^{-2} reference exceedance probability of loads in the North Atlantic wave environment are used for fatigue strength assessment. (the 10^{-2} reference probability of exceedance was selected because cumulative fatigue damage is mostly decided up to an exceedance probability of 10^{-2} and the Weibull shape parameter has almost no effect on cumulative fatigue damage in cases where an exceedance probability of 10^{-2} is used.[9)]) Therefore, design loads for fatigue strength assessment based upon the standard operating route can be easily set by incorporating a factor to modify the design loads of exceedance probability of 10^{-2} corresponding to North Atlantic route to one corresponding to the standard operating route.

7. DERIVATION OF LOAD MODIFICATION FACTOR

A modification factor for design loads (load modification factor) was developed by using wave scatter tables corresponding to standard operating route obtained as table 3 and corresponding to the North Atlantic route specified in the IACS Rec. No. 34[10)]. A wave scatter table for the North Atlantic route which was obtained by expanding the wave scatter tables of Sea Areas 8, 9, 15 and 16 indicated in Figure 1 is shown in Table 4.

The load modification factors were calculated using three different methods, which are based on RAO of stress (examination 1), RAO of each load component (examination 2) and significant wave height (examination 3), and the results were then compared to each other. Modification factor according to examination 1 and 2 are obtained in accordance with the formulae specified in APPENDIX. A VLCC (about 260,000 DWT) was used as the target of the examinations 1 and 2. The Pierson-Moskowitz spectrum recommended by ISSC 1964 was used for short-term prediction and all heading values of the long-term prediction were considered.

Table 4 Wave scatter table of North Atlantic wave environment specified in the IACS Rec. No.34

		Hs															
		3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5
Tz	0.5	1	134	866	1186	634	186	37	6	1	0	0	0	0	0	0	0
	1.5	0	29	986	4976	7738	5570	2376	704	161	31	5	1	0	0	0	0
	2.5	0	2	198	2159	6230	7450	4860	2066	645	160	34	6	1	0	0	0
	3.5	0	0	35	696	3227	5675	5099	2838	1114	338	84	18	4	1	0	0
	4.5	0	0	6	196	1354	3289	3858	2686	1275	455	131	32	7	1	0	0
	5.5	0	0	1	51	498	1603	2373	2008	1126	464	151	41	10	2	0	0
	6.5	0	0	0	13	167	690	1258	1269	826	387	141	42	11	3	1	0
	7.5	0	0	0	3	52	270	594	703	525	277	112	37	10	3	1	0
	8.5	0	0	0	1	15	98	256	351	297	175	78	28	8	2	1	0
	9.5	0	0	0	0	4	33	102	160	152	99	48	19	6	2	0	0
	10.5	0	0	0	0	1	11	38	68	72	52	27	11	4	1	0	0
	11.5	0	0	0	0	0	3	13	27	31	25	14	6	2	1	0	0
	12.5	0	0	0	0	0	1	4	10	13	11	7	3	1	0	0	0
	13.5	0	0	0	0	0	0	1	4	5	5	3	2	1	0	0	0
	14.5	0	0	0	0	0	0	0	1	2	2	1	1	0	0	0	0
	15.5	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
	16.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

7.1 MODIFICATION FACTOR DERIVED FROM RAO OF STRESS (EXAMINATION 1)

The RAO of stresses occurring at connections of the inner bottom plate, hopper plate and floor at the midpoint of the midship hold of a VLCC was obtained through load and structural consistent analysis[11)] with 5knot ship speed. The RAOs of stresses in the transverse direction were used because this stress is dominant to the fatigue strength of this position.

Each fatigue damage was calculated from the short-term distribution of the stress range and the wave scatter table corresponding to the standard operating route or the North Atlantic route, and the ratio of each fatigue damage was used to derive the fatigue damage modification factor η_D. The load modification factor η was obtained by taking the cubic root of η_D. The results are shown in Table 5.

Table 5 Result of examination 1

Location	η_D	η
Inner Bottom Plate at midship (Connection of Hopper plate and Floor)	0.193	0.578

where, η_D : fatigue damage modification factor, η : load modification factor

7.2 MODIFICATION FACTOR DERIVED FROM RAO OF EACH LOAD COMPONENT (EXAMINATION 2)

The RAO and phase angle of each load component (the hull girder vertical bending moment, hull girder horizontal bending moment, external hydrodynamic pressure, accelerations in *x*, *y* and *z* directions at the center of gravity of each tank) obtained from a direct load analysis with strip method[12)] with 5knot ship speed at midpoint of the midship hold were used. Internal hydrodynamic pressure was calculated as the inertia force due to cargo oil or ballast water based on the accelerations. Then the pressure differences were synthesized considering the difference in phase angles.

Each fatigue damage was calculated from the short-term distribution of each load component and the wave scatter table corresponding to the standard operating route or the North Atlantic route, and the ratio of each fatigue damage was used to derive the fatigue damage modification factor η_D. The load modification factor η was obtained by taking the cubic root of η_D. The results are shown in Table 6.

Table 6　Result of examination 2

Load component (at the midpoint of the midship hold)	η_D	η
Hull girder vertical bending moment	0.182	0.567
Hull girder horizontal bending moment	0.241	0.622
Hydrodynamic pressure at draught position	0.228	0.611
Hydrodynamic pressure at centre of ship bottom	0.193	0.578
Hydrodynamic pressure at ship bilge	0.225	0.608

where, η_D : fatigue damage modification factor, η : load modification factor

7.3 MODIFICATION FACTOR DERIVED FROM EXPECTED THIRD POWER VALUE OF SIGNIFICANT WAVE HEIGHT OF WAVE SCATTER TABLE (EXAMINATION 3)

Wave height is considered to follow a Weibull distribution. In such case, cumulative distribution function for a Weibull distribution is shown as Equation 1.

$$F_H(x) = 1 - \exp\left\{ -\left(\frac{x}{\beta} \right)^{\alpha} \right\} \qquad (1)$$

where α : Weibull shape parameter, β : Weibull scale parameter

Fatigue damage, *D*, of welded joint, whose inverse of slope of S-N curve is 3, can be approximated to be proportional to the third power value of significant wave height, *H*, because loads are generally proportional to wave heights. And the expected third power value of significant wave height is expressed as shown in Equation 2.

$$D \propto E\left[H^3 \right] = \beta^3 \cdot \Gamma\left[1 + \frac{3}{\alpha} \right] \qquad (2)$$

Fatigue damage modification factor is obtained from the following formula;

$$\eta_D = \frac{\beta_{SR}^3 \cdot \Gamma\left[1 + \frac{3}{\alpha_{SR}} \right]}{\beta_{NA}^3 \cdot \Gamma\left[1 + \frac{3}{\alpha_{NA}} \right]} \qquad (3)$$

An equivalent wave height, H_{eq}, which gives equivalent fatigue damage is obtained by cubic root of fatigue damage as shown in Equation 4.

$$H_{eq} \propto \sqrt[3]{D} \qquad (4)$$

Therefore, load modification factors were developed by comparing the cubic root of expected third power values of significant wave height as shown in Equation 5, in cases where the marginal distribution of the significant wave height of a wave scatter table based upon the standard operating route (suffix *SR*) and the North Atlantic route (suffix *NA*) is approximated by a Weibull distribution.

$$\eta = \frac{\beta_{SR} \cdot \sqrt[3]{\Gamma\left[1+\frac{3}{\alpha_{SR}}\right]}}{\beta_{NA} \cdot \sqrt[3]{\Gamma\left[1+\frac{3}{\alpha_{NA}}\right]}} \qquad (5)$$

The results are shown in Table 7.

Table 7 Result of examination 3

	η_D	η
Regardless of load component and location	0.249	0.629

where, η_D : fatigue damage modification factor, η : load modification factor

7.4 COMPARISON OF EACH EXAMINATION

Figure 5 shows the results of comparing the load modification factors obtained in Examinations 1 to 3. As a result, it was found that the load based on the standard route is about 0.6 times the load based on North Atlantic route in the case of VLCCs. This means that the fatigue damage on the standard route is about 0.2 times the fatigue damage on the North Atlantic route. This value, however, does not include any safety margin against scatters of the operating routes. The modification factor derived from the RAO of each load component (hull girder moment, dynamic pressure at each position, acceleration at the centre of gravity of each cargo tank) is approximately the same. Furthermore, the load modification factor derived from RAO of stress, that derived from RAO of each load component and that derived from the expected third power value of significant wave height are also the same.

From the above, it is considered that the coefficient for modification of the loads based on North Atlantic route to those based on standard operating route should be obtained from the expected third power value of significant wave height because of its simplicity.

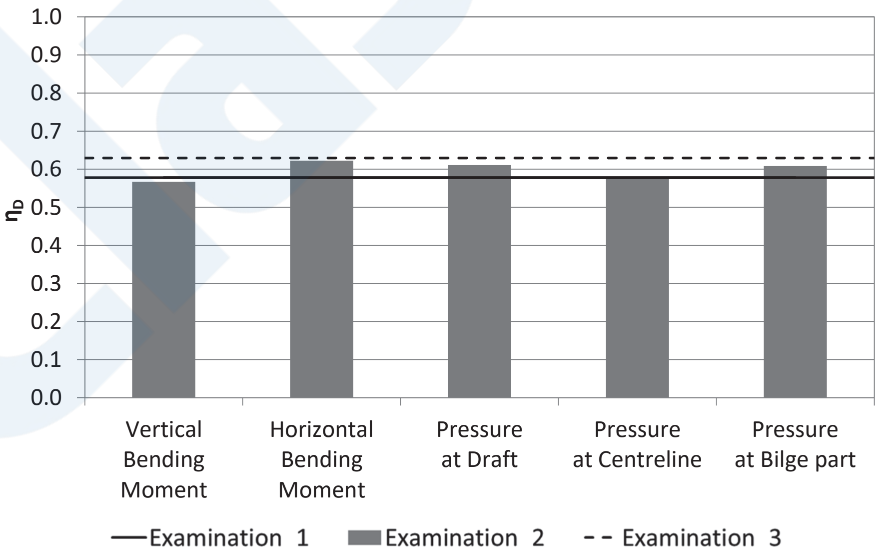

Figure 5 Comparison result of each examination

8. RELATIONSHIP OF OPERATING ROUTE AND DISTRIBUTION OF LOAD MODIFICATION FACTOR OF VLCC

Here, the safety factors corresponding to a scattering of the operating routes of VLCCs were examined.

Firstly, each wave scatter table corresponding to operating route intended for 715 VLCCs and each load modification factor were obtained in accordance with 7.3. A histogram of the load modification factor of each ship is shown in Figure 6. The transverse axis shows the magnitude of the load modification factors while the vertical axis shows their frequency. The maximum value of the load modification factor, i.e. the load modification factor for the ship which navigates the most severe sea route, is 0.786 for VLCCs. The orange line in Figure 6 shows the mean value of distribution, and this mean value corresponds to the load modification factor for the standard operating route obtained in 7.3.

The mean value plus twice the standard deviation is then calculated taking into account the scattering of the load modification factors in order to examine the safety margin, and the obtained value is shown by a red line in Figure 6. In the case of VLCCs, the mean value plus twice the standard deviation is 0.736, which corresponds to the fatigue damage modification factor of weld joints of about 0.4.

