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Everyday Performance of Ship Officer: Qualitative Analysis based on Functional Resonance Analysis Method

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Abstract. Uncertainty in a complex socio-technical system, such as ship, is given. Yet, surprisingly, most of the ship operations were done without any significant problem. In this case, the ship officer as the operator plays an important role in maintaining ship safety. Human performance is unpredictable and varies on the condition. However, variation in human performance is more likely to produce acceptable outcomes than adverse outcomes. Therefore, this study aimed to determine how human variability performance in specific officers onboard contributes to successful ship operation. Evaluation of officer variability performance for establishing safety in everyday ship operation has been done using Functional Resonance Analysis Method (FRAM) in this study. FRAM is Safety-II based tool that provides concepts and models for safety analysis that use terms called function to describe system activities. An essential feature of FRAM is the mean that is necessary to explain the activity of a system in which the functions are mutually dependent. System activities are modeled in terms of how the system works to ensure that it performs systematically. Key functions of officer activities onboard are generated through observation in training ship Fukae-maru owned by Kobe University. As a result, FRAM could define how officer variability performance contributes to system propagation and create a safe ship operation.

1. Introduction

The human role in ship operation is absolute as long as human operates the ship. Therefore, the International Maritime Organization (IMO) has put special concern into regulations and guidelines for supporting personnel development in the maritime industry. For example, the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW), was the first convention for standardization of seafarers' competence. Besides, the regulation about safety management, the International Safety Management (ISM) Code, has also got significant changes after the accident of MV Herald of Free Enterprise and other serious ship accidents in the late 1980s [1]. Therefore, IMO acknowledges the strong relationship between the human element and safety in ship operation [2].

We cannot refute that accidents were a trigger of any changes in regulation and system design. In fact, those changes have a tremendous impact on safety. However, gradually this approach began to show a deceleration in its development. Therefore, a fresh idea is needed to overcome this stagnation. This traditional safety approach that focuses on reducing the number of accidents or incidents is currently known as Safety-I. In contrast, a recent safety solution called Safety-II proposed a different



perspective that focuses on the number of successful events [3]. Safety-II is one of the fresh ideas in this field of study that can provide an opportunity for further exploration to a researcher.

The purpose of safety management in the Safety-II is to ensure that as much as possible system work goes well. It means that the system could achieve its objectives. However, even though the system is likely to go well, it does not mean that the analysis on Safety-II perspective, everything that happens in the system must be observed or analyzed. The primary purpose of this perspective is to provide alternative recommendations by trying to understand how the system goes well, where practically more likely to occur rather than the accidents.

Functional Resonance Analysis Method (FRAM) is a method that has been developed along with Safety-II development. This method has been widely used in many research areas [4]. Healthcare [5,6] and aviation [7], [8] are the field that applies this method the most. Several studies have also used FRAM in the maritime domain. Most of them were applied for accident analysis [9–12]. From a normal operation perspective, one study has applied this method to determine resilience in VTS operation [13]. The strong point of FRAM analysis is a qualitative approach that provides an understanding of how successful outcomes can produce from everyday system operation. Therefore, in this study, we aimed to present the contribution of officer performance for successful everyday ship operation from the FRAM perspective. In addition, we paired FRAM with grounded analysis to provide a more comprehensive analysis.

2. Functional Resonance Analysis Method (FRAM)

FRAM was proposed by Hollnagel to accommodate the Safety-II idea for viewing safety from a different perspective. FRAM was first introduced as a model [14] and later updated to be a method [15]. The function is an important term used in FRAM to describe the activities on the system. The system itself is described as a set of functions that are dependent on each other. System outcomes can be described as a result of unique interactions that emerge from function variability. Hence, the outcomes in this context can be either useful or harmful.

This method focus on the variability of function that could propagate the system and produce either wanted or unwanted outcomes. The essential idea is to describe the adaptive ability of the socio-technical system to cope with a complex situation. Therefore, FRAM analysis requires how work is done in everyday operation rather than how work is done based on rules or manuals to propose a model.

