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Analysis of the Prediction of Operation Processes based on Mode of Operation for Ships: Applying Delphi method

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[Abstract]

The digital transformation of the shipbuilding, shipping, and logistics sectors is predicted to lead to the introduction of autonomous ships and changes in the way ships are operated. The co-existence of various operation forms, such as autonomous operation and remote operation, with the existing operation methods is expected to lead to the transformation of the ship operation process and the emergence of new stakeholders. This paper studies the future ship operation process according to the change in ship operation method, predicts the change in the operating environment of future ships, and derives functional requirements by major tasks and stakeholders. The Delphi technique is applied to construct a ship operation scenario from the planning stage of voyage and cargo transport to the stage of arrival at the final destination port and discharge of cargo, and to predict future work changes by task and actor. Seafarers' activities are expected to be minimised by remote and autonomous operation, and experts in each field are expected to have responsibilities and tasks in different aspects of ship operation.

▸ **Key words**: Mode of operation for ships, Maritime Autonomous surface ship (MASS), Remote operation, Ship Operations Scenarios, Delphi method

[요 약]

조선 및 해운·물류 분야의 디지털 전환은 자율운항선박의 도입 및 선박의 운항방식의 변화를 이끌 것으로 예상된다. 기존 운항방식과 함께 자율운항, 원격운항 등 다양한 운항형태가 공존하며, 선박 운용 프로세스의 전환과 새로운 이해관계자의 등장이 전망된다. 본 논문에서는 선박 운항방식 변화에 따른 미래 선박 운항 프로세스를 분석하고, 미래 선박의 운항환경 변화를 예측하여 주요 업무별·이해관계자별 기능요건을 도출하고자 한다. 델파이 기법을 활용하여 항해 및 화물운송 계획 수립단계부터 최종 목적항 입항 및 화물 하역단계까지 선박 운항 시나리오를 구성하고, 업무별, 수행 주체별 미래 업무 변화를 예측했다. 원격운항, 자율운항 등으로 선원의 개입이 최소화될 것이며, 각 분야의 전문가가 선박 운항의 다양한 측면에서 책임과 의무를 갖게 될 것으로 예상된다.

▸ **주제어**: 선박운항방식, 자율운항선박, 원격운항, 선박운항 시나리오 분석, 델파이 기법

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I. Introduction

With the recent development in digital technology and information communication technology (ICT), the future maritime field is undergoing major changes. These changes are extending influence from the shipping industry to port operations, logistics, and overall infrastructure regarding maritime sectors. Particularly, a major change in the ship operating sector is expected caused by advancement in various operating methods of ship such as remote operation along with maritime autonomous surface ship that is attracting global attention[1]. In addition to the development of core technologies such as intelligent navigation and engine automation, it is preemptively preparing for changes in the ship operation sector in various forms such as establishing prototype vessels and testing centers, and the innovation of regulations to proactively adapt to the evolving ship operating environment.

The transformation of ship operation methods are currently being discussed with the development of the MASS code which has being developed by the International Maritime Organization(IMO)[2]. Due to advances in intelligent navigation technology and various changes in ship operating sector, some of issue are expected such as the presence or absence of crew members and mode of operation, including automatically, remotely, and autonomously[2][3]. One of the most significant changes among these is the shift from the traditional mode of human-crewed ship navigation to unmanned or remotely operated vessels. This transition is gaining prominent attention as one of the core technologies in MASS operation, alongside intelligent navigation and security measures. Remote navigation of ships considering the uniqueness of maritime operations and the concept of the mode of operation for vessels, is not just a simple technological advancement but an indication that the future maritime industry is likely to accommodate various forms of vessel operation coexisting together.

In this study, it aims to analyze future MASS operation scenarios based on changes in ship operation methods. Through this analysis, it seeks to predict the changes in the maritime operation field of the future and derive functional requirements for key tasks and stakeholders. This research which employs System Dynamics(SD), is intended as foundation scenario analysis for future policy development related to shifts in ship operation methods. It is expected to be a valuable resource for identifying policy challenges in light of changing ship operation methods.