In order to grasp the operating route corresponding to each load modification factor, the operating routes of the top 10 VLCCs with the largest load modification factors and those of the top 14 VLCCs whose load modification factors are less than or equal to the mean value plus twice the standard deviation were examined using AIS data. Each operating route is shown in Figures 7 and 8, and it can be seen that most of the top 10 VLCCs with the largest load modification factors operate in severe sea routes such as the Around-the-Cape route and North Pacific route.

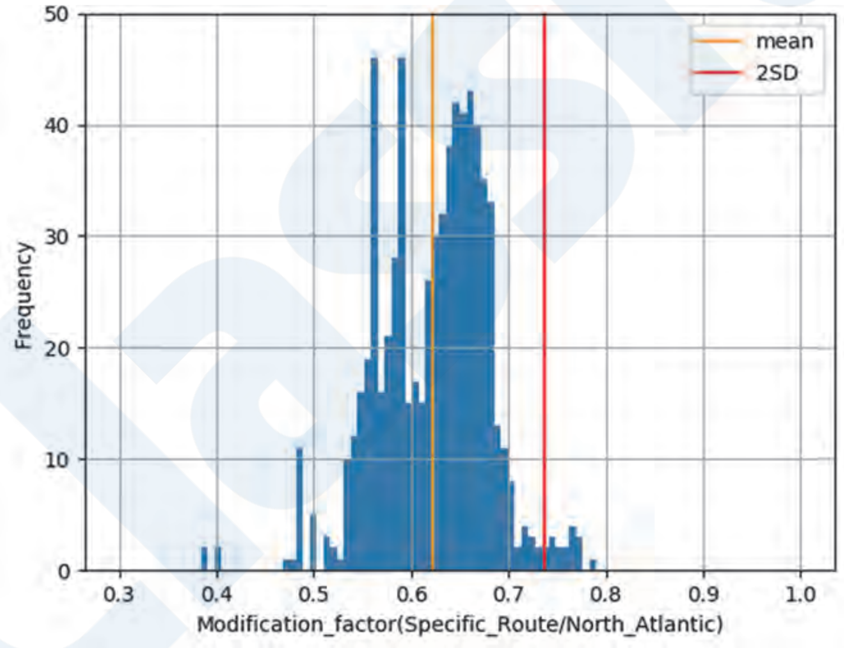

Figure 6　Histogram of load modification factors for VLCCs

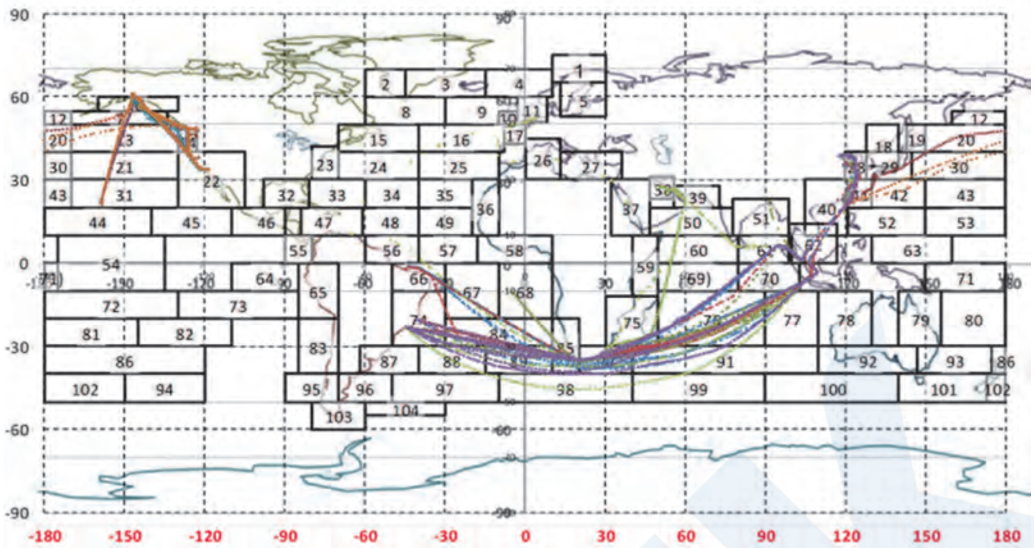

Figure 7 Operating routes of the top 10 VLCCs with the largest load modification factors

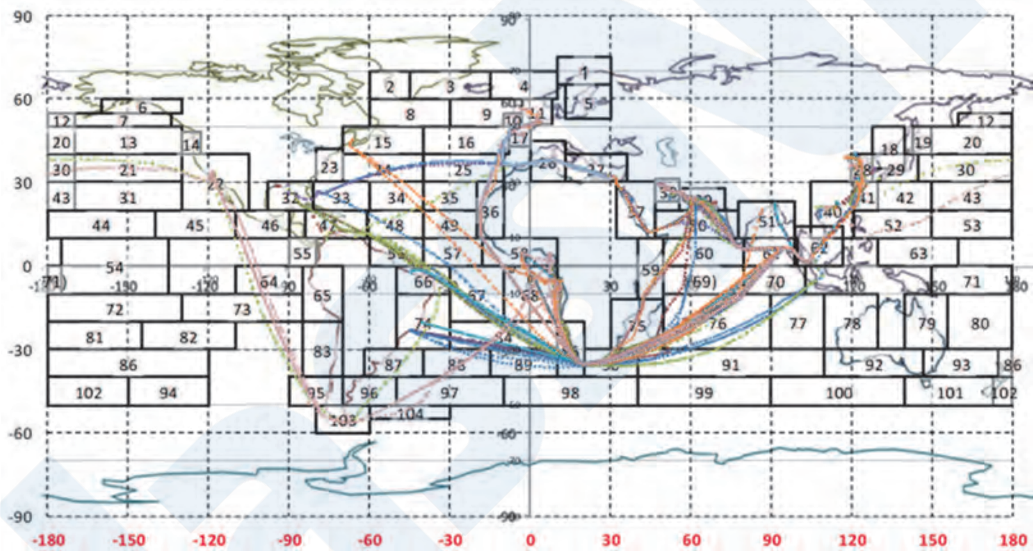

Figure 8 Operating routes of the top 14 VLCCs whose load modification factors are less than or equal to the mean value plus twice the standard deviation

9. RELATIONSHIP OF OPERATING ROUTE AND DISTRIBUTION OF LOAD MODIFICATION FACTORS OF FEEDER CONTAINER CARRIERS

The same examination performed for VLCCs in the previous section was carried out for feeder container carriers which generally navigate on a greater variety of routes than VLCCs.

Figure 9 shows the distribution of the load modification factors of 2793 feeder container carriers. The maximum value of the load modification factors of the feeder container carriers is 0.895, and the mean value which corresponds to the load modification factors of the feeder container carrier standard route is 0.625. The mean value plus twice the standard deviation is 0.781 when the scattering of the load modification factors is taken into account.

The operating routes of the top 10 feeder container carriers with the largest load modification factors are shown in Figure 10. It can be seen that 8 out of 10 ships exclusively navigated the North Atlantic route, while out of the two remaining ships; one navigated the North Pacific route, which is known to have sea conditions similar to the severity of the North Atlantic route, and the other navigated between Asia and Australia. A ship which sails between Asia and Australia passes through Area 101, which is defined as a harsh sea state in the BMT GWS, but the ship only navigated along the coast of Australia where the sea state is not considered to be severe. Since this study considers only the wave scatter tables defined by BMT GWS and the relative frequency of navigating time, the obtained load modification factors are considered to perhaps be larger than those for actual sea conditions; however, by using actual encounter sea conditions obtained from Hindcast data or Forecast data, etc. instead of BMT GWS wave scatter tables, it seems to be possible to obtain values which consider more realistic phenomena.

Since Figure 11 shows that the operating routes of the 7 out of the top 10 feeder container carriers whose load modification factors are less than or equal to the mean value plus twice the standard deviation were the North Atlantic route, it can be said that a load considering a safety margin of twice the standard deviation to a load based upon the standard operating route could be used for North Atlantic route navigation. For ships which exclusively navigate the North Atlantic route, however, it seems to be necessary to perform an evaluation using loads based upon the North Atlantic wave environment as defined by the IACS CSR-BC&OT.

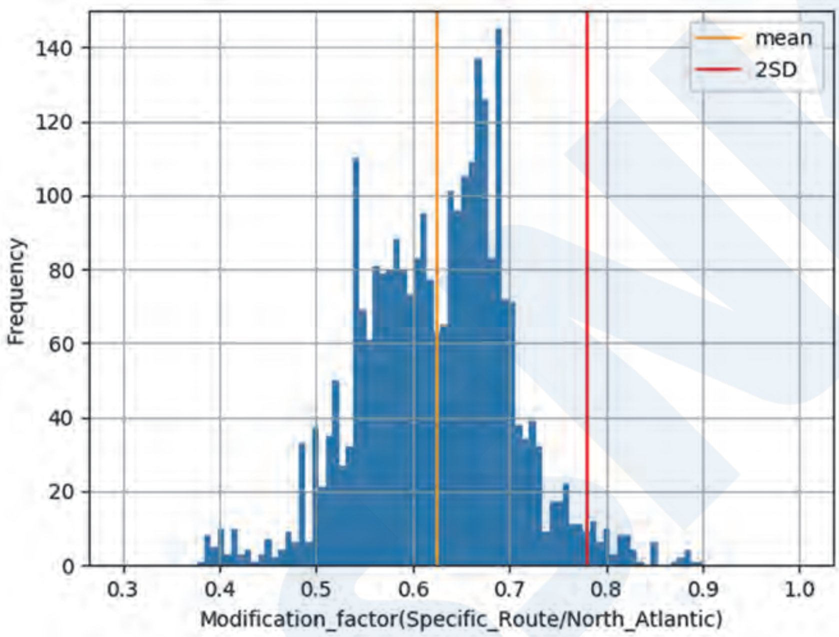

Figure 9　Histogram of modification factors of loads for feeder container carriers

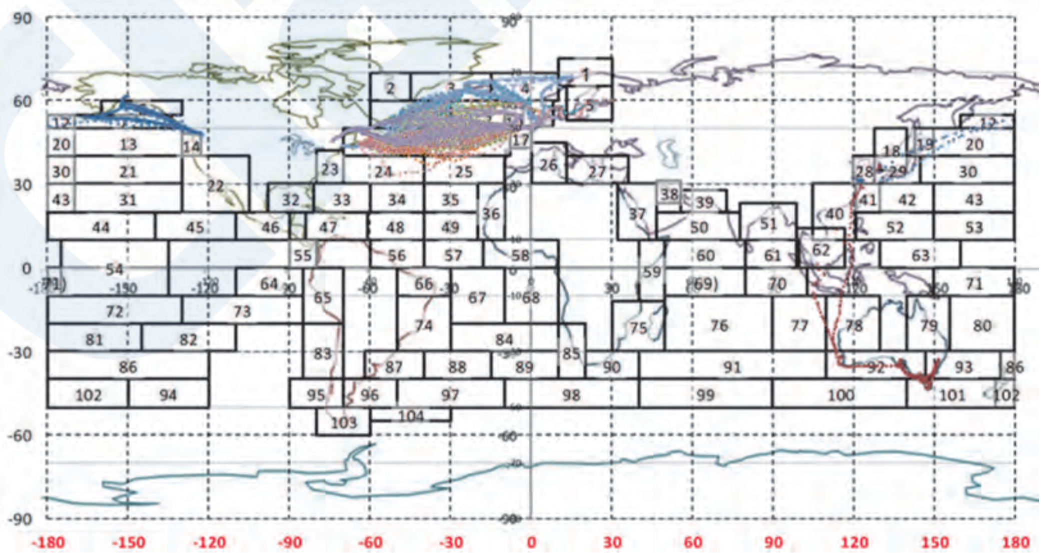

Figure 10　Operating routes of the top 10 feeder container carriers with the largest load modification factors

