Learning Officer Performance Variability from Dangerous Ship Encounter Situations in Ship Simulator

I Gde Manik Sukanegara ADHITA*, Masaki FUCHI*, Tsukasa KONISHI*, Shoji FUJIMOTO*
*Kobe University, 5-1-1 Fukae-minamimachi, Higashinada, Kobe, 658-0022, Japan
sukanegaramanik@gmail.com

Keywords: Safety-II, ship resilience, Work-As-Done (WAD), ship safety, human performance variability

ABSTRACT

Safety-II terminology tries to understand how work is done in dynamic situations, dealing with multiple constraints, yet the system can still work in (almost) normal operation. This research aimed to elaborate intensely on ship officer performance variability in dangerous ship encounters to determine how human adaptability maintains the system to work in normal performance. The dangerous ship encounters are created through ship simulation. Seven licensed officers have been invited to perform an experiment for data collection. A dangerous encounter situation was designed to force the participant to perform out of the ordinary, where the variable in performance can be distinguished. A relatively similar system propagation has been captured in two different forms. The effect of variability performance in the output of the maneuvering process has also been obtained. As a result, this study presents what performance should be managed and improved to make ship navigation more resilient.

1. Introduction

Increasing demand for safety in today's complex socio-technical system is inevitable. In the past two decades, a discourse in safety analysis has been raising some popular new terms, namely resilience engineering (E. Hollnagel, Woods, & Leveson, 2006) and Safety-II (Erik Hollnagel, 2014). The implementation of advanced technology in the industry causes the work for systems to become more complicated. It implies the situation where the unexpected situation becomes more intractable. As a result, it is argued that the traditional safety approach, which used the accident as the main source to enhance system safety, has become weak to be implemented. In this case, a new perspective is needed as a complementary and enhanced safety analysis. Performance variability is the key concept for managing safety in complex socio-technical systems (Woods, 2015).

Today's ship has equipped with advanced information technology. The need to apply automation technology for navigation is also increasing. The issue of reducing the number of crew on board is in-line with the establishment of the four degrees of Maritime Autonomous Surface Ship stated by IMO (IMO, 2021). It requires future seafarers to have extra ordinary navigation skills to compete with technological development. Research investigating the performance and perception of onboard work has suggested that crew reduction needs the right kind of knowledgeable people (Ljung & Lützhöft, 2014).

The variability of system performance is inevitable as long as humans are still part of the cognitive process in the system. On the hand, it should be admitted that the working adjustment inherited from the variable work makes the system flexible. Ship operation that works under the demanding workload and unpredictable environmental situation could benefit greatly from officer adaptive performance. The flexibility of function on board must always be in line with "safety first," such that achieving greater flexibility could enhance system safety (Ljung, 2010).

This study tried to address the onboard work flexibility in a narrower context, that is, the maneuvering process in the unexpected encounter situation. Learning from successful avoidance in difficult encounter situations would be valuable for safer navigation (Lützhöft, Jones, & Earthy, 2006). It is considered critical because collision avoidance is one of the most dominant works in ship navigation. By applying the concept of Safety-II, this study aimed to provide a clearer understanding of officer variability performance in unexpected ship encounters. Elaborate phenotypes, such as time, distance, and ship's angle, have been chosen for characterizing the variability performance. The experimental study in the ship simulator has been done for data collection. Furthermore, we would also present what variability performance should be managed and improved to create a higher resilient level in ship navigation.

2. Data Collection

The context of unexpected ship encounter situations is generated by conducting a simulation experiment in a ship simulator. The unexpected encounter situation is hard to face in actual field observation. This causes simulation experiments to be considered more relevant for data collection. Seven licensed officers, four Japanese and three Korean are invited to participate in this simulation. All simulations are done with the approval of the participant, and the data is presented anonymously. Participants onboard experiences are varied from a year as a cadet, between three to ten years, and more than ten years. Data is captured in the form of video and audio recordings. Furthermore, a structured interview is performed to better understand every officer's decision to operate their ship.

