MARITIME AUTONOMOUS SURFACE SHIPS：DEVELOPMENT TRENDS AND PROSPECTS

— HOW DIGITALIZATION DRIVIES CHANGES IN MARITIME INDUSTRY—

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SUMMARY

- With the digitalization advancement in the maritime industry, the development of autonomous ships is making headway, especially in Europe, and initiatives have been launched in Japan as well.
- Autonomous ships not only save on labor and enhance safety, but also bring change to the industry structure and influence the entire maritime transportation infrastructure.
- "Autonomous ship integrators" are expected to emerge to perform the role of highly integrating maritime-related sectors, including shipbuilding, marine transportation, port operations, and warehousing.

Interest in autonomous ships is growing rapidly because the high levels of safety and efficiency that can be attained by such ships are thought to have the potential to provide solutions for problems in the maritime industry, such as for the prevention of marine accidents and the improvement of the work environment. Autonomous ships are scheduled to be put into practical use as coastal vessels in some areas overseas from as early as the first half of the 2020s. As ships become equipped with increasingly advanced automation functions, beginning with ships using IoT, fully unmanned autonomous ships are also expected to be realized in the future.

This report presents details of development trends for large-scale autonomous ships and describes the accompanying structural changes in the maritime industry.

1. OVERVIEW OF MARITIME AUTONOMOUS SURFACE SHIPS

1-1. What is an Autonomous Ship?

Autonomous ships are highly automated (autonomous) or remotely controlled ships and their operating system. These ships use the latest technology, such as IoT, ICT, data analysis technology and onshore monitoring/control bases connected by broadband communication, and automatically operate a part of or all of onboard tasks associated with ship operations, such as observing its surroundings (lookout), equipment status monitoring, ship maneuvering, engine control, cargo management/loading, docking and undocking, and others.

Autonomous ships are said to contribute to improving the safety and efficiency of maritime transportation, the work environment and workplace attractiveness for seafarers, and increasing the competitiveness of maritime industry, such as marine transportation, shipbuilding, and other maritime business.

At the 99th meeting of the Maritime Safety Committee (MSC) of the International Maritime Organization (IMO) held in May 2018, four degrees of automation were presented as provisional definitions of autonomous ships (Figure 1).

Figure 1: IMO definitions of autonomous ships (provisional)

Degree 1	Ships with automated processes and decision support	Seafarers are on board to operate the ship. Some operations may be automated.
Degree 2	Remotely controlled ship with seafarers on board	The ship is controlled and operated from another location, but seafarers are on board.
Degree 3	Remotely controlled ship without seafarers on board	The ship is controlled and operated from another location. There are no seafarers on board.
Degree 4	Fully autonomous ship	The operating system of the ship is able to make decisions and determine actions by itself.

Source: Compiled by MGSSI based on IMO press briefing, "IMO Takes First Steps to Address Autonomous Ships" (May 2018)

In addition, Lloyd's Register of Shipping (UK) has proposed more specific definitions than the IMO by presenting a system for classifying the autonomous level (AL) from Level 0 to Level 6, taking into account the degree of each advanced function, the location where assistant function is provided, and the degree of human involvement (Figure 2).

Figure 2: Autonomy levels proposed by Lloyd's Register of Shipping (UK)

Autonomy Level (AL)		Details
AL0	Manual - No autonomous function	—
AL1	On-ship decision support	All actions at the ship level are taken by a human operator, but a decision support tool can present options or otherwise influence the actions chosen, for example DP Capability plots and route planning.
AL2	On and off-ship decision support	All actions at the ship level taken by human operator on board the vessel, but decision support tool can present options or otherwise influence the actions chosen. Data may be provided by systems on or off the ship, for example DP capability plots, OEM configuration recommendations, weather routing.
AL3	"Active" human in the loop	Decisions and actions at the ship level are performed autonomously with human supervision. High- impact decisions are implemented in a way to give human operators the opportunity to intercede and override them. Data may be provided by systems on or off the ship.
AL4	Human on the loop – operator/supervisory	Decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human operators the opportunity to intercede and over-ride them.
AL5	Fully autonomous (& rarely supervised)	Unsupervised or rarely supervised operation where decisions are made and actioned by the system, i.e. impact is at the total ship level.
AL6	Fully autonomous (& with no supervision)	Unsupervised operation where decisions are made and actioned by the system, i.e. impact is at the total ship level.

