

Operations of Maritime Autonomous Surface Ships

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ABSTRACT: Advancing technologies create unique opportunities for constructing autonomous ships, which, in turn, raise growing interest of the maritime industry, shipowners in particular. These authors have analyzed actions taken in this field and some aspects related to the operations of maritime autonomous surface ships (MASS). The presented case study refers to a ship with a skeleton crew on a deep sea voyage, where the ship's autonomy is narrowed to the fourth stage of transport task – sea voyage and its navigational aspect.

1 INTRODUCTION

The idea of unmanned transport vehicles is not new. At each stage of development, it should take into account vehicle safety and the safety of the environment (including other users). First implementations of unmanned vehicles took place in space transport. Then, commercial use of rail transport was implemented to carry freight and people. Further commercial applications take place in air transport for military and civil transport purposes. Commercial use in road transport using autonomous vehicles are known to be realized within relatively small areas, inaccessible for other users. Common use of autonomous cars and trucks on generally accessed roads are still at the phase of research. Similar actions are taken in water transport.

Water transport of people and goods is one of the oldest known methods used by humans on local routes and for very large distances. To date, there are no known commercial solutions for the operation of autonomous ships. However, tests are in progress involving autonomous ships in selected areas of local importance.

The operation of maritime autonomous ships calls for working out international solutions to legal issues. Therefore, the International Maritime Organisation has undertaken to coordinate relevant work. A lively discussion is conducted at meetings of IMO's committees and subcommittees with large involvement of Member States, affiliated organisations and commercial companies, which see their opportunities to become leaders in implementing technologies for autonomous ship operations at sea.

The implementation of technologies for maritime autonomous ships, trading locally or across the oceans, must be preceded by solving various problems. These refer to both legal and technological requirements relating to ship control and supervision, and other issues. The problems to be tackled include the maintenance of autonomous ships to ensure, similarly to aviation, their failure-free work, problems related to property salvage, prevention of environmental disasters, threats related to crime and cyber crime. Apart from these problems of global safety, the human factor remains essential: training of the crew to work in the period of transition and later,

and personnel supervising ships from land-based operational centers. Technological changes should also address typical issues that ships with crew on board normally solve through their established procedures, e.g. berthing and mooring of an unmanned ship. It seems that solving the above problems will take time, having rather evolutionary than revolutionary character. The evolution is expected to take years, as the technical solutions will undergo multiple tests, with skeleton crews still on board. These tests will be strictly verified, especially by the demanding maritime community. Therefore, the current discussion focuses on the introduction of new technological solutions, parallel to the modification of ship equipment used so far, and limiting current personnel in favour of subsequent rising levels of autonomy.

2 ACTIONS FOR MASS IMPLEMENTATION

Trials of autonomous ship operation on the seas and oceans have already been done. At the current stage, attempts are made to reduce, not eliminate, the human factor from work on board. At the same time, new technological solutions allow not only a safe ship movement without qualified crew on the navigating bridge, but also for the conduct of sea trials of unmanned ships in confined waters. The pressure is growing from the maritime industry, including shipowners, on consultative, legislative and executive bodies to develop and implement solutions allowing for the operation of autonomous ships, including the International Maritime Organisation.

The IMO has been established to solve problems of the marine environment safety and protection. Its forum is open to discuss not only new ideas related to challenges of technological development, changing the existing order and established procedures. The organisation has to work out regulatory instruments allowing the use of new technologies, especially those addressing the replacement of people by intelligent systems. The previous informal discussions on MASS have been finally included in the IMO's working schedule and since 2017 has been on the agendas of committee and subcommittee meetings. After the publication of the documents [1, 2] the report of the 98. Session of the Maritime Safety Committee [3], in the point defining the scope of MSC's work embraced the need to identify the problem and undertake a scoping exercise for MASS. That seems to be a breakthrough moment. A correspondence group was established [24], while at 99. MSC Session working groups were also set up [23, 36]. Many countries and IMO affiliated organizations have considered the development of new concepts and solutions surrounding the MASS as their duty [5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 25, 26, 27, 29, 30, 31, 32, 34, 35]. IMO's Secretariat is now attempting to consolidate these proposals and concepts [28, 33]. Besides, reports of the tests carried out have been published [20, 22].

