JKSCI

한국컴퓨터정보학회논문지
Journal of The Korea Society of Computer and Information
Vol. 28 No. 5, pp. 163-170, May 2023
https://doi.org/10.9708/jksci.2023.28.05.163

A Fundamental Study on Mode of Operation for Maritime Autonomous Surface Ship(MASS) - Based on review of IMCA M 220

Jeong-Min Kim*, HyeRi Park**

*Professor, Ocean Technology Training Team, Korea Institute of Maritime and Fisheries Technology, Busan, Korea
**Senior Researcher, Dept. of Logistics and Maritime Industry Research, Korea Maritime Institution, Busan, Korea

[Abstract]

As the development of the 4th industrial revolution in the maritime industry has accelerated, the technical development and progress of maritime autonomous surface ship(MASS), and the development of international regulations have been accelerated. In particular, the IMO Maritime Safety Committee(MSC) has established a road-map for the development of the non-mandatory goal-based MASS instrument(MASS Code) and started developing a non-mandatory MASS Code at MSC 105th meeting. Many countries are actively participating in the Correspondence Group on the development of MASS Code, and the development of detailed requirements for MASS functions in the MASS Code is underway. Especially, the concept of “Mode of Operation” for MASS functions was mentioned in the Correspondence Group for the first time, and it is expected that discussions on these modes will be conducted from the IMO MASS JWG meeting to held in April 2023. The concept of “Mode of Operation” will be useful in explaining MASS and MASS functions and will be discussed continually for the development of MASS Code. This paper reviews the contents of the IMCA M 220 document, which provides guidelines on operating modes, to conduct research on the benchmark for setting the operating modes of MASS.

▸ **Key words**: Mode of Operation, Operational Mode, IMCA M 220, MASS, Autonomous level, Autonomy, Ship system

[요 약]

제4차 산업혁명의 가속화에 따라 해운산업에서는 자율운항선박(MASS)의 기술 개발 및 발전이 이루어지고 있으며, 이에 따른 국제 규정의 개발 역시 가속화되고 있다. 특히 IMO 해사안전위원회(MSC) 105차 회의에서는 회원 당사국 간 비강제적 자율운항선박 규정(MASS Code) 개발을 위한 로드맵을 수립하고 본격적으로 규정 개발에 착수하였다. 다수의 국가가 MASS Code 개발 작업에 적극적으로 참여하고 있으며, MASS Code에서 MASS 기능에 대한 상세한 요구사항에 대한 규정 개발 작업이 진행 중이다. 특히, 자율운항선박의 자율도와 관련하여 "운항 모드(Mode of Operation)" 개념이 처음으로 언급되었으며, 2023년 4월에 개최될 IMO 자율운항선박 공동작업반(MASS JWG) 회의부터 이 운항 모드에 대한 논의가 진행될 것으로 예상된다. "운항 모드" 개념은 MASS 및 MASS 기능에 대한 설명과 더불어, MASS Code 개발을 위해 지속되어 논의될 것이다. 이 논문은 운항 모드 설정에 대한 기초 연구를 수행하기 위해 운항 모드에 대한 지침을 제공하는 IMCA M 220 문서의 내용을 검토한다.

▸ **주제어**: 운항 모드, IMCA M 220, 자율운항선박, 자율도, 자율성, 선박시스템, 자율

• First Author: Jeong-Min Kim, Corresponding Author: HyeRi Park
*Jeong-Min Kim (jmkim@seaman.or.kr), Ocean Technology Training Team, Korea Institute of Maritime and Fisheries Technology
**HyeRi Park (hrpark@kmi.re.kr), Dept. of Logistics and Maritime Industry Research, Korea Maritime Institution
• Received: 2023. 04. 21, Revised: 2023. 05. 08, Accepted: 2023. 05. 11.

http://www.ksci.re.kr pISSN:1598-849X | eISSN:2383-9945

I. Introduction

Recently, there has been a significant discussion around the development and operation of Maritime Autonomous Surface Ship (MASS) in the maritime industry. Many country, shipbuilding companies, and research institutes have been actively engaged in this topic. Essentially, MASS can automatically collect and manage necessary information to carry out the ship's purpose and mission. They will be able to determine and navigate their own routes or operate through remote control systems.

