Challenge of Technology Development through MEGURI 2040

— For Safe Navigation and Workload Reduction —

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1. INTRODUCTION

Ships, which are capable of transporting large volumes of cargos at one time, will play a key role in a modal shift as a means of transportation with low environmental impacts. Even though Japan is an island country, it has long been possible to obtain desired items anytime and anywhere in this country thanks to economic growth and globalization of the economy. International shipping companies transport raw materials and products from overseas to Japan and transport domestics goods to other countries, while coastal shipping companies in transport cargos shipped and delivered inside Japan, including those transported by international shippers. The coastal shipping industry fulfils an important function in the supply chain with other countries and is part of the infrastructure of daily life that supports domestic logistics, but has also faced labor shortages due to Japan's declining population and a special work environment different from that on land for many years. Although a reconsideration of capitalist society is now widely discussed against the backdrop of environmental destruction and the increasingly frequent and large-scale natural disasters associated with climate change, rapid changes in systems that were constructed and used over many years do not appear realistic. If this is so, it is self-evident that pork from America, salt from Mexico and iron ore from Australia will continue to be necessary, whether we aware of it or not, and the coastal shipping industry will also be a necessary presence as the infrastructure for supplying those and other goods. To provide stable supply service and promote a modal shift, it will be necessary to make efforts to improve the workplace environment by reducing the workload on seamen, and to improve navigational safety by preventing human error caused by inadequate watch duty and improper ship handling, which is also an issue.

In responding to these issues, a consortium of coastal ship companies and shipbuilders, equipment manufacturers, engineering companies and others is planning to conduct demonstration experiments of unmanned ships as part of the activities of the MEGURI 2040 Project sponsored by Nippon Foundation, which has the same sense of crisis. In this article, the author will present an overview of the MEGURI 2040 Project and examine whether its technologies offer a solution to the above-mentioned issues.

Here, the author wishes to note that his career to date has mainly involved sales and purchasing work in profit-and-loss departments, beginning with the containership department and also including start-ups of logistics projects with other companies, and he does not possess a technical background. Thus, this technical report was written from the viewpoint of the survival, business expansion and differentiation of services of shipping companies. The reader's understanding of this point is requested.

2. MEGURI 2040 PROJECT

The MEGURI 2040 Project, which is sponsored by the Nippon Foundation, was started in February 2020 with the aim of solving the problems of shortages of seamen due to an aging workforce, maritime accidents caused by human error and other challenges facing the coastal shipping industry by realizing unmanned ships. Demonstration experiments are to be conducted by the end of fiscal year 2021.

2.1 Current Status of Shortage of Seamen in Coastal Shipping

According to Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT), 28,435 seamen were employed in coastal shipping as of 2019, but the workforce is aging, as almost half of them were 50 years or older [1]. Moreover, persons aged 60 years and older accounted for more than 35 % and can be expected to retire within a few years. On the other hand, the number of suitable young seamen is small, as the percentage of seamen under age 30 is a little less than 20 %, indicating that the shortage of seamen is becoming a chronic structural problem. These conditions have led to labor pirating, i.e., efforts to hire away coastal

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seamen from other companies, and conditions where dozens of companies may attempt to recruit a single resigning seaman. This is also borne out by statistical results showing that 35 % of resigning seamen cite "personal reasons" as the reason for resigning after less than 1 year in a company. As a result, all companies consider securing the necessary number of seamen to be their highest priority, and efforts to ensure safe navigation have been shelved and are not contributing to reducing accidents.

Against this background, companies have improved the working environment for seamen, for example, by improving crew spaces, providing more toilets and shower rooms, installing complete Wi-Fi and introducing new navigational devices. Nevertheless, conditions have continued to deteriorate due to an absolute shortage of seamen, as seen in extended embarkation periods and increased total working hours because no replacement personnel are available. For ship owners, reducing the workload on seamen is the highest priority item. If it is possible to realize automation during voyages and ultimately, autonomous operation of ships, this is expected to lead to a reduction of workloads and a more stable shipboard life for seamen by reducing the number of watches to even one to two watches.

