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Situational Awareness in Autonomous Shipping – Ship Domain in Remote MASS Operation

T. Abramowicz-Gerigk & Z. Burciu
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: The introduction of Maritime Autonomous Surface Ships (MASS) in maritime transport creates new challenges that did not previously exist in the case of manned ships, and changes the approach to voyage planning, implementation and monitoring. MASS is not only supposed to be more economical, but also contributes to transport safety and environmental protection, while limiting the impact of the human factor. Taking into account the assumptions of the International Maritime Organization, the implementation of a MASS voyage, supervised by the operator of the Remote Operations Centre (ROC) will require a high level of situational awareness. The paper discusses the determination of the MASS safe navigation domain by ROC operator making decisions under risk conditions. It is expected, that according to Kahneman and Tversky's prospect theory, the enlargement of MASS domains may result in an increase in human-induced navigation hazards, especially in restricted areas.

1 INTRODUCTION

The works of International Maritime Organization (IMO) and the European Commission to develop and implement regulations governing the safe navigation of autonomous vessels are still in progress. At the 105th session of the IMO International Maritime Organisation Maritime Safety Committee (MSC) in April 2022, the works on developing assumptions governing the implementation of the work program on MASS (Maritime Autonomous Surface Ships) began and it was expected that the MASS Code would enter into force on January 1, 2028.

On the 108th session [20], in May 2024, MSC agreed to the revised Road Map for the MASS code development, including introduction of amendments to SOLAS Convention (International Convention for Safety of Life at Sea), adoption of a mandatory MASS Code in 2028 and its entry into force on January 1, 2032. This code will regulate and solve problems of technological and legal nature, transport safety, including operational reliability of MASS Complex Technical Systems, navigation, ship operation, monitoring, Search and Rescue (SAR), legal aspects, cooperation between MASS and the Remote Operations Centre (ROC), and ROC operator competencies.

One of the complex issues difficult to formalize is the relationship between human responsibility and automation of processes related to safety of ship, cargo and marine environment, when MASS is monitored and controlled from the shore by ROC operator. The competencies of the operator are covering the following areas:
- operation with legal liability for the ship and cargo,
- voyage planning, remote navigation
- new collision avoidance regulations,

– MASS safety and security monitoring,
– preventing and responding to cyber hazards,
– cooperation with SAR services in rescue operations.

In the absence of international rules and standards, the alternative way of ensuring safety was introduced by EMSA (European Maritime Safety Agency) to create the common safety levels and enhance harmonization in the analysis of preliminary MASS designs. Det Norske Veritas (DNV) was contracted by EMSA to develop a Risk Based Assessment Tool (RBAT) [15].

In the MASS hierarchical control structure presented by Thombre et al. [16], data related to situational awareness, available for Shore Control Centre operator, comes from Integrated Automation System, which uses data from MASS Autonomous Navigation System. In the opinion of experienced Ship Masters, comparing the manned and remote ship operation, situational awareness (SA) based on the data from Integrated Automation System causes the operator to change the boundaries of safety measures.

The names introduced by various authors for the land-based MASS operations centre such as Remote Control Centre introduced by DNV for remotely controlled ships or Shore Control Centre proposed by Thombre et al. [16] fall within the general concept of a Remote Operations Centre ROC.

The paper discusses one of the most important risk options related to situational awareness of ROC operator, which is the ship safety domain.

2 SITUATIONAL AWARENESS IN AUTONOMOUS SHIPPING

Human situational awareness in autonomous shipping is the ability of the Remote Control Centre operator to perceive, understand and predict changes in the actual situation in order to conduct a safe voyage, based on signals received from the Integrated Automation System.

The key elements of MASS and Remote Control Centre are presented in Figure 1.