To sum up the proposed MASS solutions, it should be underlined that the majority of States and institutions understand the many challenges to be faced. At this stage, they do not focus on technology,

whose development progresses in its own right. It seems crucial to look into the legal aspect of international shipping and make efforts, as technology is rapidly advancing, to adjust regulatory instruments and avoid a situation where technological progress is slowed down or the law is simply bypassed. Most of the proposals take into account the evolution of MASS technology, and a number of proposals focus on modifying the existing international legislation, where various levels of MASS autonomy would be defined. This particularly refers to the human factor. To put it simple, the problem to be solved is to determine levels of autonomy and propose technological solutions, which will enable the radical reduction of ship's personnel in the first place. Today, it is understandable and logical. Further steps related to the exclusion of traditional crew on a sea-going ship, transferring the ship movement control to a land-based centre and finally, regarding a sea-going ship as moving autonomously, today are difficult to implement as well as to comprehend such concept of shipping.

At present, as defined in [36], the autonomous ship is understood "as a ship which, to a varying degree, can operate independent of human interaction". Various divisions into levels of autonomy are proposed, which largely results from the complexity of the issue. The problem is vital, though, as it directly translates into engineering and technological solutions, and therefore, on ship operation understood as its use and maintenance. Another issue is the way and scope of executing each phase of the transport task - carriage of cargo and people:

- 1 arrival at the place of loading,
- 2 ship's preparation for loading,
- 3 cargo loading,
- 4 sea passage,
- 5 discharge of cargo.

These phases may be carried out at varying levels of ship's autonomy, from manual to fully autonomous modes. From this perspective, the levels of ship's autonomy may refer to the environment in which the ship operates, where distinct areas include [37]: fleet management and the control and supervision of vessel traffic, organization and execution of port operations, organization and monitoring of transport processes (logistics, transport, forwarding) (Fig. 1).

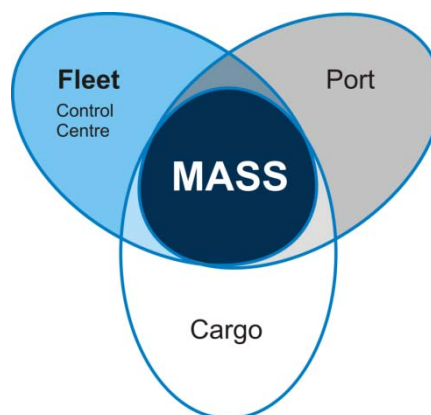


Figure 1. Environment of the maritime autonomous surface ship. Source: [37]

Considering the operation of a conventional ship, we can point out such main tasks of the ship as:

- navigation;
- steering;
- communication;
- propulsion;
- power;
- cargo handling;
- passenger service,
- maintenance and repair work.

For autonomous ships, operating independent of human interaction requires the development of technological solutions for them and setting forth standards/ requirements concerning safety, security, reliability and efficiency.

Technological solutions are already available to a large extent. Intensive research is continued into other developments, including simulation tests, tests of physical models and the construction of prototypes. The research is often done as part of national or international projects, e.g.:

- MUNN - Maritime Unmanned Navigation through Intelligence in Networks, <http://www.unmanned-ship.org/munin/>
- AAWA - Advanced Autonomous Waterborne Applications Initiative, <https://www.rolls-royce.com/~media/Files/R/Rolls-Royce/documents/customers/marine/ship-intel/aawa-whitepaper-210616.pdf>
- STM Validation - Sea Traffic Management Validation Project, <http://stmvalidation.eu/>
- AVAL - Autonomous Vessel with an Air Look, <http://aval-project.pl/>

Testing technological solutions in real conditions requires the identification of places where tests may be performed and the principles to ensure the safety of other ships proceeding in the vicinity. The work is already ongoing and mainly involves the administrations of maritime countries, as well as a recently established MSC working group on MASS [10].