2.2 Causes of Accidents

The majority of accidents at sea are caused by human error in the form of poor performance of watch duties, improper steering, failure to check the ship's position, inattention to weather and sea conditions, inadequate investigation of channels and the like [2]. What causes human error? In short, human error occurs "because we're human," but even a little analysis suggests various causes, such as human misapprehensions and assumptions, loss of concentration, failure to think deeply and panic in the face of unexpected situations. Countermeasures have focused crew training and various types of campaigns, that is, approaches to improve human performance, but this has not eliminated human error. Rather than saying "we're only human" and resigning ourselves to this situation, an approach that prevents the occurrence of human error by mechanization and automation is necessary. One aim of this Project is to verify the technical aspects of those efforts.

2.3 Purposes of Participation by Mitsui O.S.K. Lines

Although crew workload reduction and safe navigation do not directly concern the shortage of seamen, they are also important issues in the international shipping industry. Mitsui O.S.K. Lines decided to participate in the MEGURI 2040 Project with the aims of continuously provide stable service and stimulating demand for maritime transportation in both international and coastal shipping by solving these problems.

3. OVERVIEW OF DEMONSTRATION EXPERIMENTS

An autonomous navigation system will be retrofitted on existing coastal ships, and an experiment consisting of unmanned operation from unberthing to berthing will be conducted. In actuality, however, these ships will carry a normal crew. Since the manning requirements for seamen are specified in the laws which are currently in force, and no special treatment is provided for responsibility in case of unmanned navigation, the person responsible for ship operation in the demonstration experiments will be the captain, and actions to interrupt or stop the experiment will be made on the captain's judgment. The system and operation also make it possible to switch quickly from autonomous operation to ordinary manual operation during the experiment.

The Project was started in February 2020, and demonstration experiments in actual waters are planned for the second half of 2021 through early 2022 (end of FY 2022), while also developing and verifying the element technologies.

3.1 Demonstration Experiment Ships

The demonstration experiments will be conducted with ships of two different sizes and types, a large-scale car ferry called the "Sunflower Shiretoko" (owned and operated by MOL Ferry Co., Ltd.), which is a driving force in modal shift, and 749 type container ship, the "Mikage" (owned by Imoto Corporation, operated by Imoto Lines, Ltd.), which is a mainstay-size ship in coastal shipping. The demonstration experiment routes of the respective vessels will actual waters spanning 400 miles from Tomakomai Port to Oarai Port and 145 miles from Tsuruga Port to Sakai Port, respectively.

Table 1　Principal particulars and experiment routes of demonstration experiment ships

Ship name	Sunflower Shiretoko	Mikage
Type	Car ferry	Containership
Gross tonnage	11 410 t	749 t
LOA	190.0 m	95.5 m
Beam	26.4 m	13.5 m
Draft	6.85 m	3.8 m
Propellers	CPP × 2 units	CPP × 1 unit
Thrusters	BT × 2, ST × 1	BT × 1
Commercial route	Tomakomai Port ⇔ Oarai Port	Various
Demonstration experiment route	Tomakomai Port → Oarai Port (400 miles)	Tsuruga Port → Sakai Port (145 miles)


Figure 1　"Sunflower Shiretoko"

Figure 2　"Mikage"

3.2　Technology Development

Autonomous operation is realized by perception and cognition, judgment, and control (operation). Cognition means estimation of the position, course, speed and heading from the own ship of perceptual information (i.e., other ships, buoys and obstacles) obtained from various sensors, and sensor fusion which integrates that information. Judgment and control comprise the course planned by seamen, the predicted behavior of other ships in the vicinity of the own ship, creation of candidate collision avoidance paths based on nautical chart information and evaluation of those alternative paths and course and path following control.

Technology development of the perceptual and cognitive portion of demonstration experiment ships will be carried out by Furuno Electric Co., Ltd., and technology development of the judgment and control portion will be the responsibility of Mitsu E&S Shipbuilding Co., Ltd. As a mooring support technology, a technique for dropping heaving lines from the ship to the quay by using a drone (unmanned aerial vehicle: UAV) will be developed by A.L.I. Technologies.