II. Literature review

Recognizing the need to prepare for the introduction and safe operation of autonomous ships, It has been conducting a review of current regulations since 2018 in IMO. As a result, the IMO is currently in the process of developing the Maritime Autonomous Surface Ship (MASS) Code[1]. In the development of this code, discussions are taking place concerning the definition of MASS and the changes in the mode of operation of ships due to the introduction of new technologies. Presently, the definition and concept of autonomous ships vary, but according to the draft of the MASS Code being developed by the IMO, an autonomous ship can be defined as a vessel capable of operating independently in various modes (levels) without human intervention. Furthermore, it also includes as a core technologies including autonomous and intelligent technologies, land-based response and control technologies, onboard data networks, and communication technologies, and the type of operation may lead to vary depending on autonomous and intelligent technologies[2][4][5].

The concepts of remote operation and autonomous navigation currently lack internationally defined standards, so the research on these topics is actively underway alongside international discussions regarding the development of relevant regulations. Ando H. et al considered the conditions depicted in Fig. 1 when designing the ship navigation system and designed it in a way that not only operates onboard as with traditional ships but also can be operated from land. The mode of operation of ship is categorized into follow four mode. "Normal" is running without any intervention by crew or fallback from shore. Active Monitoring (AM) is System is running under the verification by operator at shore. Remote Fallback (RFB) is System is running under fallback operations by operator at shore. Independent Fallback (IFB) is running under fallback operations by system on vessel[6].

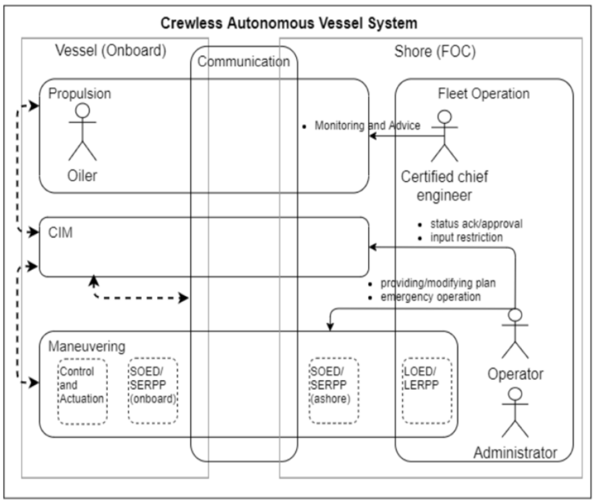

Fig. 1. Use case diagram specification of the crewless autonomous vessel system(Ando et al., 2022)

Thomas J. et al presented design of the ship is to be adaptable based on the range and conditions of the navigation area. Instead of designing ships for specific modes of operation, it aimed to enable them to operate in various ways under certain conditions. In this process, various stakeholders such as remote operators and remote operation centers may come into play, with remote navigation involving the most diverse set of stakeholders[7].

III. Change of ship operations based on mode of operation for ships

3.1 Overview of ship operations processes

In this paper, the ship operation process as shown in Fig. 2 was structured from the stage of navigation and cargo transport planning to the stage of final cargo handling and completion of navigation. To perform a time-series analysis of future ship operation processes, the existing maritime scenario (O) and the future ship scenario under analysis (A) were classified. Each task executor was analyzed, and future changes in tasks were predicted and analyzed.

The ship for analysis was assumed to be a capable of remote operation or autonomous navigation with the same objectives as the convention ship. It was designed to operate with a minimal crew and the ability to adapt its navigation method based on the operating conditions and characteristics of the navigation area[8].