The International Maritime Organization(IMO) has have defined MASS as “a ship which, to a varying degree, can operate independent of human interaction” for the purpose of conducting a Regulatory Scoping Exercise(RSE) and has divided it into four degrees[1].

However, technology development of systems and equipment is still necessary to achieve the safe operation of MASS. Furthermore, additional technological considerations for autonomous or remote operations should also be made for traditional merchant ship systems.

The MASS road-map has been created for the development of the non-mandatory MASS Code and has started developing it at the 105th MSC meeting. Many countries are actively participating in the Correspondence Group for the development of MASS Code, and the detailed requirements for MASS functions are currently being established. The concept of "Mode of Operation" for MASS functions was introduced for the first time, and it will be discussed further at the upcoming IMO MASS Joint Working Group(JWG) meeting in April 2023. This concept will aid in explaining MASS and MASS functions, and will be essential in the development of MASS Code.

This paper reviews the contents of the IMCA M 220 document, which provides guidelines on operating modes and applies these concepts to set the modes of operation for MASS. Chapter 2 examines previous studies on the classification of autonomy in autonomous vessels and analyzes the criteria that have been commonly used. Chapter 3 and 4 focus on the implications of MASS operation modes based on the contents of IMCA M 220. In Chapter 5, the conclusion of this paper and future research directions are discussed.

II. Literature Survey

The level(or degree) of autonomy of MASS has been a critical factor since the concept was first introduced. In the early stages of research, the IMO classified the autonomy levels into four stages through its Regulatory Scoping Exercise(RSE). However, various companies and research institutions involved in the development of MASS technology have argued that the four-stages classification is too ambiguous to make an accurate distinction between autonomy levels.. In order to develop the MASS Code, the IMO initially classified the autonomy levels into four stages through the RSE, but acknowledged the possibility of refining or integrating these stages at any time and continued to discuss the issue. Various studies and surveys have been conducted to establish criteria for determining the autonomy level of MASS, and the concept of "Mode of Operation" has emerged, which emphasizes considering the ship's operational form rather than categorizing it into a specific level of autonomy. This chapter reviews previous studies and examines the current understanding of the concept.

Porathe T.(2018) proposes the development of an international standard for measuring autonomy levels in unmanned surface vessels (USVs)[2]. The authors identify the need for a standardized approach to measuring autonomy levels, as there is currently no consensus on how to do so. The paper proposes a conceptual framework for defining autonomy levels and presents a methodology for measuring autonomy levels based on a set of criteria.

Resolution 2018-II-16 by CCNR(Central Commission for the Navigation of the Rhine) provides definitions for different levels of automation in inland navigation, including "operator in command", "vessel-in-command", "assisted operation", "semi automation", and "full automation"[3]. It also establishes guidelines for the use of automated systems in inland navigation and emphasizes the importance of ensuring safety and environmental protection. The resolution highlights the need for appropriate training and qualification of operators, as well as the importance of continuous monitoring and evaluation of automated systems. Overall, the resolution aims to promote the safe and efficient use of automation in inland navigation while ensuring compliance with applicable regulations and standards.

Vagia M., at al.(2015) reviewed that, the topics of autonomy, levels of automation, and taxonomies had been discussed. The paper presented a summary of taxonomies proposed by various researchers to highlight their differences. The study specifically focused on the treatment of different levels of automation by different authors. The goal of the study was to provide potential users with a range of options by presenting the differences between proposed levels of automation and taxonomies. The proposed taxonomy had been presented in eight levels according to the subject of operation, and is explained in detail[4].

Fukuto J.(2021) examined previous studies regarding the contents and definitions of automation levels for automated and autonomous ships, as well as the relationship between humans and the various automation systems. The report provided an overview of automation levels for automobiles and unmanned aerial vehicles, as well as the automation levels established by maritime organizations and classification societies. The report also summarized the factors used to classify automation levels, which clarify the differences in the relationship between humans and the systems and the tasks that require human supervision and intervention[5].