Table 2　Outline of fields and companies responsible for developed technologies

	Perceptual & cognitive	Judgment	Operation
Developer	Furuno Electric Co., Ltd.	Mitsui E&S Shipbuilding Co., Ltd.	
Outside port	Own ship surroundings cognitive technology	Collision avoidance manoeuvring automation	
Inside port		In-port manoeuvring automation	
	Berthing/unberthing support system	Berthing/unberthing automation	
	Mooring support system (A.L. I Technologies)		

The accuracy of these respective technologies is currently being improved based on repeated feedback from the ship companies and seamen who will be the users.

3.3 Guaranteeing Safety

A risk assessment by the HAZID technique was conducted by ClassNK Consulting Service Co., Ltd. and Nippon Kaiji Kyokai (ClassNK), which were appointed for this work. The items examined for the two demonstration experiment ships consisted of i) Review of operation and new technologies of unmanned ships, ii) Identification of potential hazards related to unmanned ships, iii) Investigation of the effectiveness of existing safety measures by risk analysis and iv) Additional risk control measures if necessary. A simple version of the manual was prepared for easy reference by seaman to enable sure feedback when hazards occur during a demonstration experiment.

For the technologies of collision avoidance automation, automation of manoeuvring when in port and automation of berthing/deberthing, the demonstration experiments with the actual ships will be carried out after verification of collision avoidance action and identification of points requiring improvement by using a 3D shiphandling simulator developed by MOL Marine & Engineering Co., Ltd. and implementation of the appropriate countermeasures.

3.4 Cooperation System

A cooperation system involving many persons is necessary in large-scale demonstration experiments using ships that are actually in commercial operation, as in this Project. Coordination of this system is a role of the shipping company.

Naturally, the consortium members explained these demonstration experiments to a large number of related parties, including the MLIT, Japan Coast Guard, the Maritime Safety Agency offices in each port, the port administrators and port controllers, fishery cooperatives, and the users of cruisers and fishing boats using the ports.

4. DIFFICULTIES CONFRONTED

Because one condition of the grant from the Nippon Foundation was demonstration experiments using existing coastal ships, that is, ships which are in commercial operation, the operating schedules of the ships were arranged, and a schedule for entry into dock for equipment installation and element experiments was drawn up. In arranging the operating schedules of the ships for the demonstration experiments, generous cooperation by the ship owners and operators, Imoto Corporation, Imoto Lines and MOL Ferry Co., was necessary in deciding to forgo current profits in order to invest in the future potential of these technologies.

In the case of the containership “Mikage,” a number of engineers and related parties will be aboard the ship during the demonstration experiment. Because the number of persons onboard exceeded the ship’s official capacity, it was necessary to complete temporary navigation procedures in order to temporarily increase the ship’s capacity. The ship’s living quarters were also upgraded and additional lifeboats and life vests were provided.

In the demonstration experiment using the 3D simulator, the desired control was not possible because the cycle of the signal output from the simulator was different from that of the automatic shiphandling module. This problem was resolved safely by modifying the device.

5. FINDINGS OF THE STUDY

Although the demonstration experiments are scheduled to be performed during the present fiscal year 2021, which is the final year of the MEGURI 2040 Project, the following describes the findings of the study up to this point.

5.1 Perspective of System

As the first finding of this study, the perspective of seamen and the perspective of the system used in the experiments are different. For example, in docking at a pier, a human agent (captain, etc.) determines the condition of the ship (ship position, approach angle, distance to quay, etc.) by observing the distance and angle between a part of the ship’s structure such as the mast light and a landmark on land. In contrast, the system steers the ship by using the distance and angle from the bow, stern and bridge to the quay as various types of sensor information. The former is an intrinsic perspective, that is, a subjective perspective, whereas the latter is an extrinsic perspective using back-calculation from the purpose or system design. Human agents do not have any means of evaluating this determination of the ship’s condition from a completely different perspective. Even assuming a human agent understands the meaning of the numerical values, which are different the ordinary perspective, that person does not use those values in steering the ship. Thus, it is reasonable to think that the human (mariner) cannot perform an evaluation of their validity and safety. Moreover, a cross-evaluation between different human agents is difficult because the guidelines and numerical values used as references differ depending on the captain.