Function in FRAM model presented as a hexagon with six aspects in each corner. Aspect describes the state of function while it is being carried out in the system. Those six aspects consist of Input (I), Output (O), Precondition (P), Resource (R), Control (C), and Time (T). Descriptively, the Input is information, matter, or command used by the function to produce the output. Output describes the action of the function after processing information from other aspects, such as processing instructions from the input. The Precondition describes the condition that must be achieved before the function starts. However, this does not mean that this signal can start the function by itself. A Resource is described as something that the function needs while it is being carried out; for example, a spoon for eating ice cream. Control describes something that directs the function while producing the desired output. Finally, Time represents an action that consumes time, which can affect the performance of a function.

FRAM is based on four basic principles: the principle of equivalence of successes and failure, principle of approximate adjustments, principle of emergence, and principle of functional resonance. The principle of equivalence of successes and failures expresses that whether things go right or go wrong, the events arise from the same source, which is the everyday work of the system. While a human is working, their performance is a source for the system to produce either good or bad outcomes. Humans also have the capacity to adjust their performance in a dynamic work environment. Here, the principle of the approximate adjustment was applied. Performance needs to be variable in the actual work environment to help the system successfully adapt to the operational situation. The principle of emergence shows that system outcome is explained as the emergence of variability in

performance from everyday adjustment rather than a result of specific cause-effect chains. The last principle, the principle of functional resonance, describes the potency of detecting the unintended interaction amid the variability of function performance through the phenomenon of resonance.

3. Methodology

Direct observation onboard ship was conducted to observe officer activities from preparation before departing the port, during sailing, and arriving again at the port. The observation was done on three different days, in total about 15 hours of sailing. In addition, grounded theory and FRAM were applied to analyze and generate a systematic model of officer activities on board and explain how officer performance contributes to safety in everyday ship operations.

3.1. Data Collection

The observation was conducted in the training ship Fukae-maru owned by Kobe University. There are six officers on board in every observation, including Captain, Chief Officer, Second Officer, Third Officer, and two Junior Third Officers. The data observation was collected by recording video and taking photos of officer activities onboard. Besides, a direct semi-structured interview was also performed to confirm and gain more insight into the officer's work. The direct interview has been done with the Captain, Officer of the Watch (OOW), and additional watch officer. The video recorder and interview aimed to capture the essential function of officer performance in ship operation.

The data analyzed in this study only presents the basic activities of the officer on board. The observed training ship is a ship for Cadets training that does not have cargo work. Moreover, the observation was conducted when this ship sails in a coastal area in Osaka Bay, Japan, which does not require to make a report to shore representatives such as port authority. However, other essential performances such as ship maneuvering, officers' interactions, or officers-machine interactions can be observed.

3.2. Data Analysis

Officer performance in this study is defined as the actual output of work that an Officer does to finish its work. All recorded videos and interviews were analyzed using grounded theory and FRAM. First, grounded theory was used to determine the essential work of officers on board. Data transcription was coded and stored in Microsoft Excel. Second, the essential work from grounded theory was transformed into a key function and modeled using the FRAM model. In addition, function dependency is expressed in two different categories based on the function's role and its temporal relation. The role-based category consists of background and foreground functions. The temporal relation-based category consists of upstream and downstream functions. Hence, this analysis aimed to gain a more in-deep understanding of how officer performance contributes to successful ship operation.

Everyday ship operation is divided into three main situations: departure, sailing, and arrival. Those three situations cover officers' activities start from the ship begin to sail until the ship comes back to the port again. In Fukae-maru's case, the ship departs and arrives at the same port. Consequently, ship operation conditions for departure and arrival become quite similar. The departure situation is composed of fifteen key functions, as shown in Figure 1. Six functions are background function, consist of "briefing," "to perform checklist," "to follow the rules," "to watch the vicinity," "to pay attention to the VHF radio," and "to watch the electronic devices" functions. Nine functions are foreground function, consist of "to board the ship," "to monitor (by Captain)," "to communicate with engine department," "to communicate with deck department," "to instruct Helmsman," "to prepare the engine," "to do bow and aft work," "to control the rudder," and "maneuvering/to depart" functions.