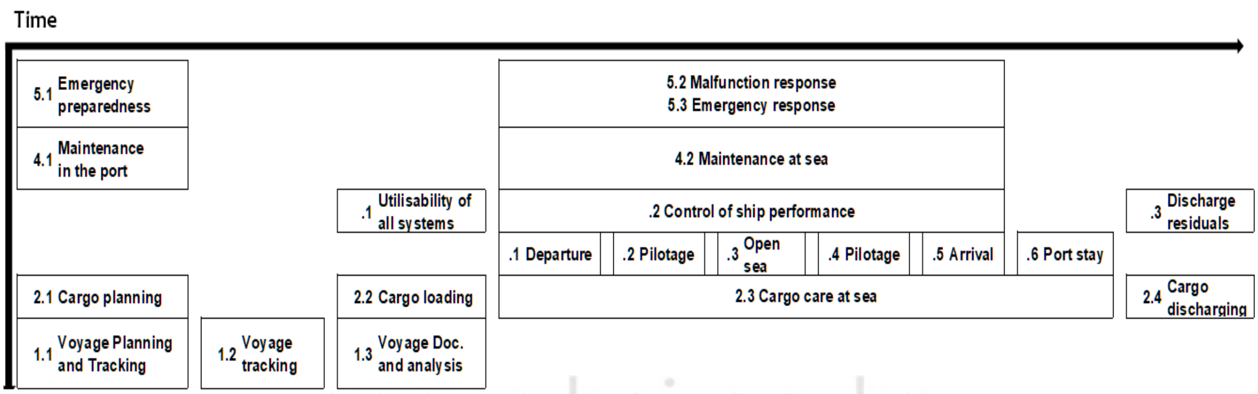

Fig. 2. Ship operations processes

3.2 Players and stakeholders

The operational tasks of the subject ship (A) have been categorized into three areas, and the key stakeholders for each field have been identified as shown in Table 1. However, it should be noted that each stakeholder does not necessarily represent a single institution or company and may vary depending on the vessel's mode of operation.

Table 1. The players and stakeholders of Ship "A"

Categories	Players and stakeholders
Navigation	- Remote operator (RO)
Ship Management	- Ship manager (SM) - Maintenance mechanic Specialist (MM)
Cargo Management	- Cargo manager (CM) - Port/Terminal (TM)

3.3 Delphi method

The Delphi method is a widely used technical approach for predicting the future, drawing on experts' empirical knowledge of experts to solve problems or make future predictions. It involves iterative surveys designed for a specific purpose to derive consensus among a group of experts on a particular topic while minimizing response variability. A crucial feature of the method is the anonymity of the experts, which fosters a more unrestricted and objective convergence of opinions. The results are evaluated with relatively high confidence based on the consensus reached by multiple experts and iteration[9][10].

In this study, the method predicts future ship operation processes resulting from changes in how ships operate. Seven expert panels underwent analysis following the steps presented in Figure 3. The expert panels consist of experts with specialized knowledge of changes in ship operation methods and rich experience in related research, and anonymity was guaranteed among the experts to ensure objective responses. These panels consist of specialists possessing in-depth knowledge of changes in ship operation methods and extensive experience in related research. Guaranteed anonymity is observed among the experts to ensure objective responses. Three rounds of feedback and revision are conducted among expert panelists to enhance the dependability of future predictions concerning changes.

In phase 1, a ship operations scenario was developed to deconstruct each task. The ship operation tasks were divided into five categories and their order and person in charge was analysed through time series analysis. The phases 2 and 3 repeated the process of investigating and modifying the conventional, remote, and autonomous ships based on the five categorised tasks.

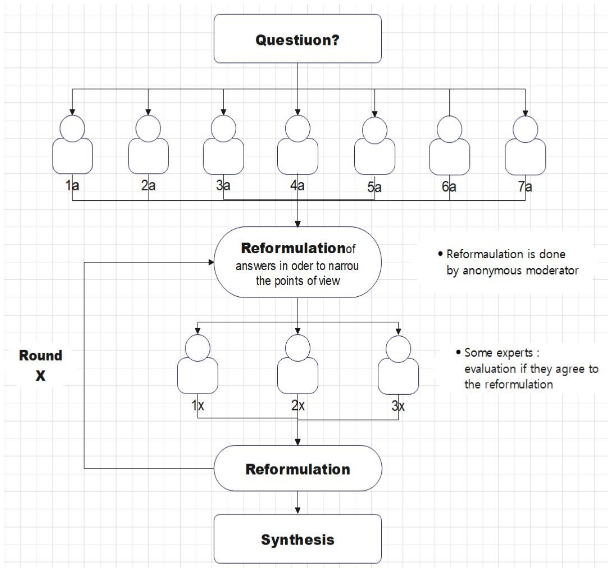

Fig. 3. Flowchart of Delphi method for the analysis of changes in ship operating environment

IV. Analysis of ship operations processes

4.1 Ship operations scenarios

In this chapter, it aims to analyze the changes in ship operational processes based on the mode of operation. The scenario is structured and organized into 5 main tasks including including voyage planning, cargo management, navigation and engineering, maintenance, and emergency response.

