TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 19
Number 4
December 2025
DOI: 10.12716/1001.19.04.05

Human Factor in MASS Shipping

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

ABSTRACT: The paper presents the influence of the human factor on the safety of autonomous shipping with respect to interaction between management personnel involved in autonomous ship operation - Ship Master and ROC (Remote Operation Centre) operator. Against the background of the works conducted by International Maritime Organization (IMO)and the European Union, the influence of the human factor was analysed depending on the MASS (Maritime Autonomous Surface Ship) level of autonomy defined by IMO. A Bayesian-based model was proposed to assess the reliability of the Ship Master, ROC operator and their influence on the operational reliability of sea voyage of MASS with level 2 of autonomy. The mutual high reliability of both the Ship Master and ROC operator allows for significant improvement of sea voyage reliability. The prospect theory was introduced in the analysis of decisions making process in risky conditions of ROC operator, remotely controlling MASS with level 3 of autonomy, without a crew on board. The influence of the operator's prospect and emotions can be described using decision weight functions. In both studied cases, decision support and cooperation is very important and the estimated influence of the human factor is lower than for a ship with level 1 of autonomy operated by Ship Master without ROC support.

1 INTRODUCTION

In 1997, IMO (International Maritime Organization) adopted a resolution setting out its vision, principles and objectives for the human element. The human element is a complex, multi-dimensional factor affecting maritime safety, security and marine environment protection, encompassing the entire spectrum of human activities performed by ship crew, shore-based management and regulators. Since the 1980s, IMO has increasingly referred to people employed in maritime transport and in 1989, adopted Resolution A.647(16) on guidelines on the management for the safe operation of ships and pollution prevention – the forerunner of the International Safety Management Code (ISM), which became mandatory under the International Convention for the Safety of Life at Sea (SOLAS).

The human factor is crucial for the proper functioning of shipping. Over the last year, EMSA has been working with the European Commission and EU Member States on a comprehensive review of the IMO International Convention on Standards of Training, Certification and Watchkeeping (STCW) for Seafarers [3][4].

Currently, work on the development and implementation of regulations governing the safe navigation of autonomous ships is being carried out by IMO and the European Union (EMSA - European Maritime Safety Agency). This work is extremely difficult due to the not fully recognized relationship between human responsibility and automation of processes responsible for the safety of ship, cargo and marine environment [4].

IMO currently uses the term Maritime Autonomous Surface Ship (MASS) to refer to any ship that is subject to the provisions of IMO instruments and exhibits a level of automation currently not recognized by existing instruments.

The MASS Code being prepared will regulate technological, legal and safety issues, including hazards resulting from the operation of MASS: navigation, monitoring, reliability of technical systems, cooperation of MASS with ROC (Remote Operations Centre) and rescuing people at sea.

To facilitate the process of defining the scope of regulations, the levels of autonomy have been organized as follows [16]:

- level one (MASS I) - 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 may be unsupervised, but with seafarers on board, ready to take control,
- level two (MASS II) - 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,
- level three (MASS III) - remotely controlled ship without seafarers on board - the ship is controlled and operated from another location,
- level four (MASS IV) - fully autonomous ship - the operating system of the ship is able to make decisions and determine actions by itself.

The paper raises an important issue of the human factor modelling in systems design. The Ship Master and ROC operator responsibilities related to different levels of ship autonomy are discussed. The Bayesian-based model is proposed to determine the reliability of MASS II Ship Master, ROC operator and their influence on sea voyage operational reliability. The prospect theory and Poisson process are proposed for the assessment of MASS III operator decision making process.

The presented selected problems of modelling the human factor in maritime shipping are related to the systemic approach of safety assessment in transportation chain [10] and maritime autonomous transport systems [2][10][14].

2 ACCIDENTS RELATED TO HUMAN ELEMENT AT SEA

From the analysis on safety investigations [3], it was determined that, from 2014 to 2023, 58.4% of accidental events were linked to human action and 49.8% of the contributing factors were related to human behaviour. When considering both events related to human action and human behaviour contributing factors, the human element relates to 80.1% of the investigated marine casualties and incidents. These trends are common for all ship types.