Ørnulf J., at al.(2022) explores the concept of autonomy in shipping and presents a framework for classifying levels of autonomy. The paper proposed six levels of autonomy for ships, ranging from manual operation to fully autonomous operation with no crew on board. The paper discusses the benefits and challenges of each level and provides examples of existing and potential applications of autonomous ships. The paper also addressed regulatory and ethical issues related to the development and deployment of autonomous ships. Overall, the paper provided valuable insights into the future of autonomous shipping and highlights the importance of careful consideration of the levels of autonomy in ship design and operation[6].

Based on previous research, the classification of autonomy for MASS has primarily focused on the inherent structure, performance, design, and operational capabilities of the vessel's system. However, since autonomous ships are still in the development stage, no one knows for certain what kind of systems and functions will be implemented or how the vessel will be designed. Thus, it is difficult to determine the level of autonomy based on the vessel's structure or equipment. Therefore, the classification of autonomy is easier to define by regulating the operation of the vessel in different modes, based on existing vessel operations.

IMCA has developed a guideline called "Guidance on Operational Activity Planning" (IMCA M 220), which is related to operational or navigational modes for specific situations of ships[7]. In this paper, it will be reviewed this guideline and explored how it can be applied to the operation of MASS.

III. IMCA M 220 "Guidance on Operational Activity Planning"

3.1 Aims

The purpose of this guidance on operational activity planning is to present an overview of the techniques used for planning and carrying out offshore marine vessel projects and routine offshore support activities. Section 4 of IMO MSC Circular 1580, which provides guidelines for vessels and units equipped with dynamic positioning (DP) systems, mandates that the DP system must be inspected before each DP operation using the relevant vessel-specific location checklist(s) and decision support tools such as ASOG, to ensure the DP system is functioning properly and configured for the appropriate operation mode. It is essential to note that section 4 Operational Requirements pertains to all applicable new and existing vessels and units[7].

This guidance discusses methods for operational activity planning that are applicable to all sectors of the offshore marine industry, including drilling, construction, and supply vessels, not just those with DP systems. The guidance provides a decision support tool, known as activity specific operating guidelines (ASOG), which defines the appropriate mode of operation for critical activities (CAM) or specific tasks (TAM). The operational activity plan should define the vessel's equipment and system configuration for the location and activity, set variable limits for equipment and operational parameters, outline responses to faults and deteriorating conditions, and be presented to key personnel in a user-friendly decision support tool[7].

3.2 Critical Activity Mode (CAM)

This guidance recommends that the critical activity mode, task appropriate mode, and activity specific operating guidelines should be developed based on a comprehensive understanding of the dynamic positioning system, DP failure mode and effects analysis(FMEA), the offshore industry mission, vessel location, and risk assessment.

The Critical Activity Mode (CAM) is a DP system configuration that ensures the highest level of station keeping integrity. It is required for all DP Class 2 and DP Class 3 vessels to have a class approved FMEA of the DP system which identifies the analyzed system configurations, meeting the classification society requirements for the assigned DP notation. However, this FMEA may not include the configuration that provides the highest level of station keeping integrity. It is important to note that the difference between CAM and TAM involves factors beyond power plant configuration, such as position references, auxiliary systems, thrust limits, and equipment availability including restrictions on IRM. The configuration for CAM should address the vessel's design, covering the seven attributes that contribute to providing the highest level of station keeping integrity, such as autonomy, independence, segregation, differentiation, fault ride-through, and fault resistance. Effective procedural barriers should also be identified to supplement these attributes[7].

3.3 Task Appropriate Mode (TAM)

Task Appropriate Mode (TAM) is a mode that is based on risk assessment. It involves configuring the vessel in a defined manner that can provide station keeping integrity and fault tolerance. When operating in TAM, the vessel's systems may be set up in a way that can cause the effects of single failures to exceed the worst-case failure design intent, resulting in limited loss of position.