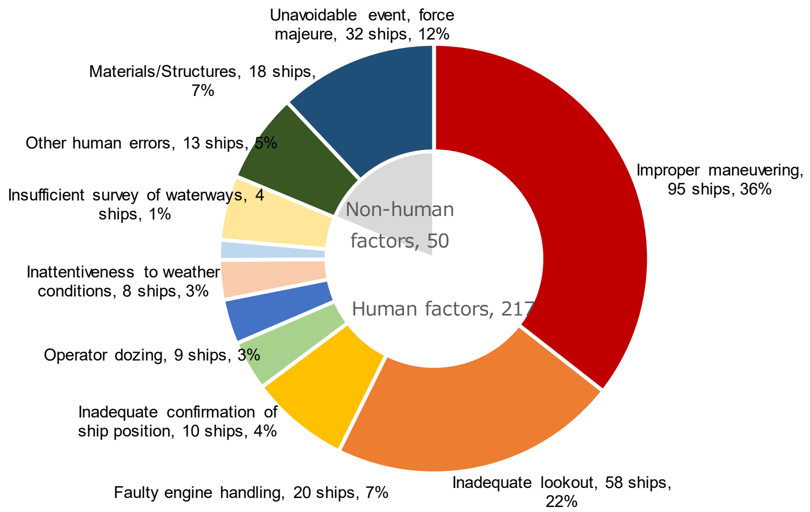
Source: Compiled by MGSSI based on a report by Lloyd's Register of Shipping (UK), "Autonomous Shipping 2019 and Beyond" (January 2019), and a Japanese-language report by Japan's Ministry of Land, Infrastructure, Transport and Tourism, "Challenges and Direction of Initiatives for Autonomous Ships" (December 2017).

Unlike automobiles, the autonomous ships are expected to have various kinds of automation because multiple crew members are responsible for many tasks other than ship handling, such as engine maintenance and cargo monitoring and even if only ship handling is automated, a fully unmanned autonomous ship cannot be realized.

1-2. What's Behind Expectations for Autonomous ships

According to the Japan Coast Guard, the number of maritime accidents has been decreasing in recent years, but approximately 80% of these accidents are caused by human factors (inappropriate maneuvering, inadequate lookout, etc.) (Figure 3). Also, according to the "Annual Overview of Marine Casualties and Incidents 2018" published by the European Maritime Safety Agency, 57.8% of accidents were attributable to human factors, illustrating a similar trend in other parts of the world. More advanced ship handling with the use of sensors is expected to improve the reliability of maritime transportation and to help prevent marine accidents.

Figure 3: Causes of cargo ship accidents in Japan (2018)



Source: Compiled by MGSSI based on the Japan Coast Guard's report, 2018 Status and Countermeasures for Marine Accidents (April 2019, Japanese language)

In addition, it has been suggested that the steady increase in the volume of global marine transportation will lead to a tight global market for seafarers in the future. In the case of coastal vessels, in particular, with the aging of seafarers continuing to progress, automation and other means are expected to help improve the work environment.

Amid such growing expectations, efforts toward the realization of autonomous ships are being boosted by wider adoption of the automatic identification system (AIS) for tracking ships, the electronic chart display and information system (ECDIS) for geographical charting, and other systems, along with the rapid advancement of maritime broadband communications, IoT, AI, and big data processing technologies, etc.

2. STATUS OF INITIATIVES FOR AUTOMATED SHIPS: GLOBALLY AND IN JAPAN

2-1. Overseas Initiatives: Europe Takes the Lead

Europe is positioned at the forefront of efforts to realize autonomous ships. The main projects implemented so far, and each company's efforts for practical use, are summarized in Figure 4.

In Europe, Rolls-Royce and Kongsberg Maritime play major roles. Both companies are leading in the development of autonomous ships by integrating existing ship technologies with new digital technologies, such as for sensors and AI. Since Kongsberg Maritime completed the acquisition of Rolls-Royce Commercial Marine in April 2019, the integration of the two companies that have been driving the development of autonomous ships in Europe has been attracting attention.