The generated data type was chosen to shed more light on officer decisions to overcome the danger of ship collisions. In addition, structured interviews are performed to understand the complex processes of maneuvering the ship in unexpected situations (Ritchie & Lewis, 2003). A licensed officer is chosen to provide a decision-making process that could mimic the actual field experience. The data collected in this research is limited only to the ship encounter process. Limitations such as the difference in navigational aids equipped in this simulator are also applied.

3. Methodology

This section explains the steps and methods applied to perform this research. The concept of Safety-II is used to elucidate the systemic process of decision-making in ship encounters. The variability performance of ship officers in the form of function and its dependency expresses how different outcomes could emerge in officer action to maintain the ship works functionally under a dynamic environment. Unexpected ship encounter situation has been designed to capture how officers react to the situation and determine how varied that reaction can be.

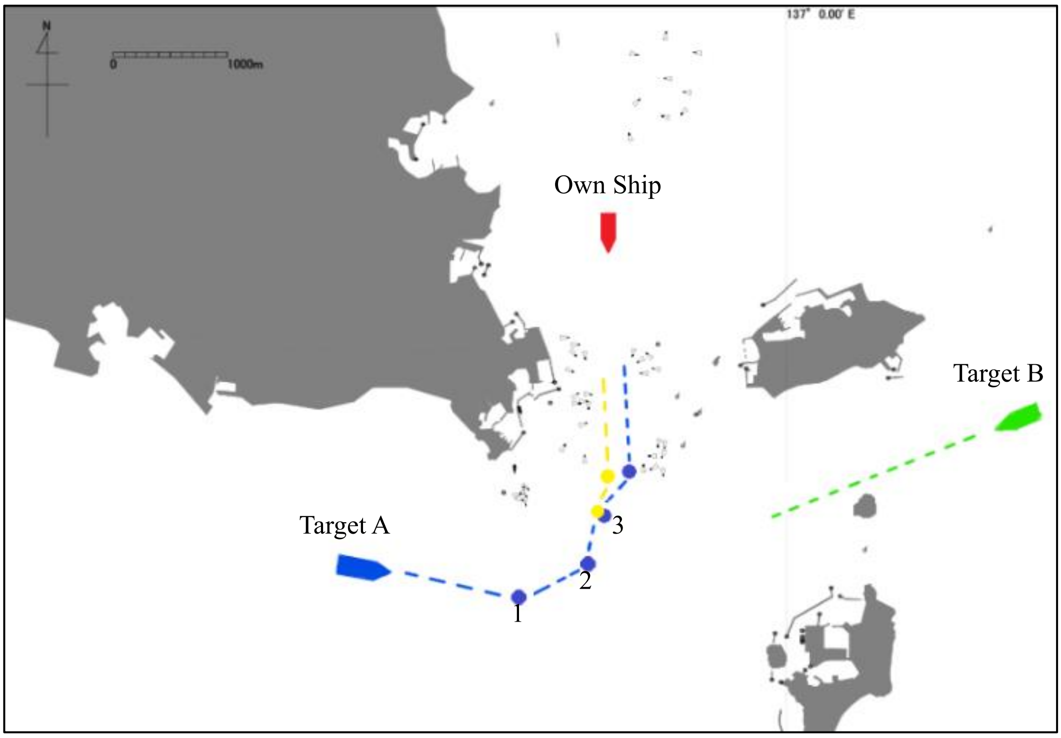

Figure 1. The overview of the location of the simulation, target ships, and own ship.

3.1. Safety-II

Safety-II offers an alternative perspective by viewing safety as an emergent phenomenon arising from a complex socio-technical system rather than a property of the system (Erik Hollnagel, Wears, & Braithwaite, 2015). System performance, in this perspective, is acknowledged to be variable. Indeed, the variability comes because of the involvement of human action. It explains why performance adjustment is essential in everyday operation (Work-As-Done). The whole system actively performs local adjustments to maintain the system works, in every condition, normally. Hence, the system can always achieve its goal, which means it operates safely.

The primary activity that happens during sailing is ship maneuvering. This activity is hardly dependent on human performance, where working variability is inevitable. Safety-II concept has been applied to learn how this variability performance affects system output, in specific, the potency to overcome difficult encounter situations. On the basis of the system functional level, this study specifies the variability performance of ship officers in the form of the system's function (Erik Hollnagel, 2012). Further elaboration in function dependency is presented in a specific instant generated from a simulation experiment. As expressed in the Safety-II concept, we tried to focus on learning the useful variability performance in ship maneuvering and what we can do to enhance ship safety from this concept point of view.

