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A Study on the Improvement of Steering Command System through Accident Analysis of Azimuth thruster using STAMP Method

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[Abstract]

With the global paradigm shift towards climate change, the shipbuilding industry is also considering propulsion systems that utilize eco-friendly fuels various propulsion systems are gaining attention as a result. In conventional propulsion systems, typically consisting of propellers and rudders, have evolved into a diverse range of systems due to the development of a special propulsion system known as the azimuth thruster. While azimuth thrusters were previously commonly installed on tugboats, they are now extensively used on offshore plant operation ships equipped with dynamic positioning systems. However, these azimuth thrusters require different steering methods compared to conventional propulsion systems, leading to a significant learning curve for the crew members boarding such vessels. Furthermore the availability of education related to these special propulsion systems is limited. This study aims to analyze accidents caused by inadequate control of vessels equipped with azimuth thrusters using the STAMP technique. And it proposes the necessity of standard steering commands for the safe operation of vessels equipped with special propellers.

▸ **Key words**: Propulsion System, Accident Analysis, Azimuth Thruster, Standard Steering commands, STAMP Technique

[요 약]

전 세계적으로 기후변화의 패러다임에 따라 조선업계에서도 친환경연료를 이용하는 추진시스템이 고려되면서, 다양한 추진기 역시 각광을 받고 있다. 일반적인 프로펠러와 타로 구성되었던 추진기들은 전방위추진기(아지무스 스러스터)라는 특수한 추진기의 발전으로부터 그 종류가 다양해지고 있다. 이러한 전방위추진기는 과거에는 예인선에 많이 설치되어 있으나, 현재는 동적위치제어시스템을 탑재한 해양플랜트운영선박에 많이 설치되어 사용되고 있는데, 이는 일반적인 추진기의 조타 방법과 상이하여 승선하는 선원들이 그 특성을 익히는데 많은 시간이 소요되고 있다. 아울러 이러한 특수한 추진기와 관련한 교육 역시 제한적으로 존재한다. 본 연구에서는 전방위추진기 탑재 선박의 조종 미숙으로 발생한 해양사고를 STAMP 기법을 통해 원인을 분석한 후 특수한 추진기를 설치한 선박의 안전 운항을 위해 표준조타명령에 대한 필요성을 시사하고자 한다.

▸ **주제어**: 추진시스템, 사고분석, 전방위추진기, 표준조타명령, STAMP 기법

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I. Introduction

With the global concern of the crisis of climate change, the South Korea has also implemented zero-carbon emission policies, such as green growth in various industries. In the maritime sector, the seriousness of emissions of sulfur oxides(SOx) and nitrogen oxides(NOx) during operations was acknowledged by the International Maritime Organization(IMO) in 1991. Consequently, the prevention of atmospheric pollution agreement was adopted in 1997, it was enshrined in the new Annex VI of MARPOL 73/78. Furthermore, various regulatory measures have been strengthened including the Energy Efficiency Design Index(EEDI) for new ships, the Energy Efficiency Operational Indicator(EEOI) for existing ships, and the Ship Energy Efficiency Management Plan(SEEMP). The regulation of SOx emissions came into effect in 2020 under the rules of the IMO, the Enforcement Ordinance of the Marine Environment Management Act was revised to designate the five major domestic ports as Emission Control Areas(ECAs). This strengthened the requirement for ships entering or leaving these ports to maintain sulfur content in fuel oil at levels between 0.05% and 0.5%.

In conjunction with these issues, the shipbuilding industry is actively pursuing new paradigms through technological advancements. In Norway, eco-friendly electric propulsion ships have been developed allowing for the coexistence of diesel fuel and electric power in hybrid vessel systems since 2015. These electric propulsion ships are equipped with various types of propellers, including traditional Fixed Pitch Propellers(FPP) as well as Controllable Pitch Propellers(CPP) and Contra-Rotating Propellers(CRP), to ensure stability and efficiency during operation.

Okamoto H. et al.(1974) analyzed the efficiency of propellers between FPP and CPP types, as a result of testing the reaction time and distance to stop, the stopping time of the CPP propulsion was 70% of the FPP and only 55% of the stopping distance was required, revealing the superiority of the CPP propulsion[1].