5.2 Evaluation of Shiphandling Method

Since this is the case, the object of evaluation is the movements of the ship based on those sensor values. This was the second finding of the study. It is appropriate to evaluate the aimed ship position and attitude after certain minutes by turning the rudder at a certain timing and to what angle. However, there is one problem here: Because steering methods also differ depending on the captain, the evaluation standard is whether the steering method is "acceptable" or not. Although an acceptable method may also be the best method, the evaluation standard is whether it is acceptable or not. In other words, it is not possible to evaluate whether the plan and movements displayed by the system represent the optimum solution or not. Thus, there are as many solutions as there are systems, and even the same system will give different solutions when logic and parameter tuning are performed. This suggests that autonomous navigation, including these unmanned ships, will contain huma-like elements, and just as humans make mistakes, the system can even also make mistakes. In order to judge this, a human machine interface (HMI) which makes it possible to understand the plan for the future and the present situation is needed. HMI is a tool for communication between humans and the system. In addition to use it on the ship, HMI is necessary and indispensable for remote monitoring and at the same time, it is also essential for improvement of the system.

5.3 Perception and Cognition by Sensors

Now let us return to the discussion of the sensors. Various statistics show that the majority of accidents are caused by human error, and many of those accidents are caused by failure to perform watch duty or poor watch performance, for example, overlooking other ships or obstacles and erroneous judgment of their condition. Although the navigation officer keeps watch by visual observation or by monitoring navigational instruments such as radar, ECDIS, etc., depending on the waters and the degree of visibility, it often happens that veteran navigators recognize other ships and observation more reliably. While some people may call this "intuition," it is the result of experience. That is, cognition which is capable of recognizing whether an object is a ship or not is possible as a result of accumulating experience in making total judgments of multiple information, such as the appearance of objects in clear weather, rainy weather and at night, how the object moves, how the object responds to the movements of the own ship, whether land is nearby, the water depth in the area, and so on. This is quite difficult for young navigators with limited experience.

On the other hand, computers can memorize patterns in which the appearance in a certain environment indicates a certain type of object and calculate their probability. Therefore, there is a high possibility that a computer can realize superior perception at night-time, in heavy fog and under other low-visibility environments that are difficult for humans. However, in order to achieve cognition on the same level as veteran navigators, it is considered necessary to develop an algorithm that realizes the similar logic as the perception and cognition performed by humans, including the above-mentioned function of making total judgments from multiple information, and a function for making corrections in judgments that have already been given based on information that changes with the passage of time. This is the third finding.

5.4 Investment in Sensor Technology

Then, what types and numbers of sensors should be installed on an unmanned ship? Because costs will increase depending on the number of sensors installed, there is little incentive to introduce sensors which do not have large visible effects. "Large effects" are not a characteristic of the sensor as such. It is necessary to show how the sensors contribute to safe navigation, and then how they contribute to reducing the workload of seamen by expanding the scope of discussion to include cognition, judgment and operation. Realistically, however, the number of sensors that can be added in addition to existing sensors is probably limited.

Another issue is how to estimate tidal currents and waves, since these phenomena cannot be captured by sensors. In systematizing the sensory process of human beings, estimation may be possible by developing an algorithm. Therefore, as the fourth finding, this Project revealed the necessity of system integration is performed by systemic design, in which the information to be acquired is selected and utilized in perception, judgment and operation.

5.5 Time Required from Development to Verification

The fifth finding is the large amount of time required to conduct the experiment. Unlike automobiles, the specifications of ships are different in every ship. Even assuming sister ships are built from the same design drawings, the performance of the two ships will not necessarily be the same if the shipbuilding berth is different. In explaining this difference, the auto industry spends considerable time and uses a number of prototype cars in performance and durability testing before marketing a line of mass-produced automobiles with identical performance. However, in the shipping industry, ship type development and performance evaluations inevitably rely on CFD and tank tests using ship models due to the small production volume, long time required for shipbuilding and high unit cost of the ships. That is, in the case of ships, adjustment of one cognition system, one judgment system, one operation system and the autonomous navigation system integrating those systems in each ship is invariably necessary. The fact of individual adjustment might also be the same in automobiles, but the timing and duration are different. As noted above, in automobiles, new performance is evaluated before a product is marketed. Tests are conducted under every conceivable environment, including wet pavement, environments with poor visibility, strong winds, environments with prolonged high temperatures and under high/low humidity conditions, and the model is only marketed after passing those tests. In the case of a ship, adjustments are made after construction is completed because performance and durability are evaluated using the actual ship in a substantially completed form. In addition, adjustments may become necessary when the environment changes. Unless the ship is fortunate enough to have an engineer onboard when such situations arise, time is also required to produce a ship that can be used in any environment. Thus, in order to commercialize and disseminate this technology in a short time, it will be necessary to improve system integration to a level that enables judgment by the optimum combination of modules for each ship, and to improve reproducibility under various environments, as recommended in "Report of the Maritime Industry Future Image Study Group" [3].