Putting autonomous ships into service calls for appropriate regulations, the basis for activities of classification societies and insurance companies. Legislative work is conducted by the IMO's Maritime Safety Committee. It is assumed that changes will be evolutionary, starting from an analysis and modification of the existing regulations referring to maritime safety and security. It has been proposed to prioritize a review of IMO mandatory instruments. First, an review of the existing IMO regulations will be carried out to determine their applicability to MASS: A) apply to MASS and prevent MASS operations; B) apply to MASS and do not prevent MASS operations and require no actions; C) apply to MASS and do not prevent MASS operations but may need to be amended or clarified, and/or may contain gaps; D) have no application to MASS operations.

The next step will consist in determining the appropriate route to assess the operation of MASS, taking into account, inter alia, the human factor, technological and operational factors by: 1) adopting the equivalence provided for in the regulations or the possibility to extend interpretation; 2) changing existing instruments; 3) developing new instruments; 4) rejecting the said solutions 1 to 3. The results of the above actions will give rise to changes, supplements

and will introduce additional regulations on the construction and operation of MASS.

Today, considerations concerning means of transport, including ships, take into account their life cycle: from demand to scrapping. Thus, defining the conditions of operation and equipment of autonomous ships we have to take into account all stakeholders present in that cycle. Five groups of such entities can be distinguished. These are shipowners (1), industry (2), research and development institutions (3), classification societies and insurance firms (4) and maritime administrations (5). Their aims are different. The first four groups are business organisations striving to achieve economic results. Maritime administrations function as coordinators balancing the targets of the other stakeholders, approving and supervising the entire process, caring for the environment, including its social, economic and political aspects (Figure 2).

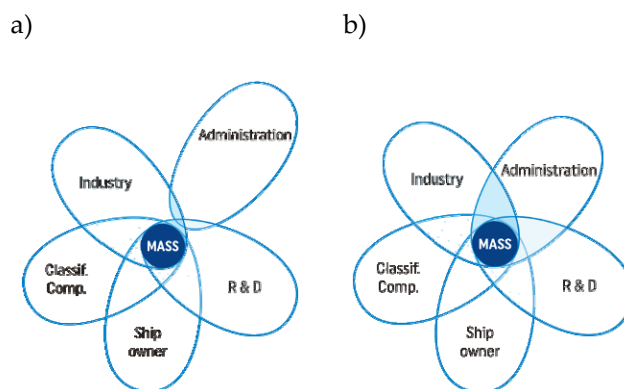


Figure 2. Stakeholders in the MASS life cycle: a) at present; b) expected

In simplified terms we can say that these entities attempt to:

- shipowners: minimize the costs of ship equipment and operation, including crew costs,
- the industry: maximize profits by using new technologies
- R&D institutions: develop cognitive functions by developing new technologies
- classification societies and insurance forms: minimize risk assessment errors for preventive purposes in the process of operation,
- maritime administrations: formalize standards to minimize operational risks applying the 'as low as reasonably practicable' (ALARP) principle.

3 EQUIPMENT OF THE AUTONOMOUS SHIP

Current considerations of the concept of developing autonomous ships are focused on finding a consensus at an international level, so that states will be able to recognize the status of autonomous ships. In the short run, such ships could be manned by fewer qualified crewmembers, while in the long run the unmanned ships would be remotely supervised by land-based operators. The discussion so far has been concentrated on setting up international regulations that would define the ship's equipment during the transition period in the context of currently binding regulations. Technological developments that

spur the progress of discussions are not limited in the sense of specific solutions or directions of further advancements to be adopted on ocean-going vessels.

At present, the shipboard navigational, life-saving and radio equipment of a marine ship is strictly defined by the SOLAS Convention. The level of automation used is one of the criteria in determining the minimum manning of a sea-going ship. The installation of additional systems supporting navigator's or engineer's work does not directly affect the composition of ship's personnel. Behind the current philosophy of fitting the ship with various technological novelties, such as decision support systems, is the intention of limiting human errors and reducing the number of accidents at sea. However, such additional ship equipment, if not required by law, is not common due to economical reasons. Each investment in additional equipment should be economically viable. It is only a legal consensus at international level that will lead to a situation where investing in IT equipment on a sea-going ship will be economically justified, i.e. it will be possible to reduce the number of qualified crew members. This is the reason of the pressure from IT equipment makers as well as shipowners who in the long run expect, rather than fewer accidents at sea, winning technological advantage resulting in lower operating costs, which is competitive advantage.