Based on this, Lee(1991) presented a paper which was analyzing optimized models of different propulsion systems including single-screw, twin-screw, ducted propeller, and CRP. The results indicated that the efficiency of the CRP was more than 10% higher than that of conventional propellers, leading to energy savings[2].

Yoshimura Y. et al.(1993) studied to demonstrate the efficiency of various propulsion systems, several studies have been conducted using field experiments. For instance, there is a case where a new CPP control system was applied to a training vessel, validating its superior maneuverability[3]. Furthermore, Altosole M., et al.(2014) presented a research study comparing and analyzing the efficiency of FPP and CPP propulsion systems through a trawler in the Mediterranean showed that CPP propulsion resulted in an average daily fuel consumption reduction of approximately 2.4% compared to FPP propulsion during low-speed operations(4.4 Knots)[4].

Based on the aforementioned research results, various type of propulsion systems are being prioritized for implementation in specialized vessels to enhance energy efficiency. In South Korea, twin azimuth thrusters and Azipod systems are installed in specialized vessels such as oceanographic research vessels for survey operations and mineral resource extraction, fisheries resource management, and anti-pollution vessels for environmental management, and buoy tender vessels for managing navigational aids. These propulsion systems are chosen to improve the energy efficiency of these specialized vessels.

However, the propulsion and steering systems installed on specialized vessels face challenges due to differences in control methods unlike ordinary propulsion systems and steering systems installed on general ships. Officers and engineers who are boarding these specialized vessels encounter difficulties in maneuvering, especially issuing steering commands and implementing specific techniques, as the control methods differ from those of general ships. Jung(2017) studied even in governmental ships, which fall under domestic institutions, there is no unified standard for steering commands, leading to communication difficulties in delivering standardized steering commands[5].

Trenkner P.(2015) studied the communication -related issues in steering commands have been identified as a contributing factor in maritime accidents, accounting for 40% of total accident in the ships equipped with azimuth thrusters[6]. Woodward M.D. et al.(2015) also presented a result, as a means to reduce such accidents, which is the need for standardized steering commands for azimuth thruster systems has been emphasized[7].

Kim et al.(2017) mentioned that the officer of vessels equipped with CRP-type azimuth thruster system require an extensive training because there are rare those system without a duct[8].

According to previous studies, only studies on the energy efficiency and maneuverability of ships equipped with special propellers have been conducted. Meanwhile, domestically, dual azimuth propellers and azipod systems are installed in professional vessels such as marine survey ships for surveying and mineral resource collection, marine resources management, pollution prevention ships for environmental management, and buoy tenders for navigational aid management. However, propulsion and steering devices mounted on special ships suffer from difficulties due to differences in control methods, unlike general propulsion devices and steering devices mounted on general ships. Officers and engineers aboard these specialized vessels face particular challenges in issuing helm orders and implementing specific skills because they differ in how they control them from normal vessels. Even in the case of governmental ships corresponding to domestic institutions, there is no unified standard for steering commands, so there are difficulties in communication in delivering standardized steering commands.

Therefore, the purpose of this study is to suggest the need for standardized steering commands for azimuth propellers based on the insights obtained by performing structural analysis using the STAMP technique on accident cases of ships equipped with azimuth propellers. To this end, the currently standardized steering commands included in the IMO SMCP (International Maritime Organization Standard Marine Communication Phrases) were reviewed and the steering command methods used in agencies currently installed with domestic special propellers were analyzed.

II. STAMP methodology

The System Theoretic Accident Model and Processes(STAMP) is an analysis technique and accident causality model developed by Leveson in 2004. It was introduced to overcome limitations of previous sequential accident analysis methods due to the rapid changes in science and technology, the evolving nature of accidents, and the emergence of new forms of hazards. STAMP provides a framework for analyzing accidents by considering the broader system context and examining the interactions between system components and their dynamic behaviors[9].

In STAMP, accidents are conceptualized as a result of inadequate enforcement of system safety constraints among the interacting components of a system during the design, development, and operation level. It emphasizes that safety is not merely a failure of prevention problem but rather a control problem. The constraints of safety can include concept on environmental or financial conditions, regulations, procedures, technology, and design.

In STAMP, accidents are defined as "the failure of the safety control structure" which means the conditions that prevent the enforcement of safety constraints. Therefore, the objective of accident investigation in STAMP is to identify the reasons why the safety control structure has been violated and determine what changes are needed in the control structure to prevent future related losses.