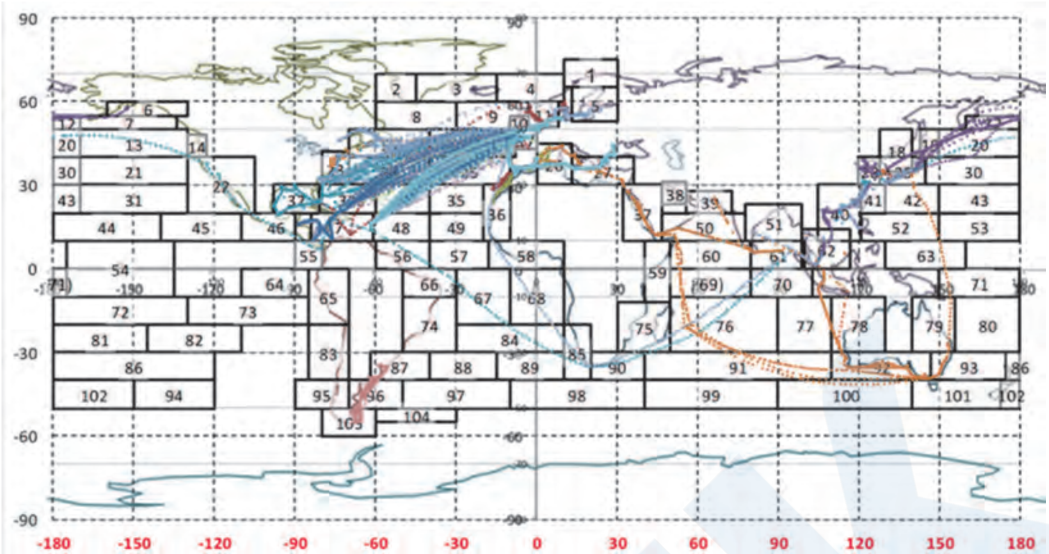

Figure 11　Operating routes of the top 10 feeder container carriers whose load modification factors are less than or equal to the mean value plus twice the standard deviation

10.　OPERATING RATIO ACCORDING TO AIS DATA

The IACS CSR-BC&OT specifies that fatigue damage is to be calculated for the number of wave cycles encountered during a design life corresponding to 25 years. 85% of ship’s service life is, however, considered as effective (i.e., in operating at sea); the remaining time (15%) corresponding to non-sailing time for operations such as cargo loading or unloading, inspection and maintenance. The factor taking into account operating time (f_0 = 0.85) is, therefore, incorporated into the IACS CSR-BC&OT.

As part of this paper, this factor was also obtained by calculating the actual operating time using AIS data.

An examination was carried out as follows:

(1) If a ship navigates at speed not greater than 1 m/sec, ship speed is regard as zero and the ship is judged to be stopping (i.e., at anchor).

(2) Operating ratios were calculated from the navigation time and the non-sailing time of each ship. Because operating ratios scattered between ships, the average values and 90% cumulative probability values were calculated taking into account that such scatterings of operating ratios are assumed to be based upon a normal distribution.

The operating ratios obtained as a result of the above examination are shown in Table 8. It can be seen that the category of ships that seem to be engaged in regular service tend to have higher operating ratio.

Table 8　Operating ratios of each ship

Ships	Operating Ratio		Ships	Operating Ratio	
	Average	90 %		Average	90 %
Baby BC, Handy BC	0.50	0.67	LPG carrier	0.51	0.73
Handymax BC	0.54	0.68	Multipurpose ship	0.48	0.64
Panamax BC, Overpanamax BC	0.58	0.75	Small OT, Middle range OT	0.48	0.73
Capesize BC	0.69	0.81	Large range OT, Aframax OT	0.58	0.76
Chemical tanker	0.50	0.68	Suezmax OT	0.65	0.84
Feeder CT	0.56	0.74	VLCC, ULCC	0.66	0.90
Panamax CT	0.72	0.85	Ore carrier	0.70	0.88
Overpanamax CT	0.72	0.84	Reefer	0.60	0.85
Mega CT	0.67	0.79	Vehicle carrier	0.70	0.83
General cargo ship	0.39	0.57	Wood chip carrier	0.64	0.85
LNG carrier	0.70	0.93			

11. OTHER KNOWLEDGE FROM AIS DATA ANALYSIS

In this paper, the results of an examination of a VLCC are provided as an example, but in order to specify the standard operating route and examine the scattering of modification factor the same analysis was also carried out for other ships. The knowledge obtained from AIS data analysis for all types of ships is shown as follows:

(1) There is a tendency to avoid some great circle routes known to have severe wave environments and to navigate less severe routes, for example, when ships navigate from North America to Europe or from Asia to North America.

(2) Ships generally do not navigate in Areas 8, 9, 15 and 16, but rather in Areas 15, 16, 24 and 25 of the BMT GWS when using the North Atlantic route.

(3) The relative frequency of mid-ocean navigation (such as the North Atlantic, North Pacific, Mid Atlantic, and Indian Ocean) is low because ships seem to navigate along lands from port to port for the purpose of loading/unloading.

12. CONCLUSION

In this paper, standard operating route for each ship type and size is identified by analysing AIS data of 24,349 ships for a period of two years and ten months. Moreover, wave scatter tables for standard operating route which are necessary to develop the design load for fatigue strength assessments are derived from relative frequency of navigation time for each sea area of standard operating route and their wave scatter table specified in BMT GWS. The modification factor of the design load for North Atlantic route to standard operating route were obtained from three different methods, using RAO of stress, RAO of load component, such as hull girder bending moment and dynamic pressure at each location, and the expected third power value of significant wave height, and compared to each other. The following remarks are obtained as a result of above examination using a VLCC.

- The VLCCs' standard operating route is identified by relative frequency of navigating time for each sea area obtained from AIS data analysis. This route corresponds to the fact that VLCCs primary transport crude oil from the Persian Gulf to Japan, USA or Europe.
- Design loads for fatigue strength assessment are reduced by about 0.6 using wave scatter table based on its standard operating route. It means the fatigue damage for the standard operating route is reduced by about 0.2 compared with one for North Atlantic route. Note that the safety factor for the design loads should be considered because navigating the routes different from standard operating route is not considered.
- The load modification factors obtained by RAO of each load component, such as hull girder vertical bending moment, hull girder horizontal bending moment, dynamic pressure at each location and accelerations at center of gravity of each tank, are almost same for a test ship.
- In addition to above remarks, the modification factor of the design loads obtained by RAO of each load component, RAO of stress and expected third power value of significant wave height are almost same for a test ship.
- It seems to be better way to use the expected third power value of significant wave height in order to modify the design load of North Atlantic route to standard operating route for fatigue strength assessment because of its simplicity.

In this paper, only a ship was chosen as test ship. The authors will carry out the same examination for several ships for confirmation of above remarks near future.

For VLCCs and feeder container carriers, the histograms of load modification factor are obtained. The mean value plus twice the standard deviation as a safety margin is obtained for each ship type. And operating routes of the top 10 ships with the largest load modification factors and the top several ships whose load modification factors are less than or equal to the mean value plus twice the standard deviation are shown.

In this paper, the authors examined the method of setting the loads for fatigue evaluation according to actual operating route. The authors continue to study the loads for fatigue evaluation specified in the Rules.

In addition to the modification of the design loads for fatigue strength assessment, the authors verified the suitability of the operating ratio specified for the IACS CSR-BC&OT fatigue strength assessments using AIS data. The following remarks are also obtained.

- Panamax container carriers, LNG carriers, VLCCs, ore carriers, reefers and wood chip carriers exceed the 0.85 specified in the IACS CSR-BC&OT with regard to their 90% cumulative probability values of a normal distribution.

PREFERENCES

1) International Association of Classification Societies: 2018, Common Structural Rules for Bulk Carriers and Oil Tankers, January 2018.
2) International Maritime Organization, 2017, the International Convention for the Safety of Life at Sea.
3) Eisinger, E., Helmers, J.B. & Storhaug, G. : 2016. A method for describing ocean environments for ship assessment. *In Proc. 6th International conference on Design for Safety, 28-30 November 2016,* Hamburg, Germany.
4) Fujii, M., Hashimoto, H., & Taniguchi, Y. : 2017, Analysis of Satellite AIS Data to Derive Weather Judging Criteria for Voyage Route Selection, *the International Journal on Marine Navigation and Safety of Sea Transportation, Volume 11, pp271-277.*
5) Fujino, I., Claramunt, C., and Boudraa A.O. : 2017, Extracting Route Patterns of Vessels from AIS data by Using Topic Model, *2017 IEEE International Conference on Big Data, pp4744-4746 11-14 Dec 2017,* Boston, USA
6) Honda, K., Shoji, R., and Inaishi, M. : 2017, A Study of Standard Ship Track with AIS Data (in Japanese), *the Journal of Japan Institute of Navigation, Volume 137, pp97-102*.
7) Teixeira, A.P., and Soares, C.G. : 2018 Risk of Maritime Traffic in Coastal Waters, *In proc. 37th International Conference on Ocean, Offshore & Arctic Engineering (OMAE), pp17-22 June 2018,* Madrid, Spain.
8) British Maritime Technology Limited: 2000, Global Wave Statistics
9) International Association of Classification Societies: 2018, Technical Background for Common Structural Rules for Bulk Carriers and Oil Tankers, January 2018
10) International Association of Classification Societies: 2001, Recommendation No.34 Standard Wave Data.
11) ClassNK: 2018, Guidelines for Direct Load Analysis and Strength Assessment
12) Salvesen, N., Tuck, E.O. and Faltinesen, O.M. : 1970, Ship Motions and Sea Load, *Trans SNAME, Vol.78, pp.250-287*

APPENDIX

CALCULATION OF FATIGUE DAMAGE RATIO

The fatigue damage for each loading condition is proportional to the following value taking into account the assumption that stress range follows a Weibull distribution:

$$D \propto \beta^m \cdot \Gamma\left(1+\frac{m}{\alpha}\right) \quad \text{(A1)}$$

where *m*: inverse of slope of the S-N curve which is 3 for welded joints, α : Weibull shape parameter, β : Weibull scale parameter, Γ : gamma function

Therefore, the ratio of fatigue damage for the standard operating route to that for the North Atlantic route were calculated as follows:

$$\frac{D_{SR}}{D_{NA}} = \left(\frac{\beta_{SR}}{\beta_{NA}}\right)^m \cdot \frac{\Gamma\left(1+\frac{m}{\alpha_{SR}}\right)}{\Gamma\left(1+\frac{m}{\alpha_{NA}}\right)} \quad \text{(A2)}$$

The suffixes “SR” or “NA” indicate whether the concerned value corresponds to either the standard operating route or the North Atlantic route.