Figure 4: Europe's initiatives toward the development of autonomous ships

Projects with Industry-Government-Academia Collaboration (mostly in the conceptual stage)	
MUNIN (Maritime Unmanned Navigation through Intelligence in Network)	● Implemented from 2012 to 2015. ● With the support of the EU, the Fraunhofer Institute took the lead in developing the concept of unmanned vessels and conducting pilot programs. ● Announced the effect of improving fuel efficiency by 10% or more and reducing the risk of collisions and sinking.
AAWA (Advanced Autonomous Waterborne Applications Initiative)	● Implemented from 2015 to 2018. ● Led by Rolls-Royce, with the support of the government of Finland. ● Examined legal regulations and technical elements necessary for the realization of autonomous ships, and conducted research based on conceptual studies.
Efforts by Companies (primarily efforts toward practical applications)	
Yara International (major Norwegian fertilizer maker) and Kongsberg Maritime (maritime division of a Norwegian public-private enterprise)	● Unmanned electric container ship "Yara Birkeland" scheduled to be put into service in 2022. Yara Birkeland was developed by Kongsberg Maritime. ● Development is supported by a subsidy (approximately ¥1.8 billion) from the Norwegian government.
Rolls-Royce Commercial Marine (now a part of Kongsberg Maritime)	● Under the SVAN (Safer Vessel with Autonomous Navigation) project, demonstrated autonomous operation of a freight and passenger ferry (coastal ship) owned by Finland's Finferries in December 2018
Wärtsilä (Finnish marine engine manufacturer)	● Demonstrated autonomous operation of a freight and passenger ferry (coastal ship) owned by Norway's Norled in November 2018

Source: Compiled by MGSSI based on corporate and project press releases, including for MUNIN and AAWA

2-2. Efforts in Japan

Japan's Ministry of Land, Infrastructure, Transport and Tourism has been holding meetings for the Maritime Innovation Subcommittee since February 2016 to promote a productivity revolution in the maritime industry. Among the subcommittee's objectives, the autonomous ship is positioned as one of priority policy measures. In addition, the industry is also pursuing practical use, and the main initiatives are outlined in Figure 5.

2-3. Projections for Realization: Schedule and Level of Autonomy

According to the Nippon Foundation's report entitled, "Future 2040 — The Future of Japan Created by Unmanned ships", issued in April 2019, assuming that ships to be newly built in 2040 are mainly expected to be unmanned, and that 50% of domestic ships will be unmanned, the economic effect of unmanned ships is estimated at approximately ¥1 trillion in 2040.

Although efforts by various countries to realize autonomous ships are gaining momentum, it is expected that pilot projects and the introduction of such ships will proceed gradually in accordance with technological developments and needs. Based on various roadmaps announced by the Japanese government and industry, the expected schedule for realization and levels of autonomy are summarized in Figure 6.

The estimated schedule described in the figure is for the realization of autonomous oceangoing ships, which are said to face the highest hurdles for practical use.[1]

[1] Small radio-controlled ships and military ships with a total tonnage of less than 20 tons for oceanographic surveys and other applications have already been put into practical use. For coastal ships, the time required to reach realization is expected to be shorter.