In the analysed period from 2014 to 2023, the average share of the human factor in the analysed co-creating factors is 80.1%. Among the types of ships, fishing vessels have the lowest impact of the human factor equal to 76.0%, while ships classified as other types show the highest impact of 89.2%. Cargo ships show 80.3% of human impact, passenger ships 79.9%, and service ships 82.5% [3].

Following the adoption by the IMO Guidelines for the implementation of the ISM Code by maritime administrations (Resolution A.788(19) in 1995), the revised Guidelines transformed the idea of implementation ISM Code based on direct compliance with the rules, with prescribed interpretation, into a culture of "thinking". This meant self-regulation of safety and the development of a "safety culture" in which everyone should feel responsible for undertaken actions to improve safety and efficiency.

The human factor is a key element in ensuring the safety of maritime transport. It is recognized as a factor contributing to the majority of casualties in the shipping sector and a key element in the protection of safety of life on ships. Therefore maritime safety and the safety of navigation can be improved by focusing more on the human element. The development of the ISM Code support and encourage the development of a safety culture in shipping.

In addition to the already heavy workload related to the human element, mainly resulting from the work of IMO Sub-Committee on HTW (Human Element, Training and Watchkeeping) - terms of reference and related regulatory instruments, such as the assessment of information provided by STCW Parties, the implementation of technical cooperation activities (in the context of environmental protection, facilitation, safety and security) and coordination of the Model Course Programmes, there are relevant activities and initiatives related to the human element arising from the scoping of MASS regulations [23].

3 MASS OPERATOR - REMOTE SHIP MASTER

The “MUNIN” project (Maritime Unmanned Navigation through Intelligence in Networks, Funding Scheme: SST.2012.5.2-5: E-guided vessels: the 'autonomous' ship) introduced the concept of the Shore Control Centre (SCC), a control room where operators would monitor and control autonomous ships, later called by IMO Remote operation Centre.

The Ship Master and Remote Ship Master – ROC operator are responsible for the control of MASS including navigation, taking actions to ensure the safety of the ship, protection of the marine environment, maintaining order on board, preventing damage to the ship, people and cargo on board. The Ship Master must hold a valid Ship's Master's Certificate and other certificates in accordance with the requirements of the applicable international instruments and national regulations established by the flag state administration. The same requirements apply to the Remote Ship Master [23].

3.1 *MASS operator decision-making process*

Depending on the information and state of environment, not controlled by the ROC operator, the decision-making process may vary depending on the existing conditions [13]:

- decision made under conditions of certainty – the effects can be predicted without error, there is neither risk nor surprise;
- decision made under conditions of risk – it is possible to determine a set of consequences and assign them a certain probability of occurrence, the entity has no basis for knowing which result will occur;
- decision made under conditions of uncertainty – it is impossible to calculate all the consequences or determine with what probability they will occur, it is difficult to determine the risk of failure.

3.2 *Psychological determinants and mechanisms of decisions made by the MASS operator*

The psychological approach is an attempt to explain the irrationality of decision-makers' behaviour, resulting from certain personality traits or the situation in which the decision-maker finds himself. In particular, factors such as: asymmetry between profit and loss, previous failures, selective attention, decision-making under external load are considered. It focuses particularly strongly on issues related to the tendency to take risks. According to the assumptions of psychological analysis, human errors are the effect of the causal chain (Figure 1) and can be traced to sources in the human psyche and personality [14].

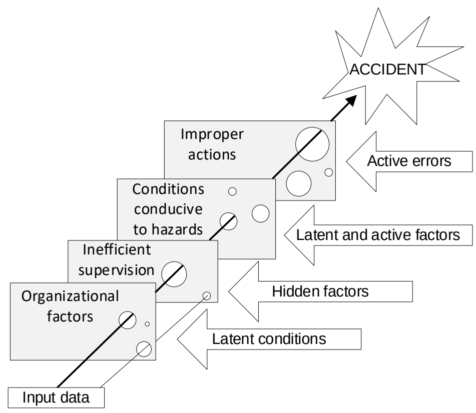

Figure 1. Causes of system failure - J. Reason's model.