There are factors affecting the fitting of the autonomous ship. These are:

- manning (without / with crew),
- the area of autonomy (stages of the transport task).
- the scope of autonomy (navigation, steering, ...).

Besides, for all the above variants, in standard and emergency situations it should be a possibility of taking over the control of the ship by an onboard operator or remotely by a land-based operator. In addition, in case of ocean shipping in particular, the problem of maintenance remains (during operation or while docked).

It is assumed that in the initial period, small unmanned ships in coastal shipping and sea-going ships with a skeleton crew will be put into operation. In the former case, e.g. on small passenger ferries, autonomy will be applied to all stages of the transport task. In the latter case, it is assumed that sea voyage will be executed in an autonomous manner, while the other parts of the task will be carried out by an operator on board or at the land-based centre or operators sent to the ship for executing scheduled operations, e.g. mooring. Given the above conditions, it seems that the equipment of the autonomous ship will be adapted to the established manning, area and scope of its autonomy. The reference point may be standard ship equipment as required by relevant conventions. However, one can expect that new technological solutions will be introduced, that is new systems and equipment on ships and in land-based centres. This entails the need to define a template/templates specifying technical measures/technologies for the assumed manning, area and autonomy range of the ship. It is necessary to ensure appropriate infrastructure on land, including the equipment of land-based centres, performing the supervisory functions and being able to take over

remote control of the ship. A preliminary concept of such a template is proposed in [8].

In the next step, technological solutions will be described in detail, including, for example, the MASS decision-making module. Particular solutions may comprise existing decision support systems, e.g. those addressing collision avoidance. The challenges also refer to guaranteeing an appropriate level of data quality, system security and system reliability. Implementation of new solutions should be preceded by a comprehensive risk assessment (IMO - FSA). An example in this case may be the equipment of a ship with a skeleton crew on a deep-sea voyage, with ship's autonomy restricted to the fourth stage of transport task – the navigational aspect of sea voyage (see Chapter 1).

4 MANNING OF AN AUTONOMOUS SHIP

The human as an operator of a complex transport system, in particular in maritime transport sector, is a complex issue. If we look into the current studies and proposals concerning the timetable of work and the overall creation of the concepts of maritime autonomous ships, four states related to the ship manning can be distinguished [10]:

- Qualified personnel, in accordance with the STCW Convention, are on board. The number of crew members is reduced compared to conventional ships.
- *Degree one: Ship with automated processes and decision support:* Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
- *Degree two: Remotely controlled ship with seafarers on board:* The ship is controlled and operated from another location. Seafarers are available on board to take control and to operate the shipboard systems and functions.
- There are no qualified seafarers on board, able to take over ship control,
- *Degree three: Remotely controlled ship without seafarers on board:* The ship is controlled and operated from another location. There are no seafarers on board.
- *Degree four: Fully autonomous ship:* The operating system of the ship is able to make decisions and determine actions by itself.

The first case requires that the number of trained seafarers on board complies with the currently applicable STCW Convention. The problem to be sorted out is the process and scale of reducing a conventional crew, to match ship's degree of autonomy. This is a relatively simple issue, which requires certain legislative changes, but it is intuitively understandable. The second issue refers to hiring a considerably smaller number of personnel with appropriate STCW certificates and, if necessary, staff required for running maintenance of shipboard systems. The problem concerns the training requirements for such personnel in marine rescue and life-saving skills. The third, completely new issue, results from the elimination of ship's deck crew and

the need to develop the concept for qualifications of personnel working in land-based control and supervision centres for autonomous ships. The basic question addresses the scale and scope of required conventional marine competencies. In other words, the question is whether land-based personnel need to have any marine competencies, or perhaps only those of transport system operators.