The modification factor of fatigue damage η_D is obtained by the ratio of total fatigue damage of full load condition and ballast condition for standard operating route to that for the North Atlantic route as shown in Equation A3:

$$\eta_D = \frac{D_{SR,Full} + D_{SR,Ballast}}{D_{NA,Full} + D_{NA,Ballast}} \qquad \text{(A3)}$$

Where the suffixes “Full” or “Ballast” respectively indicate the value is for either the full loading condition or the ballast condition.

The modification factor η for design loads (wave height) is obtained by Equation A4 using η_D obtained from Equation A3:

$$\eta = \sqrt[m]{\eta_D} \qquad \text{(A4)}$$

Performance Analysis of the Ocean Energy Harvesting Vessel

Shigemitsu AOKI*

1. Introduction

Sailing is the technology, like windmill, that has it’s origin thousands years ago.

While alternatives of the technology have been external and internal combustion engines, recently, investigations for modern sailing technology were re-started[1)] including the systematic technological studies[2)] in Japan.

Figure 1　Various Rigs

Concepts of Modern sailing technology developed since the 1970s – after oil shock – are shown in Figure 1. The concept, introduced in this paper, where an advanced sailing technology is applied not only for energy-saving but also for converting wind energy for generating power electricity (Ocean Energy Harvesting Vessel) was awarded at first 21st Century Earth Award (Nihon Keizai Shimbun) as the GISPRI prize in 1991.

Key technology of the idea is a combination of high-efficient hard sail(s) and hydro-fin(s) that provides marginal propulsive power and allows electric generation with hydro-rotor(s) with which methanation or hydrogen storage by methylcyclohexane (MCH). As is shown in Figure 2, expecting the maxmization of the wind energy, research and development as to offshore wind power including stand-still system and/or floating system are under-going.

Mode	Stand-still ←	→	Motion
Type	Monopole/Jacket/Tripod	Floating	Sailing
Depth(m)	5～60	30～200	N・A
WT type	HAWT／VAWT		Sail & Hydro-rotor
Conver-sion	Inter-connection	Water Electrolysis & Store etc.	
Customer	Utility	Thermal Power-Plant/Fuel-cell	

Figure 2　Concepts of offshore wind powerutilization

Under such a circumstances, in this paper, the feasibility of the proposed system is studied by detailed parametric research.

* Renewable Energy Department, ClassNK

2. Basic Concepts

2.1 Output performance

Basic idea is a kind of wind energy conversion system as a sailing device consists of hard-sail and hydro-fin with which additional propulsive force that counter-balances not only for the resistance of the hull but also for the drag of the hydro-rotor of which electric generation is obtained.

The relationship between true wind-speed u, speed of the hull v, relative wind speed χ and derived components like propulsive force T_a and lateral force N_a is shown in Figure 3

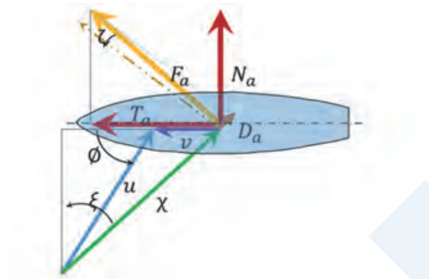

Figure 3 Composition of the propulsive Force

A fundamental equation of the hull-speed is shown as formula (1).

$$\boldsymbol{m\frac{dv}{dt} = T_a - (D_{\pi a} + N_w) - D_w - D_r} \qquad (1)$$

Where m is mass of the ship, $D_{\pi a}$ is the aerodynamic drag of the hull, N_w is the induced resistance of the hull caused by N_a, D_w is the resistance of the hull, D_r is the drag of hydro-rotor.

The speed of the hull is obtained as a solution of equation (1) as an equilibrium between related variables.

Generating Power P is obtained by equation (2).

$$P = \frac{1}{2}\rho_w v^3 \pi r^2 C_p \qquad (2)$$

Where ρ_w is density of sea water, r is radius of hydro-rotor, C_p is the coefficient of power at the hydro-rotor.

2.2 Hard-sail

Although it is preferable to adopt the hard-sail consists of high lift aero-foil section in order to achieve better performance and labor saving for the crew, according to the theoretical[3)] and detailed feasibility[4)] study, such an innovative device to hold the wing shown in Figure 4 (Delta-wing) is to be required for the purpose of take a course spreading around two- hundreds tens degree except just against the wind direction.

Figure 4 Experiment with Delta-rig

2.3 Hydro-fin

Except the mode of following wind condition (following or running), because the lateral component of the aerodynamic force

N_a by the sail is inevitable, sailboats normally equip a center board or keel and sailing ships behave a side slip motion to obtain lateral force as a counter-measure.

2.4 Representative Rig

Representative combinations of aero-foil and hydro-fin are shown in Table 1 with conceptual configures shown in Figure 5.

Table1 Various rig for sailing

Side-force \ Rig	Dyna	AIST	Delta
Yawing	A Conservative		
Flapped-fin		B Normal	
V-fin		C Semi-challenge	D Challenge

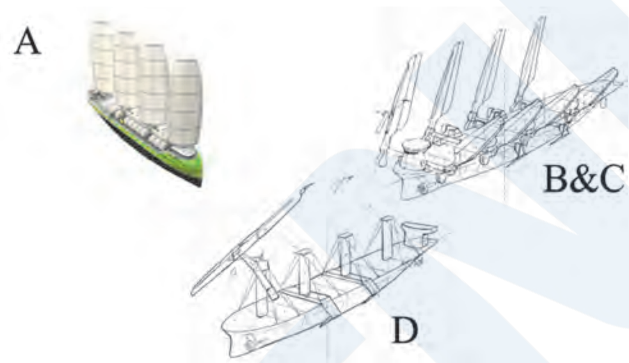

Figure 5 Various rig for sailing

Items for the evaluation could be

1. Performance of generation
2. Inclination (heel) angle
3. Side slip angle
4. Way of avoid the strong wind condition
5. Sea-worthiness

Type A (called Dyna-Rig) that is already utilized for super yachts has an arched soft wing supported by aluminum beams with actuator-motors for reefing. In case of tack, sails together with masts makes turn around and the leading edge and the trailing edge makes alternation each other.

Type B and type C(called AIST-Rig) consists of sets of cantilevered asymmetrically configured wing with high-lift device that makes alternative tilt up in case of tack motion. Type B obtains asymmetry by the hydro-fins with flaps, Type C has a hydro-foil with deep dihedral angle called v-fin.

Type D (Called Delta-Rig) has unique mechanism shown in Figure 4 to support the asymmetric aero-foil with high-lift device in case of tacking.

3. Evaluation of basic characteristics

3.1 Base Ship

Principle dimension of the base ship is shown in Table 2.

A comparison as to P, v and θ under the same condition of true wind speed u and course angle ϕ was made by setting various kind of rig like A, B, C and D described in section 2.4 to the base ship. Final equilibrium under each condition is obtained by the simulation referring Figure 3 and formula (1).

Table 2　Principle dimension of Base Ship

Terms	figure	ref.
L. W. L （m）	350	Water line length
A_{whull} （m²）	17795	Wet area of the hull
$A_{\pi hull}$ （m²）	480	Section area above water
C_{fwater}	0.001	×1.1 by wave making
R_{wrotor} （m）	～5.0	Radius of the rotor
C_{Protor}	0.45	Power coef. λ ; 1.75 （η_G ; 0.7)
C_{Trotor}	0.3	Thrust coef. λ ; 1.75
N_{rotor}	2	Number of the rotor
M （ton）	162250	Displacement of the hull
u_{hub} （m/s）	10, 12, 14	
∅ （rad.）	1.2, 1.4, 1.6	

3.2　Evaluation of Performance

The relationship between parameters as to representative rig like A, B and C are described as following formulae,

$$\chi^2 = u^2(\sin\emptyset)^2 + (v + u\cos\emptyset)^2 \tag{3}$$

$$\xi = \cos^{-1}\left({u\sin\emptyset}/{\chi}\right) \tag{4}$$

$$\zeta = \tan^{-1}\left[\left(C_{d0} + \frac{C_l^2}{\pi A}\right)\Big/ C_l\right] \tag{5}$$

while as to type D (Delta-rig), instead of formula (5), formula (6) is used because of the inclination angle of 45 degree setting for support.

$$\zeta = \tan^{-1}\left[\left(C_{d0} + \frac{C_l^2}{\pi A}\right)\Big/ \frac{1}{\sqrt{2}}C_l\right] \tag{6}$$

Similarly, the resultant aerodynamic force F_a is calculated as for A, B and C,

$$F_a = \frac{1}{2}\rho_a S_{wing}\chi^2\sqrt{C_l^2 + \left(C_{d0} + \frac{C_l^2}{\pi A}\right)^2} \tag{7}$$

as for D,

$$F_a = \frac{1}{2}\rho_a S_{wing}\chi^2\sqrt{\frac{1}{2}C_l^2 + \left(C_{d0} + \frac{C_l^2}{\pi A}\right)^2} \tag{8}$$

as to propulsion and lateral force,

$$T_a = F_a\cos(\xi + \zeta) \tag{9}$$

$$N_a = F_a\sin(\xi + \zeta) \tag{10}$$

further, as to resistances on formula (1).

$$D_{\pi a} = \frac{1}{2}\rho_a(v + u\cos\emptyset)^2 A_{\pi hull}C_{d\pi} \tag{11}$$

$$\boldsymbol{D_w} = \tfrac{1}{2}\rho_w v^2 A_{whull} C_{fwater} \quad (12)$$

$$\boldsymbol{D_r} = \tfrac{1}{2}\rho_w v^2 \boldsymbol{\pi r^2 C_T} \quad (13)$$

3.3 Incline(Heel) angle

Various force affecting the incline angle under sailing condition are shown in Figure 6. The moment caused by N_a is counter-balanced by the recovering moment produced by the buoyancy M_f of the hull, obtaining resulting heel angle θ.

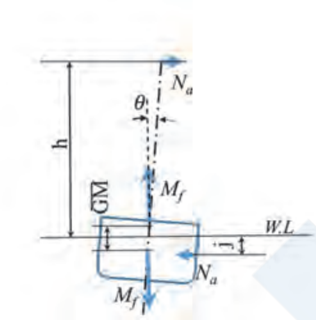

Figure 6 Lateral balance

The fundamental equation is described as,

$$M_f \overline{GM} \sin\theta = (h + j) N_a \quad (14)$$

Incline angle θ is obtained like,

$$\theta \cong \frac{(h+j)}{M_f \overline{GM}} N_a \quad (15)$$

While $\overline{GM}$ is a distance between the center of mass and meta-center, h is a height of the aerodynamic center of the hard-sail above the waterline, j is a depth of the center of lateral force acting on the hull. In case of applying V-fin, j could be negative and that brings recovery moment as is shown in Figure 7 respectively.