By referring this model to the MASS sea voyage, the following factors leading to failure can be indicated:

- organizational factors – e.g. poor organization of the structure of the sea voyage of the autonomous ship in the transportation system,
- inefficient supervision of the Ship Master/ROC operator – improper management of the sea voyage
- conditions conducive to hazards – hydrometeorological, navigational, operational conditions of the autonomous ship, posing a threat with its navigation,
- improper actions of the Ship Master /ROC operator – poor and inadequate implementation of the tasks of the sea voyage.

The research presented in [15] showed the importance of "feelings" that the seafarers perceives on the navigation bridge by looking outside of the window and experiencing e.g. "standing wave", "rolling" and "sense of balance" with the vessel. Despite the navigation equipment and observation of the environment, the feeling the vessel's motions reduced their stress. Therefore, unlike the Ship Master of MASS I, who is on the navigation bridge, for the operator in the remote operation centre, some new elements influence the operator's situational awareness due to the lack of direct feeling of the ship.

Long-term stress can affect the operator's decision-making by changing the ability to assess risk. People under stress may be more likely to make riskier decisions [5][24].

The following properties that characterize decision-makers – ROC operators [11][12] are defined by the prospect theory:

- the decision-maker is risk averse in the case of very probable gains and low probable losses,
- the decision-maker is risk prone in the case of low probable gains and high probable losses.

The MASS operator's assessment of a situation that is burdened with risk will always make losses seem greater than gains. In the second part of the prospect theory [12], its authors - Kahneman and Tversky state that: "people tend to overestimate small probabilities and underestimate large ones". It concerns the way people estimate the probabilities of individual events.

Emotions have a huge impact on risk assessment. Fear makes the perceived risk exceed the actual risk, while euphoria underestimates the perceived level of riskiness of the situation [20][21]. The operator's actions with the support of the team (experts) can cause the subjective value of risk to decrease. It results. With lower risk and motivates action.

4 INFLUENCE OF HUMAN ELEMENT DEPENDENT OF THE LEVEL OF MASS AUTONOMY

The current approach to improving safety in maritime transport is based on the pursuit of systems integration, the development of Maritime Intelligent Transportation Systems (MITS) and reducing the influence of the human factor. The implementation of the human factor in the system designs is now the usual practice. In case of MASS related systems the human factor models can be dependent on the level of autonomy.

MASS I which is the ship with automated processes and decision support systems, with seafarers 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 [16]. The contributing factors categorized as 'human behaviour' and factor related to events caused by human action are considered as influenced by human factor.

In the event of a sea voyage carried out by a fully autonomous MASS IV, there will be no human factor. This factor may occur in the event of MASS IV failure or her participation in an emergency operation, when the control will be taken over by the ROC operator/Ship Master and when MASS IV will be operated on a lower level of autonomy e.g. MASS I, MASS II or MASS III.

The new approach to human element modelling is proposed in the paper for MASS II and MASS III.

4.1 *Influence of human element on the reliability of sea voyage of MASS II*

The human factor considered in relation to MASS II, remotely controlled and operated, with seafarers on board, available to take control and operate the vessel's systems and functions when necessary [17], is related to both the Ship Master and ROC operator.

In this case, the application of the Bayesian-based method to determine the influence of the human factor on the safety of the MASS II sea voyage allows for the different Ship Master/ROC operator relationships to be taken into account in the decision-making process.

General assumptions of the Bayesian-based method [2][6][7] are as follows:

- using Bayes theorem (1), the observation results are combined with a priori information, which gives us an a posteriori distribution of the estimated parameter,
- the decision regarding the choice of the estimator of the parameter of interest is made in such a way that the expected losses resulting from this decision are the smallest.

$$\mathrm{P}\left(A_i \middle| B\right)=\frac{\mathrm{P}\left(A_i\right)\mathrm{P}(B|A_i)}{\sum_{i=1}^{n}\mathrm{P}\left(A_i\right)\mathrm{P}(B|A_i)} \tag{1}$$

where:
A – primary event,
B – secondary event.

An example of the influence of the human factor on the operational reliability of MASS II sea voyage is presented in Table 1 [1].