The STAMP model includes a fundamental control structure that encompasses system development and system operation, with each control structure organized in a hierarchical manner. The top-level structure determines safety policies, standards, and procedures, while the bottom-level structure is responsible for implementing those policies and procedures. Additionally, the system is modeled by representing its components in a hierarchical level and indicating the feedback between the top-level decisions and the bottom-level components.

One advantage of STAMP method is that it reaches a bottom-up(or downward) approach, which makes it applicable to complex systems. It encompasses various factors that can contribute to accidents, such as software, human factors, organizational aspects, and safety culture. This eliminates the need to separately control these aspects using different methods.

III. STAMP Anaylsis of the accidents

3.1 The proximate events

On April 13, 2005, Tug Thorngath collided with each other while connecting line with chemical tanker Stolt Aspiration. Stolt Aspiration was proceeding towards Birkenhead on East Lewis Quay from QWII lock. For this operation, Thorngath was tasked with assisting the arrival of Stolt Aspiration along with another Tug, Ashgarth. There were no mechanical failures in all vessel. Stolt Aspiration was maintaining a speed of 6.5 knots as it passed Quay South Terminal 12. Thorngarth approached with Stolt Aspiration in her bow side. Since Thorngarth had a structure where the tug line was given from the bow of the vessel, the Thorngarth had to approach from bow to bow. Then, Thorngarth got a heaving line from Stolt Aspiration, then backed away again. In order to move the position just forward of the Stolt Aspiration, the stern of her had to be moved to port. While Thorngarth was starting to move to port, Stolt Aspiration's bow suddenly started to move starboard. The master of Thorngarth made a corrective motion to place her back on the straight line, and when he executed the corrective motion, Thorngarth moved into Stolt Aspiration's pitcher's

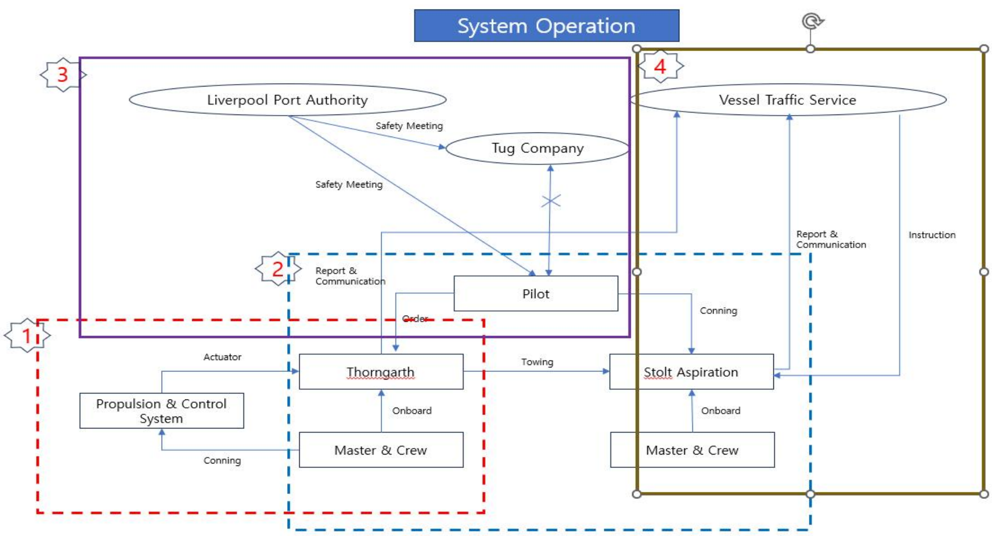

Fig. 1. Analysis Structure

course. This caused Stolt Aspiration to hit Thorngarth tug's starboard side[10].

3.2 Analysis of the physical system

The assistance for large vessel from pilot and tug boats is necessary to ensure safe maneuvering in narrow channel and harbor due to their limited maneuverability. Pilot and tugboats which are equipped with an Azimuth Control Device(ACD) provide excellent maneuvering Capabilities. The ACD propulsion and steering system on pilot and tug boats differ from ordinary propulsion and steering system such as propeller and rudder type on general ships in terms of operation. Therefore, in vessels with specialized propulsion systems like pilot and tug boats with ACD, the navigation is primarily conducted manually operating the Azimuth Thrusters by the master in the Manual mode. Moreover, even among similar pilot and tug boats, the response time of the propulsion system varies depending on the control logic, requiring captains of pilot boats to have sufficient training and experience in operating these propulsion systems. However, upon analyzing accidents, it is evident that there were no mechanical failures in the propulsion system. Rather, the cause can be attributed to the captain's lack of familiarity with the operation of the propulsion system on the pilot boat.