Figure 5: Japan's initiatives toward the development of autonomous ships

Government Initiatives	
Ministry of Land, Infrastructure, Transport and Tourism	● Announced at the 7th Maritime Innovation Subcommittee in June 2018 to promote advanced technology development and demonstrations, take a leading role in the development of international standards and regulations, and achieve practical application of autonomously operated ships by 2025. Positioned autonomous ships as a priority goal alongside "i-Shipping (Note 1)" and "j-Ocean (Note 2)," and launched the following pilot projects: ・Demonstration of automatic ship handling functions: Oshima Shipbuilding, MHI Marine Engineering, others. ・Demonstration of remote maneuvering functions: NYK, MTI, others. ・Demonstration of automatic docking and undocking functions: Mitsui E&S Shipbuilding, MOL, others. ● Established the Maritime Innovation Strategy Promotion Headquarters in October 2018. Promoting efforts to realize autonomous ships by 2025 by conducting a comprehensive and swift examination of specific measures for realizing maritime innovation. ● Strengthen efforts to realize autonomous ships by including initiatives for achieving practical use of autonomous ships to enhance marine transportation in the Future Investment Strategy 2018, which was announced in June 2018.
Industry Initiatives	
Mitsui O.S.K. Lines, Mitsui E&S Shipbuilding (marine transportation/shipbuilding)	● A research consortium comprised of MOL, Mitsui E&S Shipbuilding, and others started developing the technological concept for an autonomous maritime transport system in August 2017. The group is expected to develop the technology concept for highly autonomous ships, and formulate a development roadmap for the technologies necessary for the realization of autonomously operated vessels. ● In September 2018, MOL carried out a pilot project by installing Rolls-Royce's obstacle recognition advisory system (IAS: Intelligent Awareness System) on its passenger ferry "Sunflower."
Nippon Yusen (marine transportation)	● From June 2016, started a "study on collision risk judgement and the autonomous operation of ships". Development of functions to facilitate assessment of the risk of collision with other ships, remote maneuvering from land during emergencies, and development of equipment to transform navigation instrument information into AR.
	● In July 2018, started development of a ship operations support system for coastal ships, using AI as a core technology, and developed a system to reroute ships using AI in congested waters around Japan. A demonstration in actual waters is planned for 2021.
Mitsui & Co. (trading company/cooperation with overseas companies)	● In April 2019, began development of an automatic navigation system for large merchant ships in collaboration with ST Engineering, a major engineering company in Singapore, and Lloyd's Register of Shipping (UK). A test run was carried out in Singapore, one of the most congested ports in the world.
Nippon Kaiji Kyokai - ClassNK (ship classification society)	● In June 2018, announced the "Guidelines for Concept Design of Automated Operation/Autonomous Operation of Ships." The elements to be considered in the conceptual design were compiled from the viewpoint of ensuring the safety of autonomous ships. ● The purpose is to develop a conceptual design of an automatically operated ship based on appropriate and sufficient considerations given to safety, while giving the assumptions that seafarers perform a wide variety of onboard work, and that autonomous ships are studied based on various concepts, common basic elements that should be considered regarding safety are clarified.

Note 1: i-Shipping: Initiatives to improve productivity in all phases, from ship development/design to construction, and through to operations.

Note 2: j-Ocean: Initiatives to help Japan's maritime industry capture growth in the ocean development market.

Source: Compiled by MGSSI based on press releases issued by each company and the Ministry of Land, Infrastructure, Transport and Tourism

Figure 6: Overview of autonomous ship introduction and major technological challenges

STAGE	【Stage 1】 Proof-of-Concept Phase ～2025	【Stage 2】 Ships using IoT (Autonomy Levels 1～2) 2025～2030	【Stage 3】 Ships with automated operating functions (Autonomy Levels 2～4) 2030～2040	【Stage 4】 Ships with highly automated operations (Autonomy Levels 4～) 2040～2050 Unmanned vessel
EXPECTED EFFECTS	Toward practical use for coastal ships and in limited sea areas	• Achieve efficient navigation through stronger coordination between land and sea. • Improve maintenance efficiency by strengthening preventive maintenance. • Enhance safety and reduce workload for crews through partial automation.	• Promote optimization of operations, including increasing fuel efficiency and degree of punctuality. • Stabilize operations with advanced traceability. • Achieve both labor-saving and safe operations with ship-to-shore coordination. • Improve work conditions for seafarers through a reduction in labor force.	• Realize continuous optimization of marine transportation. • Strengthen cooperation between marine transportation and ports/warehouses/land transportation • Possible development of new marine transportation infrastructure, such as individualized transportation and marine mobile warehousing.
CHALLENGES	Calculate introduction effects, identify issues, develop new technologies	• Obstacle detection/collision avoidance technologies • Development of AI for autonomous ships • Increase speed and reduce costs of offshore communications	• Development of advanced AI for autonomous ships • Low-latency offshore communications • Precise and advanced maneuvering technologies	• Maintenance-free power • Automation of onboard ship operations and tasks

Source: Compiled by MGSSI based on the Ministry of Land, Infrastructure, Transport and Tourism's report regarding initiatives to be pursued to promote the productivity revolution in the maritime industry (June 2018; follow up to a report issued on June 3, 2016).

In the first stage, as the proof-of-concept phase for autonomous ships, issues related to autonomous ships are identified, the development of necessary technologies are pursued, and the effects of introduction are evaluated. In some cases, it may be possible to proceed to the practical use phase, such as for use in coastal ships and in limited sea areas.