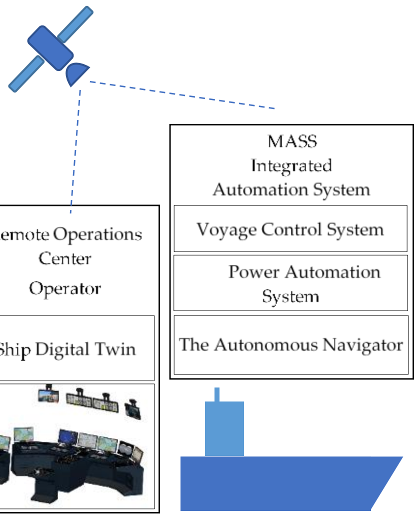

Figure 1. Key elements of MASS and Remote Operations Centre

The automatic situational awareness system, devoted to the monitoring and interpretation of own ship surroundings, manages and utilizes the information from onboard systems e.g.: AIS, ECDIS, GNSS, radar, lidar, IR, cameras, speed log, echo sound, gyro compass, microphone, thermometer, anemometer, and inertial measurement unit. Based on AI (Artificial Intelligence) algorithms, the combined sensor data - multi-sensor perception system - provides the required situational awareness [16].

In remote operation, according to IMO, MASS is managed by Remote Operations Centre, depending on the level of autonomy. The situational awareness in this case is based on operational procedures, ROC operator training, his personal attitudes and skills. SA in the MASS remotely managed voyage should help avoid accidental events resulting in disruptions.

The key objective of the situational awareness is to prevent errors that may arise at one of three levels: perception, understanding and prediction [14]. For the operator in the Remote Control Centre, as opposed to the Ship Master on board the ship, an additional area of situational awareness is created due to automation, remote sensing and remote management.

The implementation of a safe MASS voyage will involve a high level of situational awareness, which will enable the operator to counteract possible hazards and predict their status in the technical and commercial operation of the ship.

The three levels of situational awareness perception, understanding and anticipation are presented in figure 2.

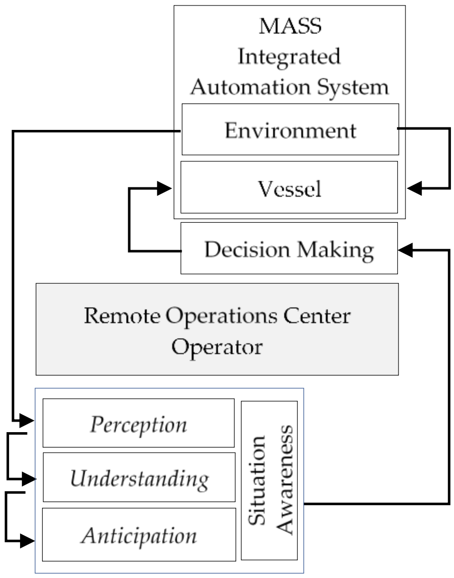

Figure 2. Situational awareness of operator in MASS operation

Level 1 of situational awareness - perception – means receiving and recognizing important information, enabling sea voyages, including proper visualization of operational, technical, environmental and navigational parameters presented by the MASS digital twin and information from vision sensors.

Level 2 - understanding – is the level of understanding and interpreting information obtained at level 1.

Level 3 - anticipation – incudes forecasting the future status of sea voyage by ROC operator.

The operator, based on the information from MASS Integrated Automation System and signals from the ship digital twin, is responsible for making decisions on restoring the deviations of system parameters from permissible values to the required range [11]. The perception of navigational and technical information provided and the understanding of its meaning is required to respond quickly to a situation. The obligation of the operator is to implement the road map of the sea voyage in case of II, III, and also IV degree of MASS autonomy in emergency situations.

Currently, the preparation of a manned ship voyage plan must meet guidelines, included in IMO Resolution A.893(21) and dependent on situational awareness of the crew onboard. The plan may be changed any time the situational awareness changes or when it is possible to find a safer option.

The commercial platforms delivering dynamic voyage planning, with multi-objective optimisation, related to real time weather observations and ship performance models, based on artificial intelligence methods e.g. Wayfinder [22], SeaPerformer [21] or Short Horizon Planner for collision avoidance, adaptable as tool for decision support or automated route deviations, presented by Enevoldsen et al. [5], have been developed. Several studies and projects of autonomous ships are at various levels of development and application including fully autonomous ships in operation [16,19].