3.3 Analysis of the crew level

In order to examine the collision accident involving the vessels Stolt Aspiration and Thorngarth, an analysis was conducted on the crew members of both ships. First, the analysis of fatigue sensitivity in relation to the collision accident, it was determined that there were no causes attributed to mental or physical fatigue, as the crew members had taken sufficient rest for approximately 8 hours prior to their duty. Furthermore, the master of Stolt Aspiration strengthened the Bridge Team Management by enhancing the personnel on the bridge duty when navigating through narrow waterways, and a pilot was also embarked to assess the risks of pilotage. However, no risk assessment was conducted for Thorngarth, and no information was provided to the pilot prior to selection. In the case of the pilot, the tug boat assigned to the contract which had a designated Bollard Pull, it was determined under the responsibility of the port authority. Although it was unknown to the pilot and the tug operator before operation about the type of tug to be assigned, it was believed that a reliable tug with sufficient capabilities would be assigned.

In the case of the Thorngarth, it was attempting a Bow-to-Bow approach due to strong currents in the area. There are two personnel were assigned In order to operate the Towing gear system installed on the foredeck, but one of them had left the location to check an engine room alarm.

Regarding the crew qualification of the Thorngarth, they had obtained their qualifications through just an oral examination, covered by the Grandfather Clause. However, there was no obligation to maintain records of appropriate training and experience under the new scheme by STCW 95. Furthermore, the master of Thorngarth was operating for the first time, indicating a lack of prior navigation experience.

3.4 Analysis of the government regulatory authorities and industry association level

Although Regular safety meetings have to be conducted through consultations between the port authorities, the pilot and the tug company, there were no meetings taking place before. To address this gap, it is necessary to establish joint consultative meetings involving the tug company, pilot and port authorities. Furthermore, guidelines regarding the operation of the propulsion system and important steering commands in communication between the master of each tug boat and the pilot need to be developed as part of the manual for operating the propulsion and control system.

3.5 Analysis of the communication level

The role of the Vessel Traffic System (VTS) is to provide maritime traffic services by identifying congested areas when a vessel enters a controlled zone. The VTS supports maritime traffic by facilitating pilotage services, embarkation and disembarkation of pilots, as well as controlling the entry and departure of vessels. It also includes tasks aimed at preventing ship accidents by intervening in advance to support safe navigation.

Prior to the collision accident, the pilot and the Thorngarth communicated using designated VHF channels. Additionally, neither of the related vessels fulfilled their obligation to report the accident to the VTS, and reporting to the port administration was delayed, resulting in delayed rescue services. Within four months after this incident, two more accidents occurred in different areas, which were attributed to operating unfamiliar propulsion and control systems. To address this issue, it is necessary to establish standardized guidelines, such as operating manuals for Azimuth thrusters, and steering commands, to mitigate similar incidents in the future.

IV. A Study on the Steering Command System Currently in Use

4.1 IMO Standard Marine Communication Phrases (SMCP)

Steering commands for ships involved in international voyages worldwide are based on Standard Marine Communication Phrases (SMCP) established by the International Maritime Organization (IMO). When the officer on duty or the captain issues a steering command suitable for the ship's condition according to these commands, the helmsman repeatedly executes the command accordingly. The purpose of these standardized steering commands is to achieve safe navigation by unifying the language and reducing potential errors through clear terms specified in the SMCP. Bialyk O.Y.(2017) emphasized that the vocabulary and grammar of steering command in SMPC should be minimized to ensure simplicity for easy understanding[11]. Sartini S.(2020) conducted research aiming to enhance the vocabulary proficiency of marine officer in SMCP through the practice of Kahoot quiz[12]. The standard steering commands presented in the SMCP are listed in Tables 1 and 2 [13].

For thrusters, the SMCP specifies standard operating orders for tunnel-type thrusters installed in the fore or aft underwater hull section of a vessel to provide transverse thrust.