In the second stage, IoT ships, which is equipped with collecting and analyzing sensors data, and supporting decision making such as route navigation and engine failure notification, will be implemented. It is assumed that real-time monitoring of ships will improve maintenance and operational efficiency, and that the introduction of operation support systems will lead to enhanced safety and help reduce the workload of crews.

In the third stage, ships equipped with automated functions will be implemented. These ships integrate onboard equipment by communicating with each other, and will use advanced data analysis and AI technologies to propose a concrete course of action to be taken by the crew. This stage is also expected to see the appearance of systems for presenting information in an audiovisual format for seafarers to make decisions, as well as ships with onboard equipment that can be directly controlled from land. However, it is assumed that sailors will still be the final decision-makers at this stage.

In the fourth stage, ships equipped with advanced automated functions will be implemented. These ships will be equipped with systems that function appropriately when docking and undocking, and even for various marine traffic and weather conditions. The ships will have a high level of autonomy, and it is assumed that there will be cases where the final decision-maker will not be a sailor.

3. CHALLENGES FOR REALIZATION

With progressive advancements in the study and development of autonomous ships, a number of challenges have surfaced. The two main challenges at present are technological issues and regulatory issues.

3-1. Technological Challenges

(1) Basic Infrastructure to Realize Autonomous Ships: Ship-to-Shore Communications Infrastructure

In order to realize an autonomous ship, a real-time information gathering from its surroundings are mandatory, and communications between the ship and land must be broadband and low-cost. Moreover, in order to provide stable and efficient support from land, such as for remote maneuvering, low-latency communication is also important.

(2) Technologies for Ship Automation: Obstacle Detection and Collision Avoidance

One of the challenges toward the realization of an autonomous ship is the development of highly accurate sensors that will allow an autonomous ship to detect obstacles at sea. Navigation radars have already been in practical use, but autonomous ships still need a technology that enables observation of the surrounding environment with greater precision across longer distances, even in the face of severe sea conditions. In addition to radar, cameras and LIDAR developed in the automotive industry are being studied for this use, and the specific functionalities of various sensors need to be effectively combined to achieve sensor fusion.

Other requirements include the development of advanced algorithms (AI for autonomous ships) to avoid collision avoidance and safe navigation after detecting obstacles, and the compilation of maritime big data in order to develop such an AI for automated ships. Furthermore, high-precision positioning technology and high-performance rudder control are also required for more precise maneuvering when docking and undocking.

(3) Technologies for Fully Unmanned Operation: Automation and Robotics Technologies

In order to realize a fully unmanned autonomous ship, work that has been handled manually must be replaced with automation or other mechanisms. Such work includes a wide variety of operations in the engine room and deck section, as well as operations on land, such as towing. For example, in the engine room, seafarers currently operate the ship while monitoring and maintaining the engine, suggesting the need for maintenance automation or maintenance-free power.

3-2. Regulatory Challenges

As existing legal systems related to ships are based on the premise that the ship is a “manned ship” with a captain or other seamen on board, for remotely operated ships and unmanned ships, the following international treaties and related legislative systems should be revised:

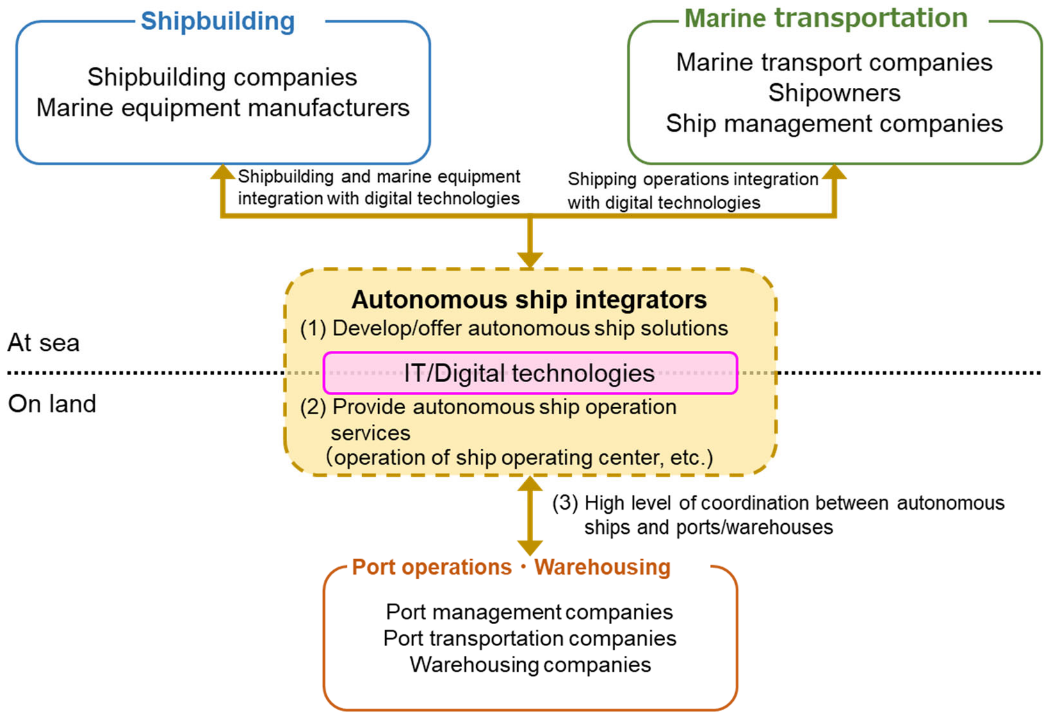
- The United Nations Convention on the Law of the Sea (UNCLOS): An agreement defining the rights and obligations of navigating ships. If an automated ship falls under the description of “vessel” as defined by the convention, the provisions will apply to such ships.
- The International Convention for the Safety of Life at Sea (SOLAS Convention): A convention that ensures hardware safety by setting standards for ship structures, lifesaving equipment, radio equipment, and other fixtures. Equipment requirements for autonomous ships will need to be considered.
- The International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW Convention): A convention on soft-side requirements, such as crew qualification and training. How the stipulations of this convention would apply to autonomous ships without a crew will need to be addressed.
- The Convention on International Regulations for the Prevention of Collisions at Sea (COLREG Convention): A convention that establishes navigation rules to prevent the collision of ships at sea (Sea Road Traffic Act). Application to autonomous ships needs to be examined.
- The International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978, (73/78 MARPOL Convention): A comprehensive convention to prevent marine pollution. It is necessary to consider the enforcement of the obligations of this convention on autonomous ships without a crew.

4. STRUCTURAL CHANGES IN THE MARITIME INDUSTRY AND THE ROLE OF AUTONOMOUS SHIP INTEGRATORS

Autonomous ships are one of the digitalization process of ships. In addition to combining existing ship technologies with digital technologies developed in other industries, autonomous ships can be realized by, with the help of digital technologies, highly integrating the roles that have hitherto been completed in each ship-related sector, such as shipbuilding, marine transportation, port operations, and warehousing. Here, the player responsible for bringing about a high level of integration is referred to as an "autonomous ship integrator," and the expectations of the role and anticipated developments in the future are described below.

First of all, the autonomous ship integrator is expected to integrate various technologies as a package of "autonomous ship solutions" by bringing together hardware-driven technologies possessed by shipbuilding companies and marine equipment manufacturers, and the software technologies owned by IT-related companies, such as AI for autonomous ships. In addition to strengthening upstream processes, such as advanced design capabilities of autonomous ships, the integrator is expected to provide higher value-added solutions by incorporating operation technologies owned by shipping companies and ship management companies ((1) in Figure 7).

Figure 7: Role of autonomous ship integrators



Source: Compiled by MGSSI

Next, the integrator is also expected to provide the stable and efficient operation of autonomous ships, such as an onshore operations center to support autonomous ships ((2) in Figure 7). Expected capabilities include route navigations, remote monitoring and maintenance of the engine room and cargo, support by unmanned tugboats during docking and undocking, support by remote maneuvering in congested waters, supply of charging infrastructure for electric ships, and to provide information on weather and sea conditions in real time (dynamic maps for autonomous ships).

Finally, by incorporating robotics technology, such as warehouse automation technology, and highly coordinating it with ports and warehouses, the integrator's role is expected to expand to advanced-level integration of maritime transportation as a whole ((3) in Figure 7). Beyond that, it will be possible to consider providing a total transportation service from the sea to land by also coordinating with land transportation.