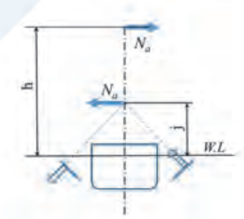

Figure7 Recovery moment by V-fin

Namely, V-fin consists of a set of fins with 45 degree dihedral angle on both sides of the hull generates a couple of hydrodynamic force that is up-word on lee-side and down-word on weather-side by additional trim angle resulting an effective lateral force against the aerodynamic lateral force N_a.

3.4 Side slip

In case of type A that has no fins, side slip(leeway) of the motion is inevitable, and resulting additional resistance was calculated referring the preceding study[4)].

3.5 Set-up parameters

Table 3　Set-up parameters

Parameter \ Type	A	B	C	D
S(m^2)	10000	5000	5000	9600
h (m)	130	80	80	105
j (m)	10	5	-35	-35
C_l	1.0	3.0	3.0	3.0
AR	8	6.25	6.25	6
r_w(m)	3.0	4.0	4.0	5.0
ref.	Dyna -rig	AIST-rig + flapped fin	AIST-rig + v-fin	Delta -rig + v-fin

Set-up parameters of each rig is shown in Table 4.

The only difference between type B and type C is the configuration of the fin that appears at the value j

3.6　Power output and incline angle

According to the conditions in Table 4, the power output and incline angle is obtained as is shown in Table 4 and Figure 8 (the result under the wind condition of 14 m/s).

Table 4　Power output and incline angle

Type \ u(m/s)	10	12	14
A	19.6 / 2.19	33.8 / 3.16	53.7 / 4.3
B	36.5 / 2.8	63 / 4.05	100 / 5.5
C	36.5 / 1.47	63 / 2.12	100 / 2.9
D	53.0 / 2.7	91.6 / 3.88	148.2 / 5.3

Power (MW)　/ Heel angle (degree)

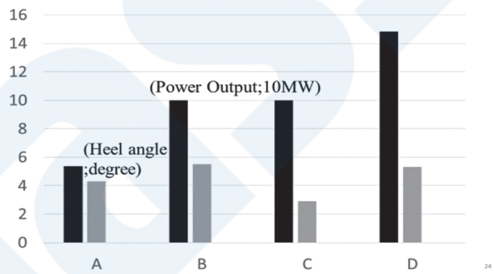

Figure 8　Power output and incline angle at wind speed 14m/s.

3.7　Comprehensive evaluation

Brief description of the comprehensive evaluation according to section 2.4 follows like,

(1) Type A

＜Merit＞

・A Dyna-rig is already established one with minimum risk of development.

・It is possible to manage the development as an usual activity, because the general arrangement is suitable for several operations in the harbor and/or avoiding the strong wind.

＜Demerit＞

・Expected propulsive power seems not enough because of smaller lift coefficient of the aero-foil section around 1.0.

・Hydrodynamic forces derived from normal hull shape by side-slip motion and/or heeling is not convenient to improve the total performance.

(2) Type B

＜Merit＞

・Almost half size of sail area compared to that of A is enough to produce twice power output.
・The retractable hard-sail makes easy to avoid strong wind.
＜demerit＞
・The arrangement must be specified to OEHV because normal operation at harbor seems to be un-convenient.
・Serious conditions by large heel angle make it difficult to arrange proper interior design and hydro-rotor installation.
(3) Type C
＜Merit＞
・The design conditions for interior and hydro-rotor installation could be relaxed with small heel angle.
＜Demerit＞
・The arrangement is limited for only OEHV.
(4) Type D
＜Merit＞
・Superior power performance.
＜Demerit＞
・Comparatively large heel angle despite an application of V-fin.
・Avoidance of strong wind condition seems to be difficult.
・New technology to support the hard-sail is required as a risky development.

Finally, through the investigation described above, it is decided to apply type C, considering type D for the choice of near future.

4. Parametric research by simulation

4.1 Basic arrangement

Basic arrangement of the vessel equipped with Type C rig is shown in Figure 9. Number of light-weight and rigid hard-sails are supported as balanced cantilever wings by supporting mechanism for retracting. Wing section composed of high-lift device with leading-edge slat and trailing-edge flap can achieve high lift coefficient around 3.0.

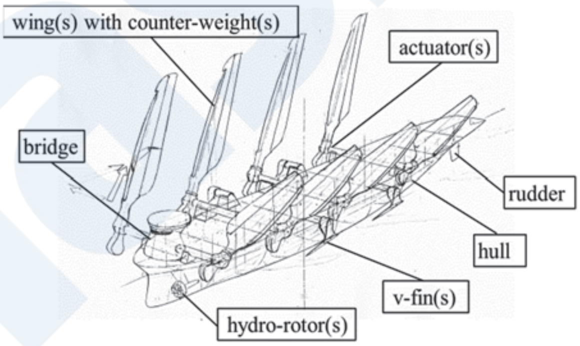

Figure 9 Basic arrangement of type C

Couple of hard-sail with asymmetric wing section works alternatively except in running condition with actuators like slew-drive for pitching and/or retracting. V-fins are also supported by the axis set on the deck with controllers to adjust the attack angle against the water flow. Hydro-rotors and/or bridges are considered to be close to the bow.

4.2 Parametric research

Similar to Table 4, a parametric research was undertaken looking the influences of variable parameters to aerodynamic property and hydrodynamic property as fundamental characteristics of the vessel. Table 5 shows sensitivity as to power output P, hull speed v, heel angle θ by 0.8～1.2 range variation as to lift coefficient C_{lair} aspect ratio AR_{air} and course angle ϕ under the 14 m/s true wind speed.

The result of power output and heel angle is shown in Figure 10.

Table 5　Sensitivity according to the aerodynamic property

Coef. Var.	Measure.	variation				
		0.8	0.9	Base	1.1	1.2
Cl_{air} (3.0)	P (MW)	73	86.7	100	112.6	124.1
	v (m/s)	16.3	17.75	18.6	19.36	20.0
	θ (degree.)	1.95	2.41	2.9	3.4	3.91
AR_{air} (6.67)	P (MW)	88.6	94.7	100	104.6	108.6
	v (m/s)	17.9	18.2	18.6	18.9	19.1
	θ (degree.)	2.78	2.84	2.9	2.93	2.97
∅ (1.4)	P (MW)	84.5	95.3	100	98.2	90.3
	v (m/s)	17.6	18.3	18.6	18.5	18.0
	θ (degree.)	3.44	3.22	2.9	2.47	2.0

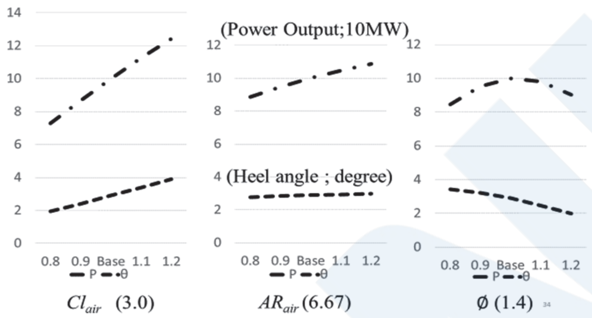

Figure 10　Sensitivity according to the aerodynamic property

(1) C_{lair}　Variation of the lift coefficient brings almost linearized change of the aerodynamic force showing that it is most important parameter. In the 1960s two dimensional maximum lift coefficient around 3.2 was already achieved according to the reference[5]. According to another reference[6], although maximum lift coefficient around 3.0 was realized even for commercial airplane in the beginning of 1970s, the level has been kept around 2.6 by the reason of cost and safety

Should it be notified as to the substantial difference between high lift device of airplane and that of OEHV, the high lift apparatus of the OEHV may not need to bring back to original wing section of high lift drag ratio as is required in case of airplane along with much handicap to the structural soundness of the system. Anyhow, the target value of maximum lift coefficient like 3.0 seems to be reasonable and also not so easy as a practice.

(2) AR_{air}　Although it is said that aspect ratio of the wing is an important measure in order to reduce the induced drag at the tip, kind of conservative attitude may be preferable against the accompanying risk of increasing weight and incline moment of the hull. In the contrary, care should be taken to utilize the effect of the deck and/or water surface as a wing-let as is shown in reference[5].

(3) ϕ　It is easy for OEHV, to keep the optimum course angle, because it is allowed to select it freely, different from the navigation of normal ship. And it means that after successive tack motion with optimum course angle, there is no risk of getting leeward because the optimum course angle lies between 1.4(rad.) to 1.5(rad.). So in these kind of circumstances, care should be taken to minimize the trim angle of the rudder by taking trim balance between hard-sail and hydro-fin.

(4) C_{fwater}　The Reynolds number of the hull under normal operation is around 6.14×10^9, which allows to apply the coefficients of friction as to 0.001 according to the formula of Houghes. The incremental factor by the wave making to be 10% , considering that related Froude number lies around 0.3 with a marginal slenderness(cubic coefficient is 0.5) around 7.0. A contribution of this factor is significant and careful maintenance to keep the condition is required together with better selection of bottom painting material.

Table 6　Sensitivity according to the Hydrodynamic property

Coef. Var.	Measure.	variation				
		0.8	0.9	Base	1.1	1.2
$C_{f\,water}$ (0.001)	P (MW)	113	106.8	100	96.4	91.9
	v (m/s)	18.7	18.4	18.0	17.8	17.5
$C_{T\,rotor}$ (0 .51)	P (MW)	107.6	104.5	100	98.4	95.5
	v (m/s)	19.8	18.9	18.0	17.3	16.6
$[d/l]_{foil}$ (0.033)	P (MW)	103.6	102.5	100	100	99.3
	v (m/s)	18.2	18.1	18.0	18.0	17.9

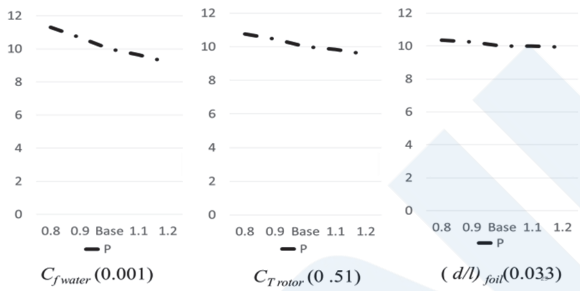

Figure 11　Sensitivity according to the Hydrodynamic property

(5) C_{Trotor} Referring the basic characteristics of turbines under relatively low tip-speed ratio, power coefficient of 0.35 and thrust coefficient 0.51 are adopted. Contribution of the thrust coefficient to the overall performance is significantly large suggesting that the resistance by the hydro rotor is superior to that of hull and sophisticated study as to this item seems to be the core technology of OEHV.

(6) $[d/l]_{foil}$ Current sail ship depends on the side slip motion of the hull to obtain the lateral force. According to the modern sailing theory, importance of the effect by the hydro-fin(s) is recognized and the aspect ratio of the fin was increased. Although influence of the lift drag ratio of the hydrodynamic fin is not so notorious by Figure 11, this new technology also seems to be important.

5.　Estimation of the energy capture

5.1　Area and mode of operation

As is shown in Figure 12, in the northwest Pacific Ocean between Sanriku coast and Aleutian Islands northwest wind prevails throughout the year.