In the case of a ship with a special propulsion system mainly used for government or public institutions in Korea, separate steering commands in Korean are issued as shown in Table 3 used by the Korean Navy [14] and Table 4 used in Korea. It is used instead of the standard steering command prescribed by the Korea Coast Guard (KCG) [15] and SMCP.

Table 1. Standard steering commands(IMO, SMCP)

Standard Wheel Order	
Midships!	Rudder to be held in the fore and aft position
Port(Starboard) 5/10/15/20/25˚	5/10/15/20/25˚ of port(starboard) rudder to be held.
Hard a port (starboard)	Rudder to be held fully over to port(starboard).
Nothing to port/starboard	Avoid allowing the vessel's head to go to port/starboard.
Steady	Reduce swing as rapidly as possible.
Steady as she goes (Steady 's go)	Steer a steady course on the compass heading indicated at the time of order.
Report if she does not answer the wheel.	
Finished with wheel, no more steering.	

Table 2. Standard thruster commands(IMO, SMCP)

Standard Thruster Order	
Bow(Stern) Thruster Full / Half / Slow / Dead slow to starboard(port)	Fore(aft) thruster full / half / slow / dead slow speed to right(left) direction
Bow(Stern) Thruster Stop	Fore(aft) thruster stop
Bow(Stern) Thruster 10～100% starboard(port)	Fore(aft) thruster to right(left) direction 10～100%

Table 3. Wheel orders used by the Korea navy

Steering Order	
현침로 잡아	Steady on heading
키 오른(왼)편 5,10,15	5',10'15' of Starboard (Port) rudder to be held
키 오른(왼)편 전타	25' of starboard(Port) rudder to be held
키 바로	Bring rudder angle to 0'
키 반대	Bring rudder angle to 00' opposite
키 오른(왼)편 가지마	Avoid vessel's head to go to starboard(Port)

Table 4. Wheel orders used by the Korea Coast Guard

Steering Order	
키 바로	Bring rudder angle to 0' degrees
키 오른(왼)편 5′,10′15′20′25′	5′10′15′20′ 25′ of Starboard(Port) rudder to be held
키 오른(왼)편 전타	Rudder to be held fully over to Starboard(Port)
키 오른(왼)편 가지마	Avoid allowing the vessel's head to go to Starboard(Port)
현침로 잡아	Steer a steady course on the heading indicated at the time of the order

4.2 Accident cases due to absence of steering commands

Accident cases occurring on ships equipped with Azimuth Thrusters and Dynamic Positioning Systems (DPS) are generally reported and managed by the International Marine Contractors Association(IMCA).

Chae (2015) presented the analysis revealed that 68% of position loss accidents, which were primarily caused by human unsafe behaviors, were attributed to technology-based errors[16]. Furthermore, the collision accidents involving the RAD type propulsion system on the vessel Burrard Beaver in 1993, as well as the grounding and collision accidents of the Azipods type on the vessels Sea Mithril and Queen Victoria in 2008, were determined to have occurred due to communication failures based on the investigation conducted by the EU AZIPILOT project. As evident from the accident cases of ships equipped with azimuth thrusters shown in Table 5, communication errors resulting from the lack of harmonized and standardized steering commands have been identified as the primary or contributory causes of accidents[17]. Particularly, during harbor maneuvers and navigation in narrow waterways, effective communication between the master, pilot, and helmsman is crucial. To ensure the safety of vessels equipped with specialized propulsion systems, it is necessary to propose steering commands specifically designed for such vessels in the IMO SMCP.

4.3 Implication

The current IMO SMCP includes steering commands in the form of rudder angle orders, which are applicable in practical operations. However, these commands do not take into account the characteristics and differences of various propulsion systems, but only propulsion system with propellers and rudders. As a result, goverment vessels in South Korea with special propulsion systems including twin azimuth thrusters, use their own reviewed methods of steering instead of international standard steering commands. However, there are often situations where they need to communicate and share steering commands with other ships for tasks or mission purposes in the case of such vessels. Additionally, there is a need to share clear information about