Table 1. The influence of the human factor on the reliability of the MASS II sea voyage

	$R_{operator}$ ROC operator reliability	$R_{ShipMaster}$ Ship Master reliability	$R_{MASS\ II}$ MASS II sea voyage reliability
R	0.89	0.87	0.57
	0	0.48	0.26
	0.54	0	0.16
	0	0	0.1
	1	0.92	0.61
	0.93	1	0.61
	1	1	0.64

Table 1 shows that:

- high experience/sea practice of the Ship Master or ROC operator mutually influences the increase in the reliability of the ROC operator or Ship Master (good understanding and communication): $R_{MASS\ II}$ = 0.64,
- decrease in the reliability of ROC operator reduces the reliability of the Ship Master and vice versa - decrease in the Ship Master's reliability reduces the reliability of ROC operator (e.g. lack of communication): $R_{MASS\ II}$= 0.57,
- lack of sea practice and lack of experience of the Ship Master and MASS II operator means that the safety of sea voyage will be low: $R_{MASS\ II}$ = 0.1.

The presented example indicates that only high qualifications of ROC operator and Ship Master guarantee a high level of safety during the voyage. The following example presents the influence of determined hazards on the MASS II voyage operational reliability with respect to the course change in order to avoid excessive approach to another vessel. The considered events are defined as follows:

- A_1 - an event where ROC operator decides to change course in order to avoid excessive proximity to another vessel,
- A_2 - an event where the MASS II Ship Master decides to change course in order to avoid excessive proximity to another vessel,
- A_3 - an event where the change of course will allow to avoid the excessive proximity
- $\bar{B}$ - an event where a change in course will worsen the excessive approach situation.

The assumed probabilities of the events B and $\bar{B}$ are equal to 0.6 and 0.4 respectively.

- $\mathrm{P}(A_1|B)=0.6$ - probability of accurate ROC operator assessments of the course change during the sea voyage,
- $\mathrm{P}(A_1|\bar{B})=0.5$ - probability of incorrect ROC operator assessments of the course change during the sea voyage,
- $\mathrm{P}(A_2|B)=0.7$ - probability of accurate MASS II Ship Master assessments of the course change during the sea voyage,
- $\mathrm{P}(A_2|\bar{B})=0.5$ - probability of incorrect MASS II Ship Master assessments of the course change during the sea voyage.

From Bayes theorem we obtain the probabilities of the correct decision regarding the change of course of MASS II by operator (2) and Ship Master (3).

$$\mathrm{P}\left(B\middle|A_1\right)=\frac{\mathrm{P}\left(B\right)\mathrm{P}(A_1|B)}{\mathrm{P}\left(B\right)P\left(A_1|B\right)+\mathrm{P}(\bar{B})\mathrm{P}\left(A_1|\bar{B}\right)}=0.64 \tag{2}$$

$$\mathrm{P}\left(B\middle|A_2\right)=\frac{\mathrm{P}\left(B\right)\mathrm{P}(A_2|B)}{\mathrm{P}\left(B\right)\mathrm{P}\left(A_2|B\right)+\mathrm{P}(\bar{B})\mathrm{P}\left(A_2|\bar{B}\right)}=0.68 \tag{3}$$

If we assume that the events A_1 and A_2 are independent, then from the Bayes theorem we obtain the probability of a correct decision related to the change of MASS II course, under the condition the opinions of the Ship Master and ROC operator are taken into account (4).

$$\begin{aligned}&\mathrm{P}\left(B\middle|A_1\cap A_2\right)=\\&=\frac{\mathrm{P}\left(B\right)\mathrm{P}\left(A_1\cap A_2|B\right)}{\mathrm{P}\left(B\right)\mathrm{P}\left(A_1\cap A_2|B\right)+\mathrm{P}\left(\bar{B}\right)\mathrm{P}\left(A_1\cap A_2|\bar{B}\right)}=0.72\end{aligned} \tag{4}$$

This example confirms that taking into account two unanimous opinions of MASS II Ship Master and ROC operator during the voyage increases the safety level of MASS II by limiting the impact of the human factor.