3.2. Experimental Design

This experiment is intentionally designed to present unexpected ship encounter situations. The participant was asked to do a simulation, in total, for about 15 minutes. There are two target ships that the participant must avoid. Figure 1 below shows an overview of the scenario location, own ship (marked as red), the first target called Target A (marked as blue), the second target called Target B (marked as green), and the target's trajectory. Target A is coming from the east and heading south. This target behavior is extremely inappropriate. The original trajectory of Target A is marked by blue color. In this simulation situation, the appropriate way for the target ship to enter the port is to go straight after reaching the third point. However, this behavior is intentionally changed to give a surprise effect to the participant. Target A is designed to take the east side of the shipping lane as its way. Hence, after reaching point three, she takes a rudder to starboard and acts like she is striking the participant's ship.

If participants cannot recognize the unusual behavior of Target A, Target A's trajectory is changed to a typical response (marked by yellow color). The surprising effect is maintained by pretending to keep giving a signal to change the target course to the starboard. After a few seconds, Target A is returned to move straight again. This intends to perceive how participants react to the target behavior. After passing the first target, participants need to avoid Target B. This target is coming from the northeast and heading southwest. In contrast to the first target, this target act normally. In general, the participants were suggested to express their minds verbally while performing the simulation in order to capture any cognitive process that happened in real time. Furthermore, a structured interview is performed after the simulation to gain further information regarding every decision the participant made to operate their ship.

3.3. Description of scenario

The own ship is a bulk carrier with a length over all of 185 meters. The state of loading is half loaded, and the engine status at the start of the scenario is standby engine full-ahead at 9 knots. Moreover, the charted course is set as "Var." and the gyro course is set at 180º. This is a scenario of departure from the port. Participants were asked to navigate the ship in a narrow area bounded by an island and peninsula. There are fishing vessels on port and starboard bow. Beyond that, they can see red buoy (starboard hand marks) and green buoy (port hand marks). All of these attributes can be seen directly on display from the beginning of the simulation.

Furthermore, there is a red and white buoy, namely "safe water marks," on the starboard side from the port hand mark. The ship was planned to alter course to starboard toward this safe water mark after passing the narrow area. However, the participant will not be able to see the mark at the beginning of the scenario. There is one ship in front of the own ship that is heading in the same direction. Therefore, the participant can follow this ship's path as a guide to reach the destination. There is also one other ship behind the own ship that is heading in the same direction but moving faster.

4. Result and Analysis

The essence of the ship encounter process is divided into 11 functions, consisting of three background functions and eight foreground functions. The analysis is focused only on eight foreground functions presented in Table 1. The remaining three background functions, <To begin sailing>, <To follow the rules>, and <To continue sailing>, are considered complementary. The function expresses the need for something to be done in navigating the ship. It includes the work of humans, technology, and organization. However, this simulation focuses on the human aspect, precisely, the officer of the watch.

Table 1. Foreground function of ship encounter process.

No.	Code	Foreground Function
1	FF1	To monitor (by OOW)
2	FF2	To do direct lookout
3	FF3	To watch electronic devices
4	FF4	To maintain ship direction
5	FF5	To communicate
6	FF6	To decide action (make a judgment)
7	FF7	To control the rudder/engine
8	FF8	To maneuver

A general outline of the simulation result is presented in Figure 2. The solution for variability performance has been obtained by characterizing it through timing and distance. The participant's variability performance can be viewed in two separate groups based on their ship's trajectory. Each group shows relatively similar system propagation. Furthermore, a specific reason for how the participant made each decision has also been obtained.