Table 5. Accidents of RAD′s, ASD, Azipod type vessel

Date	Vessel	Type	Incident	Main Cause	Others
‘93.1.6	Burrard Beaver	RAD′s	Contact	Manoeuvering error	Poor communications
‘95.11.7	Mayne Queen	RAD′s	Collision	Transfer of control issue	Failure to shut down power
‘98.4.27	Austral Salvor	ASD	Collision	Manoeuvering error	Trainee had con
‘02.4.13	Bowen Queen	RAD′s	Malfunction	spontaneous rotation of RAD	PCB Failure
‘05.4.13	Thorngarth	ASD	Collision	Manoeuvering error	Tug to Task
‘06.3.10	Red Falcon	Voith	Contact	Voith units were desynchronize	Mate unaware of desynchronization
‘06.12.10	Prospero	Pod	Contact	Transfer of control issue	No training received
‘08.2.17	Seal Mithril	Azipods	Grounding	Hand steering in Fog	Poor communications
‘08.4.14	Queen Victoria	Azipods	Contact	Transfer of control issue	Poor procedure/Training

the ship's movements among duty officers even within the same vessel. However, the absence of such command systems creates difficulties in these situations. Furthermore, there have been cases where duty crew members or navigators without experience in handling special propulsion systems have had to manually operate the vessel without using navigation equipment such as autopilot. In some cases, senior officers or the captain themselves have had to take control of the vessel due to the lack of experience among the duty crew.

4.4 Currently used azimuth propulsion steering method

To prevent communication-related maritime accidents, AZIPILOT in the United Kingdom has developed standard steering guidelines for Azipod and Twin azimuth thrusters on vessels in Table 6 [18]. These guidelines are used to provide training to ship operators boarding these special vessels. In South Korea, there is currently only comprehensive training available such as the training for watch keeping duties conducted by the Korea Institute of Maritime and Fisheries Technology(KIMFT), and the training on site and navigational technology recommended by the Korea Marine Environment Management Corporation(KOEM). There is a lack of standardized steering commands and specific details related to these propulsion systems in the existing training programs.

Table 6. Material of Steering Training by AZIPILOT

Term	Command Definition	Spoken as
Pods	Azipods	"Pods"
Direction of pod rotation	Inboard or Outboard	"Inboard" or "Outboard"
Degree of pod rotation	Degrees from 0° to 180°(inboard or outboard)	"40 Degrees"
Direction of power application	Propellers Pulling(Ahead) or Pushing(Astern)	"Positive" or "Negative"
Amount of power in RPM's	Amount of RPM's spoken as integer	"30 RPM's"
Amount of power in pitch settings	Amount of pitch spoken as an integer or percentage	"Pitch-3" or "Pitch-30%"
Amount of power in lever settings	Lever setting spoken as an integer	"Lever-3"

V. Conclusion

With the global climate change rapidly evolving, there is a paradigm shift in the shipbuilding industry along with policies such as carbon neutrality currently. The South Korean government institutions have also started showing interest in zero-carbon vessels and are constructing various types of ships including those equipped with azimuth thrusters and water-jets. However, special vessels pose difficulties in navigation due to their differences in steering technology compared to conventional ships. Furthermore, analyzing maritime accidents investigated by the EU and IMCA, there is a problem of communication gaps among operators from the perspective of maritime human resource management. Consequently, it is evident that steering commands for special propulsion systems have not been taken into consideration upon examining the standard steering commands provided by IMO SMCP internationally.

When examining the cases of boarding special vessels domestically, it is common for experienced personnel to be recruited due to the nature of these vessels. There is a lack of training on the propulsion system of special vessels, especially for beginner/junior personnel. The Azimuth thruster advanced training offered by the KIMFT is available for individuals with boarding experience on special vessels. Additionally, the KOEM conducts Azimuth thruster training as part of the training for watch keeping duties on-site. While addressing the technical aspects through training on the operation of special vessel propulsion systems can be helpful, there is a need for the initial training of standardized steering commands from a software perspective.

In this study, it is pointed out that the standard steering command in the SMCP are not suitable for application to specialized propulsion system such as azimuth thrusters. This study reviewed a various steering command, particularly the Azipilot procedure, KOEM steering training. However, this study utilized the STAMP technique for accident analysis to deduce that establishing a standardized steering command system considering control characteristics could be an effective way to reduce accident. Nevertheless, the specific approach for achieving this was not proposed.

For this purpose, future research should differentiate between ships with specialized propulsion systems based on ship type and configuration, comparing them with conventional propulsion systems through simulations. Furthermore, it is suggested that research focused on establishing standardized steering commands for specialized propulsion systems through practical validation will be necessary, ultimately requiring empirical verification.

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