4.1.1 Voyage planning

This task involves planning routes based on cargo transport plans and designing the overall ship navigation plan. It includes preparatory and review processes such as reviewing the destination port and schedule, obtaining data and cooperation from relevant authorities for ship navigation, and obtaining cooperation from ports and facilities. In the case of traditional ship (O) as shown in Table 2, this task is primarily carried out by the crew on ship. It is an early stage in the ship navigation scenario requiring collaboration among various stakeholders such as shipowners, ports, terminals, and shipping companies.

In the case of ship (A) which operate in a remote or autonomous mode with minimal onboard crew, it is expected that the voyage planning of ship. Among other preparatory tasks, it will be carried out by the Ship Operation Support Center. This represents a significant shift from the responsibilities traditionally handled by onboard crew members and requires clear delineation of tasks between the crew on ship and the support center.

Table 2. Voyage Planning

Functions and tasks	O	A
Voyage Planning		
Planning a voyage	Office	SM
Arrange all facilities(pilots, terminals and port facilities)	Office	SM
Voyage tracking		
Track the voyage	Crew	SM
The voyage plan is adjusted accordingly	Office	SM
Communication with all institutions and facilities	Office	SM
Voyage documentation and analysis		
Collecting and merging all voyage data	Crew	SM
Documentation of all voyage-related information and data	Crew	SM
Check for deviations	Crew	SM
Preparing all systems		
Bunker and supply	Crew	SM
Systems checks	Crew	RO

4.1.2 Cargo management

This task encompasses activities spanning from the point of voyage planning to cargo discharging at the final destination. It includes cargo stowage planning, cargo type and condition management, as well as cargo discharge planning. Tasks also involve the management of a cargo holds and integrity with consideration for the cargo as shown in Table 3. In the conventional ships, all these tasks were typically carried out by the onboard crew.

In the case of ship (A) which operate in a remote or autonomous mode, it is expected that external entities will handle preparation and coordination. Cargo loading and discharging preparation and supervision will mainly be performed by port and terminal personnel. The management of ship stability through cargo loading will be conducted by the remote operation center.

Table 3. Cargo Operations

Functions and tasks	O	A
Cargo planning		
Loading and stowage plan	Crew	CM
Accepting cargo, checking cargo and dangerous goods properties	Crew	CM
Distribution of masses and volumes of cargoes	Crew	CM
Definition of correct stowage and segregation, in particular for dangerous cargo	Crew	CM
Considering demands of fuel and consumables	Crew	SM
Calculation and distribution of required ballast	Crew	SM
Check and approval of stowage and ballast plan	Crew	SM
Calculation and assessment of draught and trim, transverse stability, and strength of the vessel	Crew	SM
Cargo loading		
Preparing the vessel for loading	Crew	SM
Planning and supervision of cargo securing against shifting and damages	Crew	CM
Monitoring and adjusting of trim, stability and strength values	Crew	SM
Operating ballasting the vessel	Crew	SM
Cargo care at sea		
Checking cargo securing and conditions	Crew	RO
Monitoring of temperatures in holds and certain cargoes	Crew	RO
Control of ventilation, bilges and wells	Crew	RO
Cargo discharging		
The process of discharging covers the same functions and tasks as the loading process	Crew	CM TM

4.1.3 Navigation and Engineering

This refers to the navigation and engineering process task for ship operation. It encompasses the tasks from the moment the ship departs from the port until it arrives at the destination port and includes subsequent measures(Table 4). In the case of traditional ship (O), these tasks are typically performed by the ship's crew. But for subject ship (A), it is anticipated that remote operators working in a remote operations center will carry out these tasks.