An interesting proposal for creating a system of levels of autonomy and control was put forward by Australia and other countries [9]. The levels of technical autonomy were separated from operational control, managed by qualified personnel on board. The concept combines levels of technical autonomy with the presence or absence of personnel on board. Four levels of technical autonomy have been established:

- A0, **Manual**. Manual operation and control of ship systems and functions, including basic individual system level automation for simple tasks and functions.
- A1, **Delegated**. Permission is required for the execution of functions, decisions and actions; the operator can override the system at any stage.
- A2, **Supervised**. The qualified operator is always informed of all decisions taken by the system. Permission of the qualified operator is not required for the ship system to execute functions, decisions and actions; the qualified operator can override the system at any stage.
- A3, **Autonomous**. The qualified operator is informed by the system in case of emergency or when ship systems are outside of defined parameters. Permission of the qualified operator is not required for the ship system to execute functions, decisions and actions; the qualified operator can override the ship system when outside of defined parameters. Provided the boundaries of the ship system are not exceeded, "human control" becomes "human supervision".

Operational control of the human distinguishes only two states:

- B0, No qualified operators on board but qualified operators available at a remote location
- B1, Qualified operators on board

Each of the above concepts has its strengths and weaknesses. The former, represented by the working group [10], is a closed concept, with two states including qualified crew on board and two states without crew. The latter concept, developed by Australia [9], sets forth more options and is more flexible in the implementation of the concept of maritime autonomous ships.

An analysis of the two documents [9, 10] allows for a general conclusion that automation of each process leads to greater repeatability, enhancement of safety and gradual replacement of people, which will eventually bring economical profits. This is a key statement, as the expected economic benefits resulting from the gradual replacement of man on a sea-going vessel should bring better operation of the system and improved safety at sea, the outcome of gradual exclusion of the human factor. This thesis will be verified in practice, through multiple programmes and trials, similarly to public road transport.

In the context of training of seafarers or, in the future, land-based operators of MASS systems, while accepting the need to link technological automation with maritime training, it seems relevant to build these developments on existing international regulations, including the provisions of STCW and SOLAS conventions.

Today, the STCW Convention fully regulates the training of seafarers, stipulating theoretical training supported by mandatory sea service, which together are a prerequisite to competencies needed in specific positions. The SOLAS Convention in Regulation V/14 requires a minimum manning that is determined, inter alia, by the degree of ship automation. As long as the first and second levels of autonomy are examined [10] or state B1 [9] that assume the presence of qualified or reduced crew, no conflict arises. An international consensus is needed in working out more precise links between the degree of automation and the number of qualified personnel required on board.

It is different when it comes to implementing the third and fourth levels of autonomy [10] or state B1 [9]. The absence of qualified personnel on the ship results in an entirely new operational and legal situation. In the field of training land-based operators / supervisors of a MASS system, there will be doubts as to at which particular moment supervision should be aborted and remote operation started. In the initial period, additional training of navigating officers can take place, who, with extra qualifications, may be employed as land operators of autonomous ships. In the long run, however, assuming significant reductions or complete exclusion by automatic systems, it seems now is the time to start work on setting instructional framework for such personnel. Undoubtedly, theoretical training will not face many problems. The question concerns practice. Today, without understanding the size and mass of the ship, especially the hull behaviour in stormy waves, it is difficult to imagine correct decision making. Undoubtedly, to better understand the problems of ship's work in waves, enhanced by climatic changes, gaining experience on training ships should not be excluded, which will give at least basic understanding of ship's behaviour in heavy weather.

The examined documents do not clearly formulate the situation where qualified crew is not present on the ship, but personnel performing servicing and maintenance work are. It is hard to imagine today that autonomous ships without qualified seafarers will be serviced only during short stays in port. It is regarded as an ultimate target such as already effectively functioning in aviation. The model currently operated in maritime shipping is just opposite. The normal practice is that ships carry spare parts for shipboard equipment, operational materials (e.g. lubricating oil) and qualified personnel able to perform even complex repairs. Services offered ashore are used occasionally or in major failure situations. As the marine environment is very aggressive, it is hard to imagine that regular maintenance and repair work en route is given up, and done only in ports, along with an increase in the frequency of class surveys performed in ship repair yards (Figure 3).