It is important to note that TAM involves addressing other elements besides power plant configuration, such as position references, auxiliary systems, thrust limits, and equipment availability. Additionally, TAM allows the vessel to operate at thrust levels beyond its post worst-case failure DP capability, which is a conscious choice.

TAM may be appropriate in situations where it is determined that the potential consequences of loss of position can be avoided by safely terminating the operation before the position excursion reaches a point where it may cause unacceptable consequences. Finally, the TAM configuration can be used to reduce machinery running hours when appropriate[7].

3.4 Activity Specific Operating Guidelines

The Activity Specific Operating Guidelines (ASOG) are distinct from the CAM and TAM in that they pertain to a specific location and activity. The ASOG sets the operational, environmental, and equipment performance limits for the DP vessel with respect to the particular activity it is engaged in, whereas the CAM and TAM may not be specific to a location.

An ASOG must be developed for every activity and location. A critical component of the ASOG is knowledge of the black out recovery time. Additionally, reference should be made to any relevant studies or analyses (if applicable) for the particular activity being carried out, such as analyses related to riser transfer operations, heavy lift operations, or permanent mooring connection operations[7].

3.5 Structure of Tabulated Format

The Activity Specific Operating Guidelines (ASOG) can be presented in a tabular format, which makes it easier to understand and follow. The table typically includes columns that specify the operational, environmental, and equipment performance limits for the DP vessel, as well as any relevant notes or comments. The example of tabulated format of ASOG is presented in Table 1[8].

The first column typically lists the activity being undertaken, while the second column specifies the location where the activity will take place. The subsequent columns detail the various operational, environmental, and equipment parameters that must be considered for the activity, such as allowable heading and position offsets, wind and current limits, and allowable thruster usage.

In addition to these technical parameters, the table may also include any procedural or administrative requirements that must be followed, such as communication protocols, personnel qualifications, and emergency response procedures. Finally, the table may include any relevant notes or comments that provide additional context or clarification for the various parameters. Guidance in the tabular format is presented in four categories[7].

3.5.1 Green Status

The green typically indicates normal operations, during which planned activities can be undertaken within the agreed safe limits. To be classified as normal, several conditions must be met, including proper functioning of the DP system and

Table 1. Example of Tabulated Format of ASOG

Condition	Green	Blue	Yellow	Red
Actions	Continue Operation	Consultative Status (Risk Assessment)	Ready to Terminate	Emergency
Current and predicted weather condition	> Operational Limit	Approach operational limit	Exceeding operational limit	
DRIVE OFF	All systems operating correctly	Difference in vessel position between visual and navigation equipment	Immediately when recognized by DPO	Unable to bring vessel under control
DRIFT OFF	All systems operating correctly	Difference in vessel position between visual and navigation equipment	Immediately when recognized by DPO	Unable to bring vessel under control
Vessel Footprint / Weather related excursion	No position alarm or warning	If warning position limits reach(> 5m)	If alarm position reached(>10m)	

compliance with the agreed CAM or TAM. Additionally, the operational, environmental, and equipment performance criteria must all be classified as normal. Adhering to these requirements helps to ensure the safety and efficiency of DP vessel operations[7].

3.5.2 Advisory Status

The advisory status colored blue is recommended to be used to signal a situation where operations can continue while risks are being assessed. This situation arises when operational, environmental, or equipment performance limits are being approached, or when an event or failure occurs that does not compromise the single-fault tolerance of the DP system. After conducting a dynamic risk assessment, operations may continue with mitigating measures or the advisory status will be raised to yellow. It is important to note that there are no conditions where the advisory status should be considered or treated as a normal situation. If the DP system is equipped with consequence analysis, it may trigger an advisory status[7].

3.5.3 Degraded Status

The degraded status colored yellow, where the vessel is still maintaining its position but a condition exists which may require a suspension of operations. This includes situations where a failure in the DP system has occurred, leaving its redundancy compromised, or where operational, environmental or equipment performance limits have been reached. Preparations should be made to suspend operations in a controlled manner. If the DP system has consequence analysis, it may trigger yellow status[7].