Table 4. Navigation and Engineering

Functions and tasks	O	A
Navigation when leaving the port		
Passage planning	Crew	RO
Departure / De-berthing	Crew	RO
Navigation on pilotage (outbound)		
Fix and check position	Crew	RO
Monitor for water depth, UKC, squat, ship-shore/ship-ship interaction	Crew	RO
Control course and speed	Crew	RO
Incorporation of a pilot (Master-Pilot Exchange MPX)	Crew	RO
Monitor traffic and avoid collisions	Crew	RO
Monitor environmental conditions (wind, current, visibility)	Crew	RO
Manoeuvre ship for specific manoeuvres	Crew	RO
Communication with VTS, other ships	Crew	RO
Management of navigational or ship related alarms	Crew	RO
Navigation on sea passage (open sea)		
Fix and check position	Crew	RO
Control course and speed	Crew	RO
Monitor traffic and avoid collisions	Crew	RO
Monitor environmental conditions	Crew	RO
Communication with VTS, other ships	Crew	RO
Management of navigational or ship related alarms	Crew	RO
Control of ship performance	Crew	RO
Navigation on pilotage (inbound)		
Get clearance to enter fairway and port	Crew	RO
Check controls availability and integrity	Crew	RO
all functions and tasks as on outbound pilotage	Crew	RO
Navigation when entering the port		
Anchoring / Stand-by manoeuvre	Crew	RO
Arrival / berthing	Crew	RO
Port stay		
Maintain safety and security watch	Crew	TM
Monitor shore connections	Crew	RO
Control of non-working ship	Crew	RO
Discharging waste, waste water	Crew	SM
Discharging of oily or other hazardous materials	Crew	SM

4.1.4 Maintenance

This task is dedicated to ship maintenance and can be classified into two categories: tasks during in port and tasks during navigation as shown in Table 5. During in port, the responsibilities will involve establishing an inspection plan and performing repair work on various aspects of the ship, which will be carried out by SM or MM according to regular or special inspection requirements. Furthermore during navigation, the majority of tasks will be automatically recorded and reported. However, there may be instances where manual recording and requests are necessary considering that RO is continuously monitoring. RO will take immediate action on matters that require immediate attention.

Table 5. Maintenance

Functions and tasks	O	A
Maintenance in the port		
Maintenance planning	Crew	SM MM
Overhaul and repair	Crew	MM
Spare part control	Crew	MM
Maintenance at sea		
Inspection of all equipment	Crew	RO
Propulsion system	Crew	RO
Auxiliary equipment	Crew	RO
Automation systems	Crew	RO
Deck systems	Crew	RO
Navigational equipment	Crew	RO
Safety equipment	Crew	RO
Updates software	Crew	RO
Repair on demand (easy or specific level) (corrective)	Crew	RO

4.1.5 Emergency response

It is a step to identify emergency situations on ships and minimize damage in accordance with related regulations such as SOLAS. It involves the steps taken on the ship to identify emergencies and minimize damage. This includes accident prevention through the identification of changes in emergency types and risk factors related to ship operation, as well as tasks such as emergency situation recognition and assessment, emergency response, and follow-up actions(Table 6). However, it should be noted that actual emergency response tasks are mandatory in accordance with regulations such as SOLAS, and stakeholders may vary depending on changes in related regulations.

Table 6. Emergency response

Functions and tasks	O	A
Emergency preparedness		
Performing risk assessments	Office	SM
Set-up and implementation of contingency plans	Office	SM
Training and drill of crew	Crew	RO
Malfunction response		
Handle black-out	Crew	RO MM
Handle steering gear failure or loss of propulsion	Crew	RO MM
Handle spills	Crew	RO MM
Handle extreme weather and environmental conditions	Crew	RO MM
Handle problems with communication and linkage with systems	Crew	RO MM
Handle failures of sensors or automation devices	Crew	RO MM
Handle cargo problems	Crew	RO CM
Emergency response		
Respond to structural damages, water ingress, flooding	Crew	RO
Respond to fire in cargo holds, engine, accommodation	Crew	RO
Respond to person overboard	Crew	RO
Respond on medical emergencies and operate evacuation	Crew	RO
Respond to security related matters	Crew	RO
Operate evacuation, abandon ship	Crew	RO
Operate helicopter operations in emergencies	Crew	RO
Operate SAR activities	Crew	RO
Handle cyber attacks	Crew	RO
Handle lost of data and communication connection	Crew	RO

4.2 Comparative analysis

Based on the analysis of future ship operation processes based on mode of operation, the key functions and flowchart of Subject Vessel (A) have been diagrammatically represented in Figure 4. From this information, it is evident that tasks that were traditionally carried out by onboard crew are being reallocated to more specialized professional experts(SM, MM, CM) with the emergence of these new job.