Because the actual level of situational awareness influences the necessary safety measures taken by both autonomous navigation algorithms and human control, these should be tailored to the task and take into account the operator's personal skills and confidence in the reliability of the AI. In most cases, many years of Ship Master's experience on board is the reason for less confidence in individual devices of decision support systems [3].

Table 1 presents the relationship between situational awareness and confidence, originally presented by Endsley & Selcon [6].

Table 1. Relationship between situational awareness and confidence [6]

		Situation Awareness	
		Good	Poor
Confidence level	High	Good outcome	Bad outcome
	Low	Do nothing ineffectual	Satisfactory outcome Delay

The person having Poor SA and high level of confidence, presents the worst outcome, making wrong decisions and giving false confidence to other personnel. This is the most dangerous situation of all the situations presented in table 1. The good outcome is dependent on both good situational awareness and high confidence level.

This important issue should be carefully considered to avoid over-reliance, misunderstandings or conflict between the operator and decision support systems at the three levels of SA.

Aylward et al. [2] using Advanced Intelligent Manoeuvring (AIM), developed by Wärtsilä, explored i.a. how the decision support system can influence the safety of navigation and the role of the operator in routine ship traffic situations. When a MASS operator has poor situational awareness due to limited trust in information from all decision support systems, the MASS Integrated Automation System and the digital twin, the solution to ensure a safe and satisfactory outcome is a delay, which may result in a decision to reduce the ship's speed and increase the ship's domain.

3 MASS DOMAIN DETERMINED BY ROC OPERATOR – HANNEMAN & TWERSKY PROSPECT THEORY

The concept of a safe navigational domain around the ship was created to determine the safety of ship traffic in restricted areas. The domain can be defined as the area around the ship, dependent on vessel parameters and traffic situation, in which no other objects should be present [9,13].

Various methods are used to determine the ship's domain based on analytical techniques and simulation, combined with statistical methods and AI. The factors affecting domain parameters include i.e. navigational area characteristics and ship length. A statistical study of ship domains with a method for determining the safe passing distance of a ship was developed by Goodwin [8].

The empirical data show the domains defining the navigator's comfort zone with dimensions of 4.5 ship-lengths in front of the ship and 3.5 ship-lengths behind [9,12]. This shape can be extended into a super-ellipse [5] or circle (Figure 3).

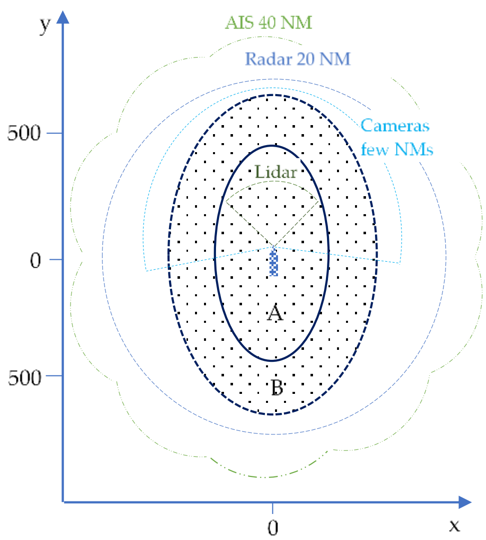

Figure 3. Ship domains: A - manned ship domain, B - remotely controlled MASS domain with the coverage areas of navigation sensors

The example of ship domains determined by Ship Master and ROC operator as safety zones, presented in Figure 3, show the approximate boundaries of ship safety navigational areas from their perspective

The larger domain is related to the operator's decision making under risk conditions. The assessment of a risky situation depends more on the reference point from which we calculate loss or gain, than on their final values. Losses always seem to be greater than gains. A major loss causes permanent risk aversion.

Limited situational awareness and lack of understanding of the situation, trigger emotions that have a huge impact on risk assessment. It is fear that causes the perceived risk to exceed the actual risk, while euphoria, in turn, reduces the perceived risk level of a given situation [1,4].

Decisions made under conditions of risk were analysed by Kahneman & Tversky [10]. In unclear conditions, choices become irrational and personality significantly influences decisions. People estimate probabilities of individual events overestimating medium and small, and underestimating large probabilities of failures. The Kahneman & Tversky prospect theory introduced the decision weights instead of the probability functions.