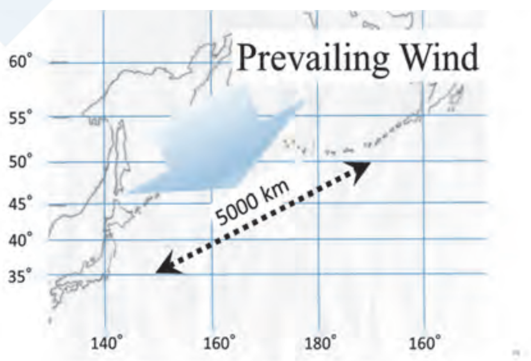

Figure 12　Expected area for operation

Regarding the estimation according to the reference[7], at the height of the aerodynamic center shown h (80m～130m) in Table 3, the vessel can enjoy the wind speed around 12m/s ～14m/s from larboard at the forward and from the starboard at the backward, holding suitable course angle from 1.4(rad.) to 1.6(rad.) as a heuristic voyaging.

5.2 Estimation of the energy capture

Following the course setting described above, and also assuming that available term of 4 month as to 12m/s wind speed and 6 month as to 14m/s wind speed, estimated annual energy capture reaches around 610GWh by the potential of 63MW at 12m/s and 100MW at 14m/s shown in Table 4. Net electricity production after subtraction around 15% as the operational demand of the vessel is about 520GWh with the availability of 60%.

5.3 CO2 reduction

Mass of annual CO2 reduction considering the CO2 emission factor of the utility as 0.46kg/kWh, is shown in Figure 13.

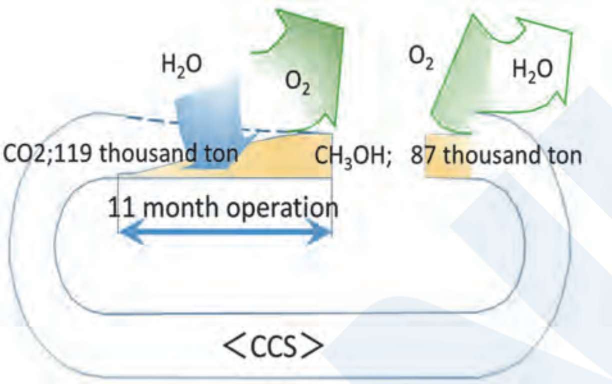

Figure13 Annual CO2 Reduction by OEHV

Kind of material-circle system by methanation that converts hydrogen and CO2 supplied by CCS into methanol utilizing the 520GWh of effective annual electricity for electrolysis and desalination is capable to supply CO2 free fuel for the onshore power plants. Methanol production is 87 thousand ton and annual CO2 reduction by the emission factor of 0.46kg/kWh of the current power plant is counted around 119 thousand ton that is worth to 0.01% of total annual CO2 emission of Japan.

5.4 Technological future research work

Because the concept of OEHV consists of established technologies like aeronautics, maritime technology and chemical engineering that are already established in practice level, there could be no outstanding technological problem that should be overcome for break-through. Besides, kind of efforts like risk analysis for newly arranged combination of current technologies are inevitable, and the investigation of utilizing IT technology for the efficient development and management of the system also seems to be essential.

6. Conclusions

A comprehensive research work for the fundamental characteristics of the sailing type ocean energy conversion system was carried out. At first, a simulation model on which the principal of sailing is reflected, was prepared together with representative parameters which may affect to overall performance of the vessel. A comparison between three types sailing system combined with base ship was done in order to select one equipped with particular rig named AIST-Rig. Finally, characteristics of hard-sail, hydro-fin, hull itself and hydro-rotor that configure the AIST-Rig were successively changed to evaluate the sensitivity as to power performance and heel angle. As a result, it was found to be noticeable that the lift coefficient of the hard-sail and the thrust coefficient of the hydro-rotor are affective to the total performance of the system, letting the strategy of the investigation in the future more clear and viable.

Following these kind of understanding, an estimation for annual energy production under the condition of repeated voyaging from the eastern shore of Hokkaido to Aleutian, where strong wind is dominant, was conducted to obtain around 520GWh, worthy of 60% availability.

Acknowledgement

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References

1) CE Delft., Study on the analysis of market potentials and market barriers for wind propulsion technologies for ships/1891 Development of Wind Energy, http://wind-ship.org/en/research http://www.cedelft.eu/publicatie 20.07.2017.
2) Kazuyuki Ouchi, wind force utilization for ship「Wind Challenger Project」, *Journal of the JIME* Vol. 47, No. 4(2012)
3) Dr. J. F. Wellicome., Some comments on the relative Merits of Various Wind Propulsion Devices, http://windship.org/en/research//cfd.mace.manchester.ac.uk/twiki/pub/Main/FlettnerRotors/Wellicome_JWindEng_1985.pdf 02.08.2017.
4) Grant E Hearn., Concept Design of a Fast Sail Assisted Feeder Container Ship, http://wind-ship.org/en/research http://eprints.soton.ac.uk/173137/1/Concept_Design_of_a_Fast_Sail_Assisted_Feeder_Containership.pdf 02.08.2017.
5) Masao Yamana・Hiroshi Nakaguchi, *Hikouki Sekkeiron*, Yokendo, first edition, 1968, p.476.
6) Advanced Aircraft Technology Center, the Society of Japan Aerospace Industrial Association, A design scheme development of the high-lift device applying the optimization method. *Report of research work as to the environment-conscious aeronautical technology. No.2215*, 2011, pp.8
7) NASDA Monthly averaged wind speed data on offshore and Pacific Ocean surrounding Japan. (average wind speed) http://photojournal.jpl.nasa.gov/catalog/PIA0389

Recent topics at IMO

— Outline of discussion at IMO Committees —

External Affairs Department, ClassNK

1. INTRODUCTION

This article introduces recent topics discussed at IMO (International Maritime Organization). At the 1st issue, a summary of the decisions taken at 74th Marine Environment Protection Committee (MEPC 74) held from 13 to 17 May 2019 and 101st Maritime Safety Committee (MSC 101) held from 5 to 14 June 2019 is provided as below.

2. OUTCOMES OF MEPC 74

2.1 Greenhouse Gases (GHG) emission reduction measures

GHG emissions from international shipping have been deliberated at IMO, and so far, the Energy Efficiency Design Index (EEDI), the Ship Energy Efficiency Management Plan (SEEMP) and the Data Collection System for fuel oil consumption of ships (DCS) were introduced. Further, at MEPC 72, Initial IMO Strategy on reduction of GHG emissions from ships, which includes emission reduction target and candidate measures to reduce GHG emissions, was adopted.

2.1.1 Review of technological developments for EEDI

Regulation 21.6 of MARPOL Annex VI sets out that a review of the status of technological developments which may contribute to the improvement of EEDI should be conducted. It also requires, if proved necessary, to amend the subsequent requirements, i.e. “when to start the each phase” and “the reduction rate”. At MEPC 71, it was agreed to establish a correspondence group (CG), coordinated by Japan, to consider an early implementation of phase 3 and possible introduction of phase 4.

At this session, consideration was made based on the report of the CG and agreements reached at MEPC 73.

1) Strengthening EEDI phase 3 requirements

Draft amendments to MARPOL Annex VI were approved based on followings consensus. The draft amendments will be adopted at MEPC 75.

- For general cargo ship, LNG carrier and cruise passenger ship, advance starting year from 2025 to 2022 and retain 30 % reduction rate.
- For gas carrier (LPG carrier) with 15,000DWT and above, advance starting year from 2025 to 2022 and retain 30 % reduction rate. For gas carrier (LPG carrier) below 15,000DWT, retain the current requirements of starting year in 2025 and the reduction rate.
- For container ship, advance starting year from 2025 to 2022, and strengthen the reduction rate based on the ship sizes as follows:

DWT	Reduction rate
10,000 and above but less than 15,000 DWT	15～30%
15,000 and above but less than 40,000 DWT	30%
40,000 and above but less than 80,000 DWT	35%
80,000 and above but less than 120,000 DWT	40%
120,000 and above but less than 200,000 DWT	45%
200,000 DWT and above	50%

- For ship types other than above, retain the current requirements of starting year in 2025 and the reduction rate.

2) Reference line for very large bulk carriers

Recognizing that EEDI requirements for very large bulk carriers become too stringent, draft amendments to

MARPOL Annex VI to relax the reference lines for very large bulk carriers more than 279,000DWT were approved. The draft amendments will be adopted at MEPC 75.

3) Requirements for ice class ships

To add a correction factor for ice class ships of IA Super and IA, amendments to 2018 Guidelines on the Method of Calculation of the attained Energy Efficiency Design Index (EEDI) for new ships were adopted.

4) Introduction of possible EEDI phase 4 requirements

It was agreed to continue the CG to consider the possible introduction of EEDI phase 4 taking into account status of technological developments for improvement of energy efficiency and ship safety aspects for various ship types and implications for the human element. The interim report of the CG will be provided at MEPC 75, and final report will be submitted to MEPC 76.

2.1.2 Requirements of minimum propulsion power and EEDI

2013 Interim Guidelines for determining Minimum Propulsion Power to Maintain the Manoeuvrability of Ships in Adverse Conditions were developed in order to avoid construction of extremely under-powered ships. At MEPC 71, it was agreed to extend the application period of the guidelines towards phase 2 of EEDI regulation. Meanwhile, consideration on strengthen of the phase 3 requirements continued. Under these circumstances, concerns were raised that the requirements of minimum propulsion power in the Guidelines might become a barrier for meeting the phase 3 requirements.

At MEPC 73, to address the conflict between EEDI and minimum propulsion power requirements, a limitation of a ship's shaft power under normal ships' operation for EEDI calculation was proposed, and it was agreed to keep consideration of the proposal.

At this session, a proposal to introduce the idea of Shaft Power Limitation (SHaPoLi) as an option was considered, and generally accepted. To improve the idea and for further discussion, it was agreed to keep consideration at future session. It was also encouraged to expedite the work to complete the revision of the interim minimum power guidelines.

2.1.3 IMO strategy on reduction of GHG

The Paris Agreement specifies the ambitious target of GHG reduction to hold the increase in the global average temperature to well below 2°C above pre-industrial levels. Accordingly, MEPC 72 adopted Initial IMO Strategy on reduction of GHG emissions from ships. The initial Strategy identified three levels of ambition and listed the candidate measures for each level;

1) to reduce the carbon Intensity, as an average across international shipping, by at least 40% by 2030 compared to 2008,

2) to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008, and

3) pursuing efforts towards phasing out GHG emissions in this century.

At this session, following an intersessional meeting held from 7 to 10 May, candidate short-term measures to reduce GHG emissions from ships in operation were considered. The Committee agreed to continue consideration of the following proposed measures at future sessions, with a view to agreement to be reached in 2023.

- Calculation of Energy Efficiency of Existing Ship (EEXI)
- Annual Efficiency Ratio (AER)
- Establishing Maximum operational speed (expressed as annual average)
- Strengthening of the SEEMP, and improvement of operational energy efficiency

Further, the Committee adopted MEPC resolution on invitation to Member States to encourage voluntary cooperation between the port and shipping sectors to contribute to reducing GHG emissions from ships. To stimulate the discussion on GHG reduction measures, the Committee agreed to hold intersessional meeting in November 2019 and March 2020.