3.5.4 Emergency Status

The emergency status colored red, is considered a severely degraded or emergency situation that requires an immediate end to operations. This status may result from a system failure, inability to maintain position or heading control, exceeding operational limits, or any other emergency situation that requires the rapid termination of activity. When the DP system is in red status, contingency procedures should be immediately initiated to terminate all DP dependent operations, as the vessel is about to lose position and/or heading[7].

IV. Implication and Limitation

Although IMCA M 220 provides guidelines for DP vessel operations, its purpose is to reduce maritime accidents caused by human errors, and it can be applied and used as a tool in other types of vessel operations as well. Previous research on MASS's autonomy has focused on the presence or absence of human intervention, as well as the structure, equipment, and systems of the vessel. However, this classification system cannot provide clear guidelines as the technology for MASS continues to develop. It is a well-known fact that there are limitations to this approach.

Generally, the types of navigation for cargo ships can be broadly classified as follows; arrival and departure in ports and harbors, navigation when entering the port, coastal navigation, and ocean-going navigation. In addition, factors to consider include traffic density, weather conditions, ship status (loading condition, etc.), and designated navigation laws and zones according to international or domestic laws specified example in Table 2.

Table 2 Example of "Mode of Operation"

<table>
<tr><th colspan="4">Status</th><th>Mode</th></tr>
<tr><td rowspan="3">Green Status</td><td rowspan="3">Advisory Status</td><td rowspan="3">Degraded Status</td><td rowspan="3">Emergency Status</td><td>Critical Activity Mode (CAM)
- Arrival and Departure</td></tr>
<tr><td>Task Appropriate Mode (TAM)
- Oceangoing Navigation</td></tr>
<tr><td>Activity Specific Operational Mode
(ASOM)
- Specific Area Navigation</td></tr>
</table>

To prepare for these general navigation elements, it is important to clearly distinguish the performance and limitations of the technology and equipment being developed for autonomous navigation vessels. By categorizing them in the Tabulated Format proposed in IMCA M 220, it is possible to approach the basic concept of "Mode of Operation.“

In the Tabulated Format detailed instructions are provided for the actions that ships must take based on the status and settings of their equipment, compared to the corresponding action items. According to this methodology, vessels are not only governed by specific equipment, but standards are established and implemented for all equipment used on the vessel. Therefore, for MASS, setting an 'mode of operation' means identifying all factors that can ensure the safety of ship operations, including navigation areas and traffic congestion, and establishing standards for the actions that the vessel must take to ensure safety in that operating mode.

However, it is true that presenting all of these items in a Tabulated Format is not easy to operate, and in order to adopt this format, factors that can determine the safety of all operations must be identified. To analyze the risk factors associated with the equipment installed on the vessel, the FMEA is used to identify them during the vessel's construction phase as a verifying tool, and standards are set for the FMEA Proving Test to supplement this[9]. But, not all factors related to the operation of MASS are identified, and additional research related to these factors must be conducted in the future.

V. Conclusion

MASS technology is an emerging trend in the maritime industry during the 4th industrial revolution, and it is seen as a transformative technology that will bring a new paradigm shift to shipbuilding and the maritime sector. The primary objective of MASS is to minimize maritime accidents that result from human errors, and it is crucial to develop a system that prioritizes safe operation above everything else[10].

guideline on operational activity planning for offshore marine vessel projects and support activities. It presents techniques that can be used for planning and executing offshore marine vessel projects and activities, with a focus on decision-making tools such as the ASOG. The guidelines recommend developing CAM and TAM based on a comprehensive understanding of the dynamic positioning system, DP FMEA, the offshore industry mission, vessel location, and risk assessment. The ASOG sets operational, environmental, and equipment performance limits for the DP vessel with respect to the particular activity it is engaged in. The ASOG is presented in a tabular format that specifies technical parameters such as allowable heading and position offsets, wind and current limits, and allowable thruster usage, as well as procedural and administrative requirements. The guidelines also provide guidance on black-out recovery time and emergency response procedures.