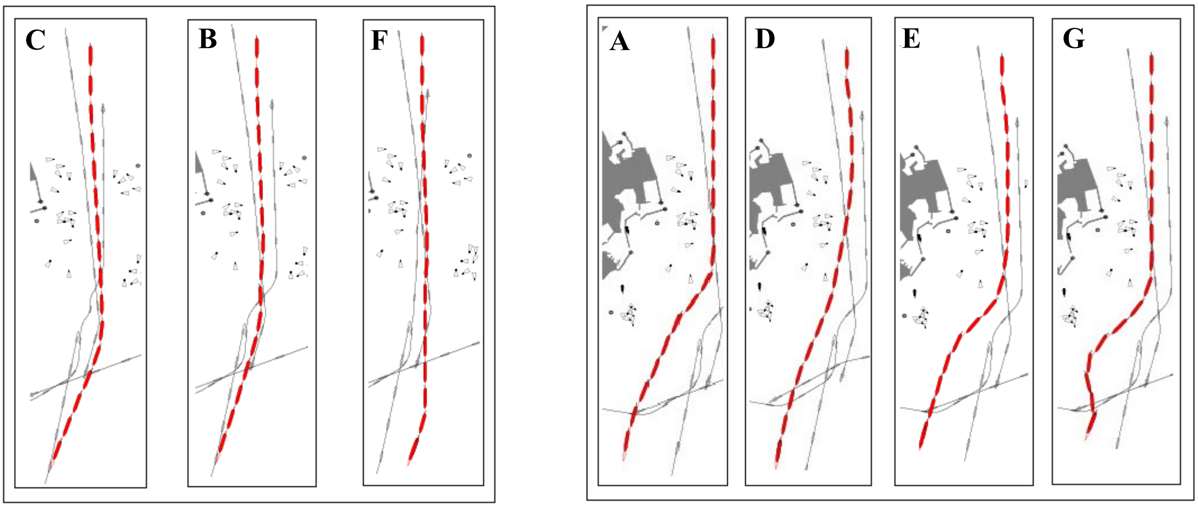

Figure 2. The trajectory of the “own ship” operated by participant.

4.1. The first ship encounter

The relatively similar system propagation has been found in two separate patterns. The first pattern is made by participants B, C, and D. After conducting brief observation, participants B, C, and D decide to change their ship’s course, as shown in Table 2. They all thought about the need to pass a group of fishing vessels on the starboard side and portside just right in the middle. Besides, they realized the existence of Target A in the first two minutes of the simulation and decided to examine the target behavior further.

Table 2. The remarkable initial action was done by participants B, C, and F.

Participant	Initial action	Time and distance	Active function
Participant B	Ordering “178” to Helmsman	Just right after the start	All foreground function
Participant C	Ordering “177” to Helmsman.	At about 0:25*	All foreground function
Participant F	Ordering “178” to Helmsman.	At about 1:37*	All foreground function

Note: * This expresses the time scale based on a recorded simulation.

The peculiar behavior was recognized at about 6:10 on a simulation time scale. At that time, Target A changed her heading to the northeast and kept going straight for about one and a half minutes. At this point, participants B, C, and F have the same thought: Target A should be going straight. They also think that Target A’s movement is unbelievable. Participant F argued that using VHF radio could be difficult in this condition because this is congested water. In a typical encounter, because “own ship” has confessed her intention to keep going straight (maintain heading 177°/178°), Target A must be understood that they should meet starboard-to-starboard.

Table 3. The remarkable initial action was done by participants A, D, E, and G.

Participant	Initial action	Time and distance	Function
Participant A	Participant thought there was enough distance between his ship and a group of fishing vessels on the starboard side. The ship’s heading was maintained at 180°.	Early after start The shortest distance with a group of fishing vessels was about 0.1NM	FF1-FF4 and FF6
Participant D	After observing the situation, a participant decided to use VHF radio and found Target A on the radar.	At about 1:05*	FF1-FF4 and FF5-FF6
Participant E	Participants found that a group of fishing vessels is not moving. He feels that there is no need to change the ship’s course.	Early after start The shortest distance with a group of fishing vessels was about 0.1NM	FF1-FF4 and FF6
Participant G	Participants found a group of fishing vessels and thought that the “own ship” could safely pass those fishing vessels by maintaining the ship’s course.	Early after start The shortest distance with a group of fishing vessels was about 0.1NM	FF1-FF4 and FF6

Note: * This expresses the time scale based on a recorded simulation.