2.2 Air pollution

2.2.1 2020 global cap of sulphur content in fuel oils

Regulation 14 of MARPOL Annex VI sets out control measures to reduce emissions of Sulphur Oxides (SOx) and Particulate Matter (PM) from ships. From 1 January 2020, the limit of the sulphur content of any fuel oil used on board ships will be tightened from 3.50% m/m to 0.50% m/m outside emission control areas (ECAs).

At this session, 2019 Guidelines for Consistent Implementation of the 0.50% Sulphur Limit under MARPOL Annex VI were adopted. The Guidelines provide the following contents for procurement and use of compliant fuel oil.

- Properties of fuel oil to be considered

- Inspection items by flag States and port State control (PSC)
- Guidance for development of Fuel Oil Non-Availability Report (FONAR) to flag States and port States in case of non-availability of compliant fuel oil

Further, Guidance for Port State Control on Contingency Measures for Addressing Non-Compliant Fuel Oil, which describes how to address the case where the ship loads non-compliant fuel oil on board, was agreed. This guidance invites port State to consider whether the non-compliant fuel oil may be discharged to the port or retained on board, taking into account of environmental, safety, operational and logical implications. The port State, the flag State and the ship are also invited to work together to agree on the most appropriate solution to address the situation.

2.2.2 Sampling of fuel oil used on board

Following 0.10% sulphur limit required inside ECAs from 2015, onboard sampling for the verification of the sulphur content of fuel oil used on board ships are being undertaken at PSC inspections. At MEPC 70 Guidelines for onboard sampling for the verification of the sulphur content of fuel oil used on board ships were adopted.

At this session, draft amendments to MARPOL Annex VI to mandate the designated sampling points for the verification of the sulphur content of fuel oil used on board ships, and draft amendments to Appendix VI of MARPOL Annex VI to specify verification procedures for the sulphur content of fuel oil sample were approved. The Guidelines for onboard sampling were also amended to designate the sampling points.

Further, it was agreed to publish a circular to encourage early implementation of the above amendments to MARPOL Annex VI, prior to the adoption at MEPC 75.

2.2.3 Discharge of wash water from exhaust gas cleaning system (EGCS)

Regulation 4 of MARPOL Annex VI permits use of equivalent means as long as the reduction method is evaluated as to be equivalent to the required reduction of SOx in the regulation 14 of MARPOL Annex VI. An exhaust gas cleaning system (EGCS) is one of such equivalent means and EGCS complying with 2015 Guidelines for EGCS (resolution MEPC.259(68)) is to be used. Wash-water discharged from EGCS should meet wash-water discharge criteria in the Guidelines. On the other hand, some ports prohibit the use of EGCS due to the concern on the impact of the wash-water to marine environment.

At this session, new work programme of MEPC was agreed to investigate the environmental impact of the wash-water discharged from EGCS with a view to establishing uniform requirements. The investigation will be started at PPR Sub-Committee to be held in February 2020.

2.2.4 Failure of exhaust gas cleaning system (EGCS)

Installation of exhaust gas cleaning system (EGCS) is increased toward 2020 global sulphur cap and it was recognized that there is an urgent need to develop guidance on the failure of EGCS.

At this session, Guidance on recommended actions to take in the case of the failure of a single monitoring instrument and the EGCS fails etc. was adopted. The Guidance specifies the procedures that a short-term temporary emission exceedance due to the system response should not be considered as a breach, and the system malfunction that cannot be rectified within one hour is regarded as a breakdown and should be reported to flag States and port State’s Administration. The Guidance also specifies the procedures to show the ongoing compliance, in case of the failure of a single monitoring instrument, with other parameters continuing at the normal levels.

2.3 Ballast Water Management

During the discussion until MEPC 73, it was agreed to conduct commissioning testing of BWMS at its installation to ships, and also conduct sampling and analysis of treated ballast water to confirm the performance of the BWMS. In light of the above, it was pointed out that the commissioning testing, the sampling and analysis are not required at initial survey of the BWM Convention by the Convention itself.

At this session, draft amendments to BWM Convention were approved to specify the requirements to conduct commissioning test including the sampling and analysis. The draft amendments will be adopted at MEPC 75.

2.4 Others

2.4.1 Electronic record books under MARPOL

MARPOL Convention requires that ships are to be provided with several record books for the purpose of management of pollution prevention, such as oil record book specified in MARPOL Annex I. Today, electrification of record books spreads for ease of access and maintenance, and it was proposed to develop standards for implementation and use of electronic record books.

At this session, Guidelines for the use of electronic record books under MARPOL, and amendments to MARPOL Annex I, II, V and VI, as well as the NOx Technical Code to allow the use of electronic record books were adopted. On or after 1 October 2020, approval of the electronic record books will be needed if the electronic record books are used.

2.4.2 Marine plastic litter

With a view to tackling the problem of plastics in the oceans, MARPOL Annex V prohibits discharge of plastics from vessels. However, it was often pointed out that this prohibition regulation was not effective and that some additional actions were needed at IMO level to reduce plastic pollution in the marine environment. To solve this problem, it was agreed to conduct IMO study on marine plastic litter from ships to estimate the contribution to marine plastic litter by all ships.

At this session, terms of reference for the IMO Study was approved. Further, relevant Sub-Committees will consider the issues, such as reporting of accidental loss or discharge of fishing gear, and obligation to report the loss of containers.

2.4.3 Control of Harmful Anti-fouling Systems on Ships (AFS Convention)

AFS Convention entered into force in 2008 to prohibit the use of harmful organotin in anti-fouling paints used on ships, -i.e. TBT. European countries proposed to prohibit the use of anti-fouling paints that contains cybutryne under the AFS Convention.

At this session, draft amendments to AFS Convention were considered and it was recognized that further consideration is necessary on the controls of cybutryne which has already been used for existing ships' paint. PPR Sub-Committee, to be held in February 2020, will consider the matter further.

2.4.4 Guidelines for sewage treatment plant

MARPOL Annex IV stipulates requirements for the discharge of sewage from ships, and sewage treatment plant shall be approved in accordance with 2012 Guidelines on Implementation of Effluent Standards and Performance Tests for Sewage Treatment Plants (resolution MEPC.227(64)). However, it was reported there are cases where ships discharge virtually untreated sewage from type approved sewage treatment plant, and a proposal was made to strengthen the requirements.

At this session, new output to investigate the requirements for sewage treatment plant was approved. The relevant discussion will be started at PPR Sub-Committee.

2.5 Amendments to mandatory instruments

MEPC 74 adopted amendments to mandatory instruments as follows:

(1) EEDI for ice class ships

Amendments to MARPOL Annex VI to exempt category A ships as defined in the Polar Code from EEDI requirements were adopted.

Entry into force: 1 October 2020

(2) MARPOL Annex II and IBC/BCH Code

Amendments to MARPOL Annex II were adopted to specify requirements related to prewash and discharge of persistent floaters.

Further, amendments to IBC Code and BCH Code including provision of Hydrogen sulphide (H2S) detection equipment for bulk liquids and revision of minimum requirements were also adopted.

Entry into force: 1 January 2021

(3) Electronic record books

Amendments to MARPOL Annex I, II, V and VI, and the NOx Technical Code to allow the use of electronic record books under MARPOL were adopted.

Entry into force: 1 October 2020

(4) SCR Guideline

NOx certification of diesel engines fitted with SCR is conducted in accordance with procedures referred to as Scheme A, in which NOx emission measurement test is conducted on diesel engines combined with an SCR, or Scheme B in which NOx emission measurement test for diesel engine without an SCR as well as NOx reduction efficiency measurement test for the SCR itself are conducted separately. The current NOx Technical Code stipulates that Scheme B is applicable in cases where the Administration deems that the combined testing (Scheme A) is not appropriate.

At this session, amendments to the NOx Technical Code 2008, to make the approval by the Administration unnecessary for applying Scheme B and allow Scheme A and Scheme B to be equally applicable were adopted. As per the amendments, either certification scheme can be selected by the applicants.

Further, amendments to 2017 Guidelines addressing additional aspects of the NOx Technical Code 2008 with regard to particular requirements related to marine diesel engines fitted with SCR systems, were also adopted to reflect the amendments to the NOx Technical Code.

Entry into force: 1 October 2020

3. OUTCOMES OF MSC 101

3.1 Adopted mandatory requirements

Mandatory requirements were adopted at MSC 101 as follows:

(1) Amendments to Forms C, E and P in the appendix to SOLAS certificates

Amendments to item 8.1 “Details of navigational systems and equipment - Rudder, propeller, thrust, pitch and operational mode indicator” in the appendix to Safety Certificate for Cargo or Passenger Ships (Forms C, P) and in the appendix to Safety Equipment Certificate for Cargo Ships (Form E) were adopted, in order to uniform the indication in case the equipment is not on board.

Applied: on or after 1 January 2024

(2) Amendments to FSS Code

Amendments to FSS Code Chapter 15, replacing the wording “forward of” with “downstream of” to avoid misunderstanding on design requirement of inert gas system, were adopted.

Applied: on or after 1 January 2024

(3) Amendments to IGF Code

Amendments to regulations on fuel tank locations (paragraph 5.3.4.2 of IGF Code), loading limit for liquefied gas fuel tanks (paragraph 6.8.3), fuel piping (paragraph 9.5.3~9.5.6), internal combustion engines of piston type (paragraph 10.3.1.1.1) and fire protection for fuel storage hold space (paragraph 11.3.3, 11.3.3.1), were adopted.

Applied: on or after 1 January 2024

(4) Amendments to LSA Code

Two (2) amendments to the LSA Code were adopted as listed below.

1. Amendments to LSA Code 4.4.8.1 that the requirement of buoyant oars and related equipment is not applicable for lifeboats equipped with two independent propulsion systems.
2. Amendments to LSA Code 6.1.1.3, in order to accept launch of a rescue boat with manual hoisting from the stowed position and turning out to the embarkation position by one person instead of stored mechanical power on cargo ships equipped with the rescue boat which is not one of the ship's survival craft, having a mass not more than 700 kg in fully equipped condition.

Applied: on or after 1 January 2024

(5) Amendments to IBC Code

Amendments to IBC Code Chapter 15 (Special requirements), Chapter 16 (Operational requirements), Chapter 17 (Summary of minimum requirements), Chapter 18 (List of chemicals to which the Code does not apply), Chapter 19 (Index of products carried in bulk), Chapter 21 (Criteria for assigning carriage requirements for products subject to the IBC Code), etc. were adopted following a comprehensive review of carriage requirements for products subject to the IBC Code. The detail of the amendments would be informed by issuing ClassNK Technical Information separately.

Applied: on or after 1 January 2021

(6) Amendments to 2011 ESP Code

Amendments to 2011 ESP Code were adopted to align with IACS unified requirements (UR) Z10 series and to modify expression of the mandatory requirements of the Code, etc.

Applied: on or after 1 January 2021

(7) Amendments to IMSBC Code

The 5th amendments to IMSBC Code including new cargos were adopted. The detail of the amendments would be informed by issuing ClassNK Technical Information separately.