In conclusion, while IMCA M 220 serves as a guide for DP vessel operations, it can also be utilized as a tool in other types of vessel operations to reduce accidents caused by human error. However, as the technology for MASS continues to develop, the classification system based on human intervention and vessel structure may not provide clear guidelines. To address this, it is important to conduct FMEA to identify potential risks and hazards associated with various factors, and to develop guidelines for safe operation through FSA tools established by the IMO[11]. By categorizing the technology and equipment in the Tabulated Format proposed in IMCA M 220, a basic concept of "Mode of Operation" can be established, which will help to clearly distinguish the performance and limitations of autonomous navigation vessels and prepare for various navigation elements such as arrival and departure in ports and harbors, coastal and ocean-going navigation, traffic density, weather conditions, ship status, and navigation laws and zones.

REFERENCES

[1] International Maritime Organization, "REGULATORY SCOPING EXERCISE FOR THE USE OF MARITIME AUTONOMOUS SURFACE SHIPS(MASS)", MSC 99/5/11, 2018.

[2] Porathe T., "Autonomy Level for Unmanned Surface Vessels: Towards an International Standard", Proceedings of the International Conference on Computer Applications in Shipbuilding (ICCAS), Trieste, Italy, 2018.

[3] CCNR Press, "First International Definition of Levels of Automation in Inland Navigation", http://ccr-zkr.org/

[4] Vagia, M., Transeth, A. A., & Fjerdingen, S. A., "A literature review on the levels of automation during the years. What are the different taxonomies that have been proposed?". Ergonomics, 53, pp. 190-202, 2016, DOI: 10.1016/j.apergo.2015.09.013.

[5] Fukuto J., "Automation Levels of Automated/Autonomous Ships", NK Reserach, 2021. https://www.classnk.or.jp/hp

[6] Ørnulf Jan Rødseth, Bjørn Jalving, Rolf Skjong, Frode Meling, and Odd M. Faltinsen, "Levels of autonomy for ships," IEEE Transactions on Intelligent Transportation Systems, Vol. 23, No. 6, pp. 2546-2557, 2022, DOI: 10.1088/1742-6596/2311/1/012018.

[7] International Marine Contractors Association, "Guidance on Operational Activity Planning", IMCA M 220, pp. 1-20, 2017, https://www.imca-int.com/

[8] Topaz Energy and Marine, "DP Operation Manual Section 3 CAM-TAM-ASOG", pp. 1-15, 2023.

[9] International Marine Contractors Association, "Guidance on failure modes and effects analysis (FMEA)", IMCA M 166, pp. 1-23, 2017, https://www.imca-int.com/

[10] Kim J. M. and Park H. R., "Application of a Dynamic Positioning System to a Maritime Autonomous Surface Ship (MASS)", Journal of Navigation and Port Research, 46(5), pp. 435-440, 2022, DOI: 10.5394/KINPR.2022.46.5.435

[11] International Maritime Organization, "REVISED GUIDELINES FOR FORMAL SAFETY ASSESSMENT (FSA) FOR USE IN THE IMO RULE-MAKING PROCESS", MSC-MEPC 2/Circ.12, pp. 3, 2018.

Authors

Jeong-Min Kim is master mariner and received the B.S degree in Coast guard., Master degree in Business Administration and Ph.D. candidate in Offshore Management from Korea Maritime and Ocean University, Korea, in 2009 and 2017, respectively.

Prof. Kim joined the faculty of the Ocean Technology Training Team at Korea Institute of Maritime and Fisheries Technology (KIMFT), Busan, Korea, in 2021. He is interested in development of Maritime Autonomous Surface Ship(MASS), Dynamic Positioning (DP) system in vessel specially, He is in charge of TM in KIMFT DP Training Center.

HyeRi Park received the B.S., M.S. and Ph.D. degrees in Maritime safety and environment Engineering from Korea Maritime and Ocean University, Korea, in 2012, 2014 and 2017 respectively.

Dr. Park joined the senior researcher of the Logistics and Maritime Industry Research Department at Korea Maritime Institution, Busan, Korea. She is interested in Maritime Safety and Maritime Industry Research field, development of Maritime Autonomous Surface Ship(MASS) specially.