4.2 *Influence of human element on the safety of sea voyage of MASS III*

Safety of MASS III which is a remotely controlled ship, operated from another location, without seafarers on board [16] depends on ROC operator who will undertake a number of actions to ensure a safe voyage.

The operator’s decisions are influenced by both the psychological and professional factors, and ROC personnel support.

The decisions making process in risky conditions is dependent on the prospect and subjective opinion related to operator’s emotions. Therefore instead of a probability function, the prospect theory [12] introduces a function of decision weights (Figure 2), showing the decision weights not always corresponding with the determined probability.

The risk assessment is greatly influenced by emotions, which cause people to underestimate medium and high probabilities and overestimate low probabilities. Fear makes the perceived risk exceed the actual risk, while euphoria lowers the perceived riskiness of the situation [20].

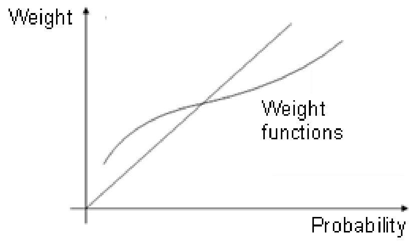

Figure 2. Decision weight functions

To minimize the possibility of the operator’s stress, each planned stage of the journey must take into account possible hazards. The conclusion from the analysis of hazards, based on the MASS III sea voyage risk matrix [1] and the Poisson process determining the probable number of maritime accidents in a designated area is that MASS III operator should have an appropriate team of advisors. Poisson process used as a model determining the number of accidents allows the operator to be guided by the criterion of the expected value of the utility function - a weighted average of the utility values of all possible results. The weights are equivalent to the probabilities of occurrence of these results.

The actions of the operator with the support of the team of experts can cause the decrease of the subjective risk value and motivates an action. Therefore, the influence of the human factor in MASS III operation, provided that the above statements are maintained, should be lower than for manned MASS I.

5 CONCLUSIONS

The introduction of Maritime Autonomous Surface Ships to shipping routes caused the impact of the human factor on the safety of a sea voyage dependent on the level of autonomy (Figure 3).

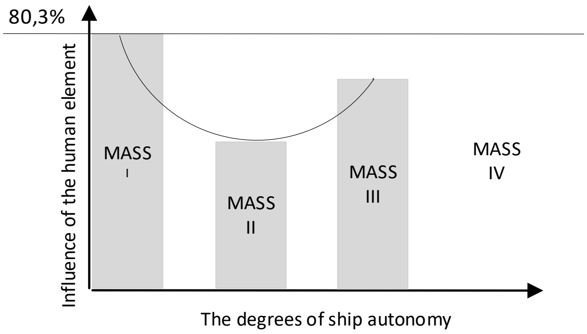

Figure 3. Estimated impact of the human factor in MASS shipping

The impact of the human factor on the safety of a voyage carried out by both the ROC operator and Ship Master of MASS II, in the case of harmonious cooperation will be smaller than for a crewed MASS I. According to theorems based on Kahneman and Tversky's prospect theory [12], the MASS III operator's actions should be cautious and more conservative due to the overestimation of low probabilities. Thanks to the support of the advisory system and the ROC staff, the influence of the human factor is also lower in this case than in the case of MASS I.

ACKNOWLEDGEMENT

This work was supported by the projects of Gdynia Maritime University No. WN/2025/PZ/03 and No. WN/2025/PZ/08

REFERENCES

[1] Abramowicz-Gerigk T., Burciu Z. Risk assessment in maritime autonomous surface ship long-distance route planning. Scientific Journals of the Maritime University of Szczecin Vol. 81 (153), 76—83, 2025.

[2] Abramowicz-Gerigk T., Burciu Z. Safety assessment of maritime transport - Bayesian risk based approach in different fields of maritime transport. in C. Guedes Soares, & F. Lopez Pena (eds.) Developments in Maritime Transportation and Exploitation of Sea Resources. Balkema, London, Proc. 15th Int. Congress of the International Maritime Association of the Mediterranean (IMAM’2013), A Coruna, Vol.2, 699-704, 2013.

[3] Annual overview of marine casualties and incidents 2024. 30th of June 2024. European Maritime Safety Agency).file:///C:/Users/zbj/Downloads/Annual%20Overview%20of%20Marine%20Casualties%20and%20Incidents%202024.pdf.