This system propagation, unfortunately, leads to the collision accident for the first ship encounter if Target A moves as designed. It was found that the participant did not perform any adjustment after noticing the unexpected movement of Target A, such as using the ship's whistle. For this point, participant B argued, "I do not have any experience using a whistle. Therefore, I have no idea to use that at that time." It shows that, in this situation, the learning and monitoring process in FF1-FF3 <To monitor (by OOW), To do direct lookout, To watch electronic devices> cannot trigger the activation of FF6 <To decide action (make a judgment)> to activate the FF5 <To communicate> and perform local adjustments.

The second system propagation happens in the simulation done by participants A, D, E, and G. They are all choosing to maintain their ship's course at 180º, as explained in Table 3. There is no particular action taken for a couple of minutes later. The vicinity observation is done continuously, especially to pay attention to Target A. Participant D is the only person who chooses to use VHF radio for further examination. The lack of an AIS device is why participant D chose this action. The contact with Target A was done three times in total. The last call happened at 08:11 on the recorded simulation time scale because Participant D worried that Target A would violate the meeting agreement.

Table 4. The action related to participants A, D, E, and G for the first ship encounter.

Participant	Action	Time and distance	Function
Participant A	Target A behavior has been observed	At about 3:44*	FF1-FF3
	Participant saw that Target A changed her bearing and thought she would safely pass his ship bow (heading at 180 º).	Distance with Target A was about 3NM	FF6
	Target A was observed changing her course to the north	At about 5:43*	FF1-FF3
	Ordering "Starboard 20" to Helmsman.	At 6:10*, DCPA ± 1NM	FF6 – FF7
	Blowing the whistle to warn Target A	At 7:31*, DCPA ± 0.3NM	FF6 – FF7
Participant D	Port-to-port agreement with Target A has been made through VHF communication. The participant also gradually changes the ship's direction, from 188 º, 190 º, to 200 º.	Start at about 5:42*, a distance about 1.5NM away from the target	FF6 – FF7
Participant E	Participant saw Target A's bearing was not changing and suddenly felt the danger of ship collision.	At about 4:03* Distance with Target A was about <3NM	FF1-FF3
	Participant decided to go to the port side and order port 5 to the Helmsman.	At about 6:42*	FF6 – FF7
	Participant changed his mind and took a massive leap to the starboard side by ordering "starboard 20" to the Helmsman.	At about 7:10*, DCPA ± 0.6NM	FF6 – FF7
Participant G	Participant realized there is a danger of collision with Target A. He decided to go to the starboard side by ordering "starboard 20" to avoid that target.	At about 6:00*, DCPA ± 1NM	FF1-FF3 and FF6 – FF7

Note: * This expresses the time scale based on a recorded simulation.

The relatively similar reaction from Participants A, E, and G can be seen from 6:00 to 7:00 on a recorded simulation time scale, as presented in Table 4. At that time, Target A turned her course to the port side and headed north. It causes the "own ship" in a head-on situation with the target. Therefore, they all decided to go to the starboard side and take "starboard 20" to avoid Target A. There are minor differences in their action. While participant A instantly ordered "starboard 20", participants D and E gradually turned their ship's direction to the starboard side. Participants D and E started with a low angle and realized that their ship's rate of turn (ROT) was low. They decided to take a huge leap by ordering "starboard 20" a few seconds later. This variable in activation time of FF6<To decide action (make a judgment)>, number of interactions between FF6-FF7 <To decide action (make a judgment), To control the rudder/engine>, and ship's angle have been captured. However, that does not affect the output of the maneuvering process. The only noticeable adjustment happens only by participant A. He took further action by operating the ship's whistle. By considering the intended inappropriate movement of Target A in this simulation, this system propagation leads the ship to avoid the danger of ship collision successfully.

4.2. The second ship encounter

The second ship encounter happens after the participant passes Target A. All participants, except participant G, can successfully avoid the danger of ship collision with Target B. The earliest decision, at about 6:50 on the recorded simulation time scale, was made by participant D using VHF communication. This action is normally performed in advance because it takes time to be done properly. However, in this case, it should be admitted that participant D uses VHF communication too much. The work generally starts by activating FF1-FF3 to gather information about Target B. All participants did a relatively similar process to determine target speed and direction to activate FF6 and judge whether Target B could pass their ship bow safely or not. A minor detail is recognized in more experienced participants. They argued that if there are sudden changes happen to the target heading, they will make a call by VHF radio.