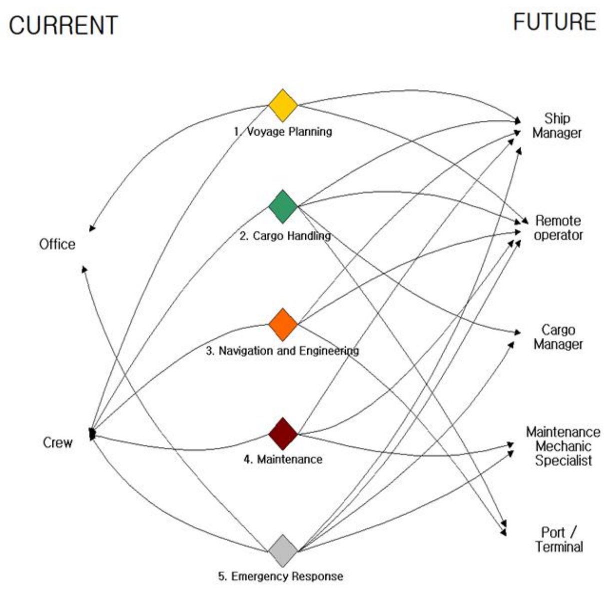

Fig. 4. Flowchart of ship operation processes

In traditional ships, there are personnel on board responsible for various tasks. In practice, the marine officer do not only perform navigation tasks; their responsibilities often span across cargo management and emergency response, among others. Similarly, in addition to maintenance staff(marine engineer) also handle a number of tasks including cargo management (especially reefer container management) and emergency response. However, operating in this manner may lead to a dilution of expertise, as it can result in increased workload and decreased professionalism and specialization. Especially with the continuous development and advancement of technology and equipment, it is not feasible to provide blanket education for all these diverse methods. Swason R.A. and Holton E.F. defined expertise as the optimum level of performance that can be achieved in specific areas of human activity or expected outcomes[11]. In other words, the concept of MASS aims to reduce the human workload and minimize human intervention to prevent accidents. Therefore, it seems more appropriate for experts in each field to be responsible for and accountable for various elements of ship operation. Furthermore, having specialized experts in different areas of ship operation can provide a wealth of knowledge and experience, and problem-solving capabilities in case of incidents are likely to be superior compared to traditional ship operation.

V. Conclusions

Recent discussions on IMO regarding the changes in mode of operation are expected to diversify and advance with the development of digital and information and communication technologies (ICT) such as automatically, remotely, and autonomously, including types of traditional ship operations. It is anticipated that these developments will not follow a linear progression but will instead result in various modes of vessel operation coexisting within the future maritime industry.

This study analyzed the future processes of ship operation in response to changes in mode of operation in ship and predicted the changes in the operational environment for future vessels including MASS to derive functional requirements for different tasks and stakeholders. It constructed scenarios for ship operation based on changes by mode of operation in ship and analyzed the maritime operational processes, from the stage of planning navigation and cargo transportation to the final arrival at the destination port and cargo handling. The main ship operation tasks have been categorized into five, and it is expected that these tasks will vary depending on their nature and timing of work. Firstly, for navigation and engine operation, as well as emergency response tasks, the tasks that were traditionally performed by the crew on traditional ships will transition to Remote Operators (RO). As for cargo management and maintenance tasks, these will be managed through experts. This transition is anticipated to create new job areas such as Ship Manager (SM), Maintenance Mechanic Specialist (MM), and Cargo Manager (CM). In addition, new technologies such as DP System, which were not used in traditional cargo ships, will be incorporated into autonomous ships which will require other experts[12]. However, it is essential to consider that these job sectors may overlap with current traditional shipping companies and others. Given the changes in mode of operation and conditions resulting from digital transformation, there is a need to reevaluate the processes in the shipbuilding, maritime, and logistics industries.

It should be noted that this study serves as a fundamental analysis of ship operation scenarios, and it does not consider changes in tasks by navigation area or the difficulty levels of key functions. In future research, a comprehensive assessment and analysis of workload, difficulty, weighting, etc., can be conducted to identify policy challenges for future ship navigation method changes. In addition, it will be used to analyze changes in the actual ship operation process by specifying ship types and routes, and to conduct research on optimal route selection and ship operation optimization measures according to ship operation modes. This information will help inform future policy decisions.

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