Figure 3. On-ship operational tasks

Undoubtedly, the experience of the ongoing operation of ships indicates in such situations the need to increase the number of salvage ships that even in the long run will not be converted into autonomous ships without qualified personnel.

5 CONTROL AND SUPERVISION OF AUTONOMOUS SHIPS

Today land-based safety related assistance to ships at sea has a few aspects. Each of the currently considered aspects is based on the sheer fact that on board are qualified seafarers who utilize various types of information worked out on land. The basic function of such centres or arrangements is to ensure an adequate level of safety of shipping in standard and emergency situations.

Weather services have been provided on the oceans for years, tasked to recommend optimal weather routes ensuring safe navigation within optimized period of time. These are paid-up services. Shipowners pay for the access to information, and ships usually get specific recommendations, which may be taken into account by the captain fully, partially or ignored. For future autonomous ships, the role of such services will undoubtedly be increased. In the case of unmanned vessels, a recommended ocean route will change its status to the mandatory route, as it seems that a system operator will not be able to ignore such recommendations. Naturally, working out an optimal weather route is also possible on board using autonomous software. At present this process requires the presence of a qualified person on board.

In frequented coastal routes and port approaches Vessel Traffic Service systems are in use. The role of such systems for unmanned ships passing near a coastal state and calling at a specific port will have to be verified and extended. This applies to automatic reporting and responses to emergency situations occurring in areas covered by VTS systems.

In extraordinary situations at sea, including emergencies, presently the master is assisted by a designated person or an entire emergency response team. The essential feature of such assistance to the master is that the designated personnel have sea experience and seamanship, usually supported by a representative of the insurer. The captain receives current advice on actions to be taken, while the emergency team arrange for rescue party, port of shelter and undertakes other external actions. In an emergency situation occurring on a unmanned ship,

the role of such a team must be coordinated with the ship operator at the land-based facility.

The operation of unmanned autonomous ships will require establishment of shipowner centres for ship management, regardless of the autonomy level 3 [10] of remotely controlled ships or level 4 [10] of fully autonomous ships. Monitoring function will be performed in these cases. When such concept is implemented, a group of operators controlling autonomous ships and a monitoring group will be established. In the long run, the STCW Convention might be broadened to include sections on the training process and competencies of land-based operators at the third and fourth level of autonomy.

6 THE OPERATION OF THE AUTONOMOUS SHIP - CASE STUDY

The study focuses on the equipment of a sea-going ship with skeleton crew, with its autonomy narrowed to the fourth stage of the transport task - ship's navigation on a sea voyage (compare chapters 1 and 2). Proposed guidelines for autonomous vehicles: ships [Korea] and cars / trucks [NHTSA] have been taken into account. The following method of analysis is adopted: identification of the selected stage tasks, determination of the necessary functionalities and implementation. The following tasks are distinguished:

- acquisition, integration and fusion of data (situational awareness),
- avoidance of collisions and groundings (analysis and assessment of the navigational situation, determination of a safe trajectory in a collision situation or risk of grounding),
- navigation along a set trajectory according to the voyage plan, and in case of a collision situation, along a safe determined trajectory,
- human-machine interface (HMI), ship-shore communication and alerting in emergency situations (emergency procedures),
- remote monitoring/control.

The above tasks have been considered from various points of view:

- Operational Design Domain (ODD): operating parameters, environmental conditions, and any other domain constraints,
- situational awareness and collision avoidance - Object And Event Detection And Response OEDR: detection and respond adequately to circumstances,
- Human Machine Interface HMI - means and events calling/generating the interaction seafarer - MASS,
- Minimum Risk Condition MRC - fallback: transition to a condition with minimal risk: risk control options or transition from autonomous mode to human control,
- protection from intrusions and disruption - cybersecurity: incorporation of cybersecurity into the design of MASS.