The different output of the second avoidance can be recognized from the participant who chose to go straight compere with the participant who took the rudder to the starboard side in the first encounter. The final destination of this simulation is located in the southwest. Participants B, C, and F did only one order to navigate their ship to the destination. It indicates that the time activation of FF6 is more flexible. On the other hand, participants A, D, E, and G must perform a consecutive order to navigate their ship to the final destination. Participants A, D, E, and G start positioning their ship to the southwest at around 9:25. Participant G takes a huge leap to the port side and orders "port 20" to the Helmsman. In contrast, Participants A, D, and E slowly maneuver their ship to the port side. They all manage to perform that action in about two and a half minutes. Participant G does not realize that his ship is quickly approaching Target B, located on the port side of his ship. At about 0.5NM away from Target B, Participant G suddenly realize the danger of ship collision. However, that was too late to take action. Some actions have been performed to save the "own ship." Participant G argued, "I thought about using the whistle, but it was different from the actual operation. I do not think that could work in this situation. I decide not to do that."

5. Discussions

This study reveals how variable the OOW works can be in a simulated difficult ship encounter situation. This inappropriate situation allows the variable in response can be easily recognized. There are some limitations that differentiate the actual and simulated working environment, such as the lack of natural disturbance, time boundaries, social interaction, and work routines. However, we should admit that unexpected situation is rare in nature. It means the situation could involve any kind of problem, including something that we could never imagine. The spirit presented in this work is how to understand safety from its present. The learning process is started from how solutions are created, in which motivation and initiative of the officer are valued as a resource. Furthermore, technological developments can always take advantage of human flexibility without having to remove it from the system.

Two different system propagation has been captured from the simulation. It is important to note that both decisions can lead the ship to avoid the collision accident successfully. The first system propagation caused Target A to be in the position on the starboard side of the "own ship" at about 6:10 on a recorded simulation time scale. It is clearly understandable why participants B, C, and D decide to keep their ship going straight. The point should be remarked if considering the unusual movement of Target A is the need for FF6 <To decide action (make a judgment)> to be more flexible. In this kind of situation, FF6 <To decide action (make a judgment)> must be able to be activated and adjust the situation by performing some responses, such as utilizing the ship's whistle.

On the other hand, at the same time in the simulation, the second propagation leads the "own ship" to be in a head-on situation with Target A. In this case, all participants could possess relatively identical responses. It indicates the variability performance is managed and controlled. The other important thing that should be remarked on is the proper use of VHF radio. The overuse of VHF radio could cause unnecessary action that could emerging dangerous situations. In line with this finding, Tasaki et al. have pointed out the importance of proper bridge-to-bridge communication via VHF in congested water (TASAKI, KASHIMA, KUNIEDA, & TAKEMOTO, 2015). In addition, the second ship encounter has shed light on how variability performance could be varied and produce noticeable unwanted system output. The continuous and repetitive activation of function causes functional resonance among functions to become higher. Especially the variable in the ship's angle and the function activation time hardly affect the maneuvering process.

The simulation has also revealed that at some point, the participant with less onboard experience could perform as participants with higher onboard experience did. The noticeable difference in performance adjustment between young and senior seafarers is how they utilize communication aids, such as whistles and VHF radio. This can be used to indicate that officer performance's flexibility should be enhanced. This study, indeed, presents the specific result of a specific scenario that cannot be generalized for every situation. However, the commitment to appreciate human performance (Erik Hollnagel, Laursen, & Sørensen, 2022) is what we try to obey. Human performance is variable, and that is what makes the system flexible and resilient.

6. Conclusions

The analysis indicates that timing in the function's activation and rudder angle strongly affect the output of the maneuvering process. Practical knowledge of officer adaptability in unexpected encounter situations has also been obtained based on how the adjustment takes place in the simulation. This study presents one of the ways to understand safety from routine challenges happening in everyday ship operations. It provides a small example of what to learn from a successful activity. The simulation experiment is hard to conduct in today's situation. In addition, it is also difficult to invite professionals to join the experiment. Future analysis is suggested to be done by constructing mathematical simulations to get a more comprehensive result of human variability performance.