6. PERSONAL OBSERVATIONS

One year has already passed since the start of the MEGURI 2040 Project, and various points have become apparent. Many of these points would not have been discovered without actually carrying out this work, and the issues that must be addressed have become clear. The author will look forward to seeing the condition when each of these problems has been solved and the experiments are conducted in the second half of FY2021.

On the other hand, many other issues also require study, such as securing redundancy, ensure safety, including the safety of other ships, by communication and mutual cooperation with other ships and navigation traffic control, engine automation, etc. The largest obstacle is economic rationality. The possibility of achieving results that justify the cost is both an old issue and a new one. Considerable costs are incurred in analyzing the functions performed by ship operators and automating each of the analyzed tasks. Referring to Fig. 3, this means obtaining external information not with the human senses, but with existing or newly-developed sensors; developing a system that appropriately selects or rejects, corrects and integrates the sensor values; developing an algorithm that judges what action to take based on those results; and installing a system that gives operational instructions. Ongoing investment is also necessary in order to improve the accuracy of those functions. Can we say that dissemination of this technology is a chicken-and-the-egg problem? Is a different approach needed in order to reduce costs? Is this a problem of the setting of the operational level? Will changes occur depending on the purpose? Hints might be found in the aviation industry, where automatic navigation technology has already been applied practically. Why do the pilots of aircraft use manual operation when taking off and landing, rather than relying on the autopilot function? This may be because there are airports where only manual operation is possible depending on the ground equipment, or for pilot practice, or for psychological reasons, that is, since the pilot must take the final responsibility if an accident occurs, the pilot cannot rely on machines in the high-risk situations of takeoff and landing. Although unmanned commercial airplanes still do not exist, the technical and psychological barriers to the concept of unmanned aircraft are even higher, and those barriers must be understood correctly and confronted head-on. Technologies that cannot be used will be discarded. The shortest road to actual adoption of a technology is not the self-satisfaction of the developer, but imaging the situations in which users will actually use the technology, and addressing those situations one by one.