[4] Baldauf, M., Rostek, D. Identify training requirements for remote control operators of maritime autonomous ships. Proceedings of 18th International Technology, Education and Development Conference 2024. (doi:10.21125/inted.2024.2036).

[5] Burciu Z., Reliability of rescue operations in maritime transport. ISBN 978-83-7207-994-7. Publishing House of Warsaw University of Technology 2012.

[6] Grabski F., Jaźwiński J. Bayesian Methods in Reliability Diagnostics. Communication and Communication Publishing House Warsaw 2001.

[7] Cao Y., Wang X., Wang Y., Yang Z., Liu Z. Wang J., Shi R. Analysis of factors affecting the severity of marine accidents using a data-driven Bayesian network. Ocean Engineering 269, 113563, 2023.

[8] Enevoldsen T.T., Blanke M., Galeazzi R. Sampling-based collision and grounding avoidance for marine crafts.

Ocean Engineering 261, p. 112078. (doi: 10.1016/j.oceaneng.2022.112078.
[9] Formela K. , Weintrit A. , Neumann T. Overview of definitions of maritime safety, safety at sea, navigational safety and safety in general. TransNav International Journal on Marine Navigation and Safety of Sea Transportation Vol. 13, no. 2, 285-290, 2019.
[10] Gerigk, M. Interference between Land and Sea Logistics Systems. Multifunctional Building System Design Towards Autonomous Integrated Transport Infrastructure. TransNav The International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 16, No. 3, 439-446, 2022.
[11] Jajuga K., Organizational Management. PWN Scientific Publishing House. Warsaw 2007 (in Polish).
[12] Kahneman D., Tversky A., Prospect theory: An Analysis of Decision under Risk. Econometrics, 47(2), 263-291. March 1979 (available online https://www.jstor.org/stable/1914185 on 04.06.2025).
[13] Kozmiński A. K., Piotrowski W.; Management. Theory and practice, PWN Warsaw 2002 (in Polish).
[14] Lebkowski A. Design of an Autonomous Transport System for Coastal Areas. ThransNav The International Journal on Marine Navigation and Safety of Sea Transportation Vol. 12, 1,117-124, 2018.
[15] Makarowski R. Risk and stress in sports aviation. Difin Publishing House, 2010 (in Polish).
[16] Man Y., Lundh M., Porathe T. Seeking Harmony in Shore-based Unmanned Ship Handling - From the Perspective of Human Factors, What is the Difference We Need to Focus on from Being Onboard to Onshore. Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE 2014, Krakow, Poland 19-23 July 2014. Edited by Ahram T., Karwowski W. and Marek T., 1-10, 2024.
[17] MSC 100/20/Add.1 Annex 2, page 1. Annex 2 Framework for the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS).
[18] Porathe Å., Hoem Ø., Rødseth K., Fjørtoft S.O. ,Johnsen A. At least as safe as manned shipping? Autonomous shipping, safety and “human error”. Safety and Reliability – Safe Societies in a Changing World. Edition1st Edition. First Published 2018 Safety and Reliability – Safe Societies in a Changing World – Haugen et al. (Eds), Taylor & Francis Group, London, ISBN 978-0-8153-8682-7, 2018.
[19] Porathe T., Prison J., Man Y. Situation Awareness in Remote Control Centres for Unmanned Ships. Chalmers University of Technology, Sweden. February 2014.DOI: 10.3940/rina.hf.2014.12.
[20] Ramosa M.A., Utnea I.B., Mosleh A. Collision avoidance on maritime autonomous surface ships: Operators’ tasks and human failure events. Safety Science Vol. 116, July, 33-44, 2019.
[21] Rotter J.B., Generalized expect for internal versus external control of reinforcement. Psychological Monographs. 80, 1028. 1966.
[22] Rotter T. Taking risks in speed sports, in Goszczyńska M., Studenski R. (red.) Psychology of risky behavior. Warsaw, Academic Publishing House ,,Żak”, 2006.
[23] https://www.imo.org/en/OurWork/HumanElement /Pages/Default.aspx