Acknowledgment

We would like to acknowledge the Japan Society for the Promotion of Science (JSPS KAKENHI Grant Number 22K04598) for funding this research. We would also like to thank you to all participants for participating in this research. Their willingness to share their knowledge has been essential for this research.

References

(1) Hollnagel, E., Woods, D. D., & Leveson, N. (2006): Resilience Engineering: Concepts and Precepts. *Ashgate*.
(2) Hollnagel, Erik. (2012): FRAM: the Functional Resonance Analysis Method. England: *Ashgate*.
(3) Hollnagel, Erik. (2014): Safety-I and Safety-II: The Past and Future of Safety Management. https://doi.org/10.1201/9781315607511
(4) Hollnagel, Erik, Laursen, T., & Sørensen, R. (2022): A day when (Almost) nothing happened. *Safety Science*, **147**(April 2020). https://doi.org/10.1016/j.ssci.2021.105631
(5) Hollnagel, Erik, Wears, R. L., & Braithwaite, J. (2015): From Safety-I to Safety-II : A White Paper From Safety-I to Safety-II : A White Paper Professor Erik Hollnagel University of Southern Denmark , Institute for Regional University of Florida Health Science Center Jacksonville , United States of America Prof. (October). https://doi.org/10.13140/RG.2.1.4051.5282
(6) IMO. (2021): Outcome of the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (Mass). *MSC.1/Circ.1638*, **44**(0), 1–105.
(7) Ljung, M. (2010): Function based manning and aspects of flexibility. *WMU Journal of Maritime Affairs*, **9**(1), 121–133. https://doi.org/10.1007/BF03195169
(8) Ljung, M., & Lützhöft, M. (2014): Functions, performances and perceptions of work on ships. *WMU Journal of Maritime Affairs*, **13**(2), 231–250. https://doi.org/10.1007/s13437-014-0057-x
(9) Lützhöft, M., Jones, B. S., & Earthy, J. V. (2006): Making Safety by Tying the Knot : Examining Resilience in Shipping. *2nd Resilience Engineering International Symposium*, (November). Retrieved from https://docs.google.com/a/wmu.se/file/d/0B2lfx_f4ofuXWDZhUEduTkJNLVU/edit?usp=sharing
(10)Ritchie, J., & Lewis, J. (2003): Qualitative Research Practice: A Guide for Social Science Students and Researchers. London: *SAGE Publications*.
(11)TASAKI, Y., KASHIMA, H., KUNIEDA, Y., & TAKEMOTO, T. (2015): The Feature of Bridge-to-Bridge Communication Using VHF in Marine Traffic Density Area. *The Journal of Japan Institute of Navigation*, **133**, 58–65. https://doi.org/10.9749/jin.133.58
(12)Woods, D. D. (2015): Four concepts for resilience and the implications for the future of resilience engineering. *Reliability Engineering and System Safety*, **141**, 5–9. https://doi.org/10.1016/j.ress.2015.03.018

Author's Biography

I Gde Manik Sukanegara Adhita is the 2nd grade Doctoral Student at Graduate School of Maritime Sciences, Kobe University. His research interests are related to safety science, especially related to the Safety-II concept and resilience engineering.

Masaki FUCHI is an associate Professor at Graduate School of Maritime Sciences, Kobe University, Doctor in Human Sciences. He has experience as navigation officer of oceangoing ship, and also occasionally serve as Master of training ship of Kobe University. His research interests are related to the safety of shipping, especially about education and training of Captains and officers.

Tsukasa KONISHI is an Assistant Professor at Graduate School of Maritime Sciences, Kobe University, Master in Maritime Science and Technology. His research interests are related to situation awareness and decision of navigation officer when they maneuver the ship, especially recently the people involved in Maritime Autonomous Surface Ships (MASS).

Shoji FUJIMOTO is a Professor at Graduate School of Maritime Sciences, Kobe University, Doctor of Philosophy in Law. His research interests are law and policy of competition of various use for Japan area and safety navigation.