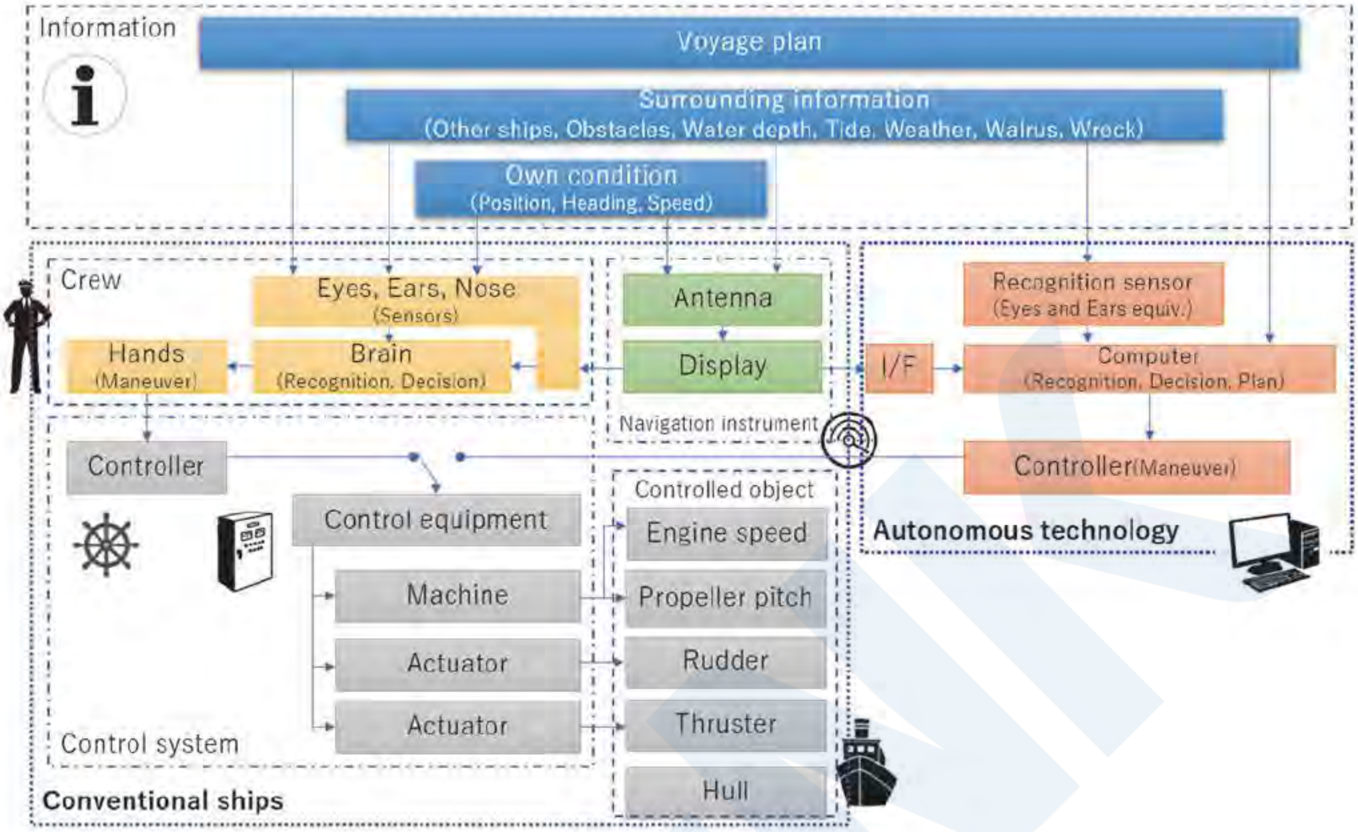

Figure 3 Differences with existing ships in service

7. CONCLUDING REMARKS

The author realizes that this is a prosaic contribution which is quite unsuitable for this Technical Report. Considering the title, I may be criticized for "false advertising." While I accept that criticism, in writing this article, I hoped to respond in some small way to the plain questions of readers concerning why a shipping company is participating in this Project, and what role we are playing.

In the Smart Ship Division of Mitsui O.S.K. Lines, where I work, the stance toward research and development is open innovation. We create new technologies that our company alone cannot produce by bringing together others who have their own respective strengths and roles. We do this for the participating companies, seamen and society. We promote research and development with this belief. Having said that, however, it is not possible to accomplish great things if no budget is available. If you do not try, you will not find out – there are landscapes that you cannot see until you start walking. In the MEGURI 2040 Project, the Nippon Foundation gave us that opportunity. During the remainder of this Project, we hope that we can continue to respond to the cooperation and enthusiasm of all the member companies of the consortium.

ACKNOWLEGMENT

First, I wish to express my heartfelt thanks to the Nippon Foundation for giving us the opportunity to carry out this technical development with the support of the MEGURI 2040 Project.

We also received generous cooperation from the members of the consortium, of course, and also from the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), the Japan Coast Guard, the Maritime Safety Agency offices at the ports concerned, the port administrators and port controllers, fishery cooperatives, and the users of cruisers and fishing boats that use at the ports, among others. I am strongly aware that this experiment was only possible because of sympathizers and supporters of this project, and I would like to take this opportunity to thank all those concerned.

We also received generous cooperation from the ship owners/operators, Imoto Corporation, Imoto Lines and MOL Ferry Co., who adjusted the schedules of the demonstration ships for preparations for the experiment. In particular, I wish to thank the

many seamen who spared their own vacation and rest time to participate in the demonstration experiment.

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