ROC operator having Ship Master skills and experience, managing MASS in restricted navigation zones, will designate the MASS domain, which, assuming the prospect theory of Kahneman & Tversky, will be burdened with risk aversion. This results in the larger domain "B" than the domain designated by the Ship Master on board the manned ship "A" (Figures 3, 4).

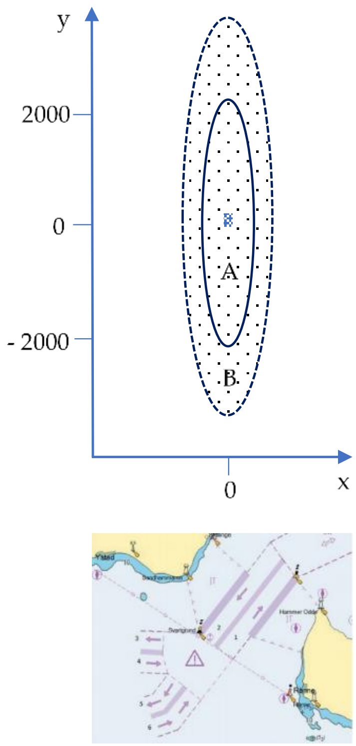

Figure 4. Domains of a ship with length >150 m in Traffic Separation Scheme: A – computed on the basis of statistical AIS data [13] and B enlarged domain of the remotely controlled MASS

The domains observed in traffic situations show different domains, e.g. for ships with length greater than 150 m, in Bornholmsgat TSS (Traffic Separation Scheme) the domain dimensions computed on the basis of statistical data from AIS, were about one NM in front and behind ship [13] (Figure 4).

By increasing the area of the MASS domain, ROC operator will expand the situational comfort zone, increase the time reserve, eliminating the time pressure for making rational decisions, and at the same time will gain time to obtain additional information. Enlarging the domain will cause the operator to maintain a safe MASS speed.

4 DISCUSSION AND CONCLUSIONS

It is expected that autonomous shipping will reduce the impact of the human factor on the risk of failure.

One of the elements ensuring larger comfort zone related to the situational awareness of Ship Master, is creating own ship domain, providing the availability of time to make decisions and avoiding hazards.

Full information will enable the voyage to be maintained at the required level of safety. The perception of navigational and technical information provided and the understanding of its meaning requires to respond quickly.

Possible misunderstanding of the ship's situation may result from delays in communication and decision-making resulting from long lead time to approval - throwing people out of the loop, as well as errors resulting from the "transfer effect" when the operator is involved in simultaneous monitoring of several ships and assesses their response based on signals from devices without feeling the ship's reaction.

Taking into account the research on conventional ship domains [13] and using Kahneman and Tversky's prospect theory in relation to the dimensions of the MASS domain, in order to avoid domain violations and hazardous situations, the parameters of navigation areas e.g. traffic separation systems, traffic lanes and separation zones should be reconsidered.

The important issue is that the instruments used onboard MASS and in Remote Operations Centre will meet performance standards [17] and whether the training and development of skills of seafarers, and ROC operators will be of high priority for IMO [2, 18].

The problem is more complex when the MASS operation is carried out in autonomous integrated transport chain [7], by several operators, at individual stages of the voyage and when an operator controls several autonomous ships. This is also related to the cooperation between VTS and ROC.

Baldauf et al. [3], who presented simulation study on the VTS collaboration with ROC, concluded that VTS operators took earlier actions, than in their usual practice, to establish communication with MASS, which means less confidence. The biggest concern was related to the uncertainty of MASS remote operator's situational awareness and conclusion was that the new technologies enhancing SA should be applied.

The same data should be available in ROC as is available on board the ship and the skills of the ROC operator should be consistent with the STCW requirements for shipmasters and officers of the watch. However, in the case of many MASS units in a traffic separation zone, a situation may arise that the dimensions of the traffic separation zones may be insufficient.

If the presented theses of the paper regarding the enlarged MASS domains by ROC operator are realized, it may result in an increase in navigation hazards caused by the human factor, especially in restricted areas, in traffic separation zones.

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