Applied: on or after 1 January 2021 (Administrations may apply it on a voluntary basis as from 1 January 2020)

3.2 Approved mandatory requirements

The following mandatory requirements were approved at this session, and are expected to be considered for adoption at MSC 102 in May 2020.

(1) Amendments to SOLAS regulation II-1/3-8 relevant to mooring equipment

New Guidelines on the design of mooring arrangements and the selection of appropriate mooring equipment and fittings for safe mooring and new Guidelines for inspection and maintenance of mooring equipment including lines were approved in principle as shown in below 3.3.2.(1). Accordingly, amendments to SOLAS regulation II-1/3-8 to refer to those Guidelines were also approved.

(2) Amendments to B-1 to B-4 of SOLAS chapter II-1 to ensure consistency with regard to watertight integrity

Amendments to B-1 to B-4 of SOLAS chapter II-1 were approved to ensure consistency with regard to watertight integrity.

(3) Amendments to IGF Code

Three (3) amendments to the IGF Code were approved as listed below.

1. In paragraph 6.7.1.1, to remove tank cofferdams from the scope of requirement of pressure relief system.
2. To add new paragraph 11.8, in order to require fixed fire-extinguishing system for fuel preparation rooms.
3. To modify paragraph 16.3.3.5.1 concerning tensile tests for materials such as aluminium alloys.

(4) Amendments to IGC Code

As well as the amendments to the IGF Code as mentioned in above 3.2.(3)3, amendments to paragraph 6.5.3.5.1 of the IGC Code concerning tensile tests for materials such as aluminium alloys were approved.

3.3 Approval of unified interpretations (UIs), guidelines and guidance etc.

The following unified interpretations (UIs), guidelines and guidance etc. were approved during MSC 101.

3.3.1 Unified interpretations (UIs)

(1) Amendments to unified interpretations to include provisions on openings to ventilation systems for closed ro-ro and vehicle spaces

Amendments to the interpretations (MSC.1/Circ.1535, MSC.1/Circ.1537, MSC.1/Circ.1539) were approved in order to include provisions to consider openings to ventilation systems for closed ro-ro and vehicle spaces in respective stability calculation required within LL, 2008 IS Code and SOLAS.

(2) Unified interpretation on 2008 IS Code

The interpretation for Part B 3.4.2.3 of 2008 IS Code was approved to clarify assumed loading conditions to calculate the intact stability for tankers assigned with a tropical load line.

(3) Unified interpretation relevant to liquid level monitoring systems of passenger ships

The interpretation was approved for the sake of clarification that liquid level monitoring systems serving tanks containing liquids, which are used as, or replace flooding detection systems of passenger ships, should also meet the safe return to port (SRtP) requirements in SOLAS regulation II-2/21.4.13.

(4) Unified interpretation on SOLAS Chapter II-2

Three (3) unified interpretations on SOLAS Chapter II-2 were approved as listed below.

1. The interpretation for regulation 9.2 to clarify the required fire integrity of a separated space, in which urea or sodium hydroxide solution tanks for EGCS etc. were installed.
2. The interpretation for regulation 9.7.5 clarifying requirements in case where fixed gas fire-extinguishing systems are installed for galley exhaust ducts.
3. The interpretation for regulation 10.10.4 to provide details on explosion proof and intrinsically safe of two-way portable radiotelephone apparatus for fire-fighter's communication.

(5) Unified interpretation on SOLAS Chapter III

Two (2) unified interpretations on SOLAS Chapter III were approved as listed below.

1. The interpretation of regulation 20.11 in order to clarify that overhauls and operational tests of lifeboats, rescue boats and their launching appliances and release gear carried out at intervals of at least once every five years should be done in the presence of the surveyor. (related to IACS UI SC144)
2. The interpretation to clarify that a lifebuoy fitted with both a light and a lifeline for compliance with SOLAS regulation II-1/3-9 should not be taken into account when considering the minimum number and distribution of lifebuoys under

regulation III/22.1.1 and III/32.1.1.

(6) Unified interpretation on IGC Code

Two (2) unified interpretations on IGC Code developed by SSE Sub-Committee were approved as listed below.

1. The interpretation, on the application of the design temperature for piping, fittings and related components of the water-spray system within cargo area as required by paragraph 11.3.6, to clarify the scope of the "cargo area".
2. The interpretation to clarify the onboard discharge test of a dry chemical powder fire-extinguishing system as required by paragraph 11.4.8.

Four (4) unified interpretations on IGC Code developed by CCC Sub-Committee were approved as listed below.

1. The interpretation of paragraph 4.19.1.6 to clarify that duplication of heating system components is required in essential, as redundancy requirement for heating system to protect ship structure. (related to IACS UI GC23)
2. The interpretation of paragraph 5.13.1.1.4 to clarify that an emergency shutdown valve in which components made of materials do not contribute to the shell or seat tightness of the valve, should not be included in the requirement of melting temperatures. (related to IACS UI GC24)
3. The interpretation of paragraph 11.3.1 clarifying that remote survival crafts facing the cargo area should be protected by a water-spray system. (related to IACS UI GC22)
4. The interpretation of paragraph 11.3.3 providing clarification on "two complete athwartship tank groupings" those which an appropriate protection is necessary in consideration of the capacity of the water spray pumps. (related to IACS UI GC22)

(7) Unified interpretation on SOLAS regulations II-1/28, II-1/29 and II-1/30

The interpretation for regulations II-1/28, II-1/29 and II-1/30 on propulsion and steering considering modern combined propulsion/steering systems such as azimuth thrusters, etc. was approved. (related to IACS UI SC242)

(8) Unified interpretation on IGF Code

Four (4) unified interpretations on IGF Code were approved as listed below.

1. The interpretation of paragraph 6.3.10 providing clarification as to whether or not drip trays are required to protect the deck from leakages from tank connections of liquefied gas fuel storage tanks. (related to IACS UI GF2)
2. The interpretation of paragraph 12.4 and 12.5 which introduces that categorization of gas admission valves at dual fuel engines and gas engines is equivalently applicable to the examples for hazardous area zones as laid out in paragraph 12.5, provided with an appropriate risk assessment.
3. The interpretation of paragraph 12.5.2.1 to clarify the hazardous area classification of fuel storage hold spaces. (related to IACS UI GF14)
4. The interpretation of paragraph 15.10.1 to provide clarification on requirements of audible and visual alarm for ventilation system. (related to IACS UI GF15)

3.3.2 Guidelines, guidance and other circulars

(1) Two (2) sets of new guidelines and one (1) revised guidance on mooring equipment

Guidelines and guidance relevant to mooring equipment were approved in principle as listed below. These are expected to be finally approved in conjunction with the adoption of the draft amendments to SOLAS regulation II-1/3-8 referred to in above 3.2.(1) and would take effect on 1 January 2024.

1. New Guidelines on the design of mooring arrangements and the selection of appropriate mooring equipment and fittings for safe mooring
2. New Guidelines for inspection and maintenance of mooring equipment including lines
3. Amendments to the Guidance on shipboard towing and mooring equipment (MSC.1/Circ.1175)

(2) Amendments to the Guidelines on alternative design and arrangements for SOLAS chapters II-1 and III

The Guidelines on alternative design and arrangements for SOLAS chapters II-1 and III (MSC.1/Circ.1212) were amended to presents goal, functional requirements and expected performance criteria for SOLAS Chapter III.

(3) Amendments to the Guidelines for developing operation and maintenance manuals for lifeboat systems

The Guidelines for developing operation and maintenance manuals for lifeboat systems (MSC.1/Circ.1205) were amended in order to make reference to Assembly resolution A.1116(30) on escape route signs and equipment location markings resolution.

(4) Amendments to Assembly resolution A.658(16)

Draft amendments to Assembly resolution A.658(16), which is referred to in 1.2.2.7 of LSA Code, in order to accept weatherometer other than carbon arc type on accelerated weathering test for retro-reflective material, were approved. The draft amendments are expected to be adopted at 31st Assembly Committee (A31) in November 2019.

(5) MSC circular on carriage of Chapter 19 products, amended IGC Code

The circular which provides example of an addendum to IGC Certificate to enable for ships constructed on or after 1 July 1986 and before 1 July 2016 to carry the additional products listed in Chapter 19 of the amended IGC Code (resolution MSC.370(93)) was approved.

(6) Update of lists of solid bulk cargoes for which a fixed gas fire-extinguishing system may be exempted

In relation to the amendments to IMSBC Code as indicated in above 3.1.(7), MSC.1/Circ.1395/Rev.3 was amended to update a list of solid bulk cargoes, for which a fixed gas fire-extinguishing system may be exempted.

(7) Guidance for navigation and communication equipment intended for use on ships operating in polar waters

Guidance for navigation and communication equipment intended for use on ships operating in polar waters, which is consist of Module A (General part related to equipment under environmental conditions of the Polar waters) and Module B (Specific part on selected equipment), was approved.

(8) Interim guidelines on life-saving appliances and arrangements for ships operating in polar waters

Interim guidelines on life-saving appliances and arrangements for ships operating in polar waters, including the requirement of personal life-saving appliances and survival crafts etc., were approved.

(9) Interim guidelines for minimizing the incidence and consequences of fires in ro-ro spaces and special category spaces of new and existing ro-ro passenger ships

Interim guidelines for minimizing the incidence and consequences of fires in ro-ro spaces and special category spaces of new and existing ro-ro passenger ships were approved. The guidelines consist of following five (5) items.

1. PREVENTION/IGNITION
2. DETECTION AND DECISION
3. EXTINGUISHMENT
4. CONTAINMENT
5. INTEGRITY OF LIFE-SAVING APPLIANCES AND EVACUATION

3.4 Others

(1) Consideration of requirements for Maritime Autonomous Surface Ships (MASS)

Taking into account recent investigation of automation surrounding a ship, it has been discussed at MSC on conventional requirements of safety and environmental protection relating to MASS.

At this session, in accordance with the framework and methodology for Regulatory Scoping Exercise (RSE) which have been agreed at previous MSC 100, the ongoing working progress of first step (identification of provisions in IMO instruments) of the RSE in each convention or chapter basis was reported. The final consideration on the working output of RSE might be given at MSC 102 held in May 2020.

Further, interim guidelines for MASS trials were approved. These Guidelines indicate principles and main objectives which should be used when conducting trials of MASS-related systems and infrastructure.

(2) Consideration of measures to enhance the safety on use of fuel oil

Triggered by the global 0.5% sulphur limit, which will enter into force on 1 January 2020, safety measures on use of fuel oil have been discussed, in order to develop SOLAS requirements in addition to requirements of MARPOL.

In conclusion at MSC 101, MSC resolution on Recommended interim measures to enhance the safety of ships relating to the use of oil fuel was adopted, to recommend flag States to report the cases of deliveries of oil fuel having a flash point of less than 60℃ to IMO.

In addition, action plan for the development of measures to enhance the safety of ships relating to the use of oil fuel was endorsed, with a view to finalizing the measures at MSC 104 in 2021. In accordance with the action plan, development of the relevant mandatory requirements, such as amendments to SOLAS Chapter II-2, would be proceeded.

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