Acquisition, integration and fusion of data (situational awareness). The MASS operation is based on information about own ship and the environment, obtained from devices and systems

available on board in any conditions. The definition of the conditions for 'proper lookout' for a MASS seems to be of key importance. This means the need to indicate additional, compared to conventional ships, data and systems and equipment for data acquisition. Similarly to conventional ships, mandatory systems, scope, accuracy and reliability of data after the processes of integration and fusion of data should be defined. More complete use of already available data may be a partial alternative. The aim is to provide data needed for the performance of MASS tasks and the supervision by ship crew or the land-based operators. The minimum risk condition refers to situations where the correct operation of the ship is threatened. It is related to ensuring appropriate redundancy of systems and equipment for the acquisition, integration and fusion of data in case those in use suffer a failure, and to assure data reliability and accuracy through appropriate methods and tools of cybersecurity (standards and levels).

Navigation along a set trajectory according to the voyage plan, and in the case of a collision situation, along a safe determined trajectory. The provision of safe operating conditions involves defining the limits of ship movement parameters, taking into account the ship's manoeuvring capabilities in current environmental parameters (hydrometeorological parameters, other ships, navigational obstructions, etc.). Depending on the nature of changes, they may result in activation of the task of collision avoidance. The question to be answered in this respect is in what conditions and how the crew or operator should be informed of such events: should any or specific event be signalled, should it be information or warning, or instruction to take over the ship control (HMI). The minimum risk conditions may relate to additional functions of the autopilot for keeping the ship on a chosen route. Cybersecurity should be ensured by appropriate solutions incorporated in the task of data acquisition and integration.

Avoiding a collision or grounding includes an analysis and assessment of the navigational situation, then determination of a safe trajectory in a collision situation. In this case, the conditions of operation refer to criteria and limitations in the determination of safe trajectory and methods for determining solutions. The relevant requirements are defined in the existing navigational decision support systems. Their solutions may be used in the construction of HMI for MASS. The essential functions within risk minimization will be systems of automatic communication and negotiations. These will contribute to increased situational awareness, in particular the planned actions of other ships. They will allow for agreeing on manoeuvres of the encountering ships, and in a close quarter situation for coordinating actions to avoid a collision. Like in the task of data acquisition and integration, it will be important to ensure an appropriate level of cybersecurity. Part of the adopted solutions may also be used in this task.

Communication with the crew and land-based centre is to ensure that the continuous monitoring of MASS voyage is carried out by the crew or the centre operators, with the capability of taking over the ship control. The loss of MASS communication with the

crew and land-based centre should be considered as critical for the safety of navigation. Therefore, the solutions applied should ensure the communication in emergencies as well, by using dedicated HMI designed for various working modes (standard, emergency, etc.). The minimum risk condition can be ensured, inter alia, by redundant systems of communication and synchronized use of additional means of communication and signalling: voice and/or light. The MASS - crew and MASS - centre communications must meet adopted standards and levels of cybersecurity.

Remote monitoring/control. The implementation of this task requires ensuring continuous monitoring of the MASS voyage, and control of ship-based systems and equipment by land-based operators in any conditions, and the possibility of relaying the control function to the crew through established procedures. Land-based centre HMIs should feature functions, in addition to those in use, related to the monitoring and management of vessel traffic monitoring and management, and functionalities for HMI used by the crew. The minimum risk condition can be ensured, inter alia, by redundant communication systems. This task in particular requires high level of cybersecurity. The need therefore arises to set forth standards and levels of cybersecurity for MASS - land-based centre communication systems.

7 SUMMARY

The presented analysis of the operation of the autonomous ship refers to the equipment of a ship with a skeleton crew in the sea-going voyage, where ship's autonomy is restricted to the fourth stage of the transport task, navigation during the sea voyage, and does not exhaust the subject of autonomous ship equipment. It may serve as a template for consideration of other cases varying in the type of navigation, ship type or conditions of operation. It seems inevitable to engage all five groups of stakeholders in the process of establishing MASS operation conditions. The implementation of MASS technology in maritime navigation is largely dependent on the activity of the widely understood maritime administration.

ACKNOWLEDGMENTS

This research outcome has been achieved under the research project No 1/S/ITM/ 2016 financed from a subsidy of the Polish Ministry of Science and Higher Education for statutory activities of the Maritime University of Szczecin.

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