The sailing situation is the activities when the ship sails in the open sea. This situation is divided into thirteen key functions, as shown in Figure 2. Six functions are background function, consist of "to follow the rules," "to monitor the weather condition," "to do direct lookout," "to pay attention to the VHF radio," "to watch the electronic devices," and "standby (Captain)" functions. Seven functions are

foreground function, consist of “to monitor (by OOW),” “to instruct Helmsman,” “to control the rudder,” “to communicate with other ship,” “to communicate with VTS,” “to take over the bridge control,” and “maneuvering” function.

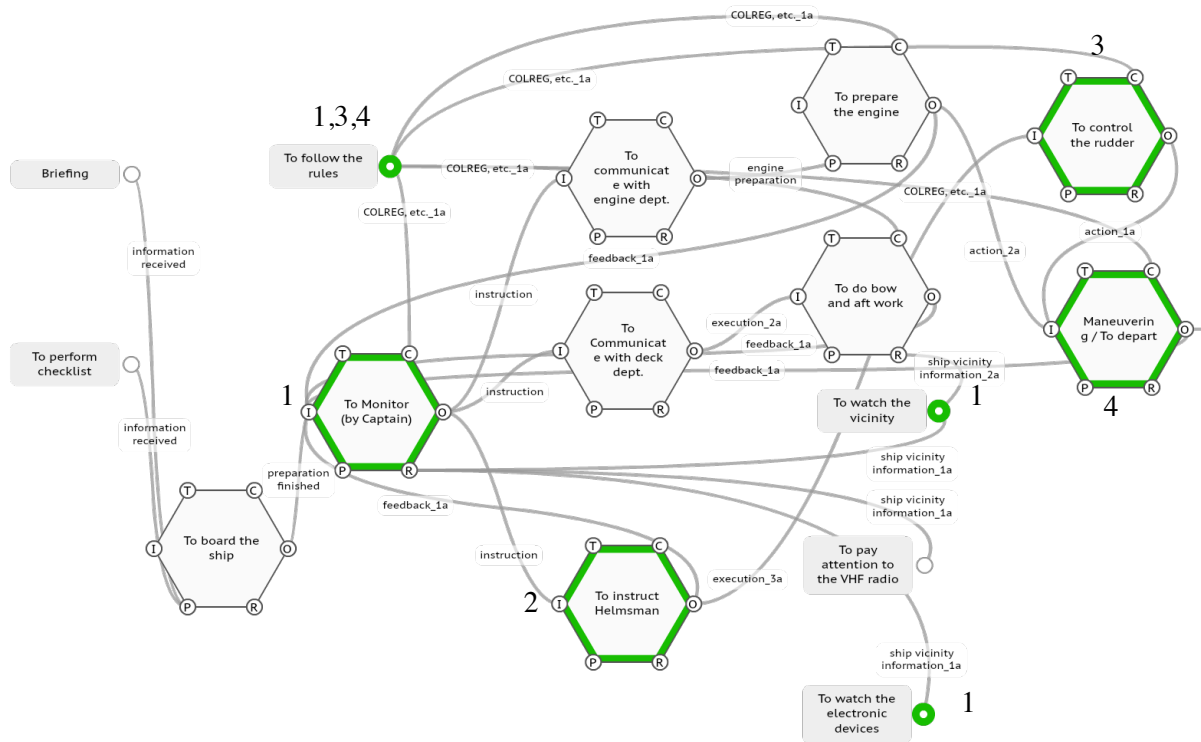


Figure 1. Key functions and their couplings for departure situations.

The arrival situation is composed of thirteen key functions, as shown in Figure 3. Five functions are background function, consist of “to follow the rules,” “to watch the vicinity,” “to pay attention to the VHF radio,” “to watch the electronic devices,” “and maneuvering/to arrive” functions. Nine functions are foreground function, consist of “to take over the bridge control,” “to monitor (by Captain),” “to communicate with engine department,” “to communicate with deck department,” “to instruct Helmsman,” “to control the engine,” “to do bow and aft work function,” “to control the rudder,” “and maneuvering/to arrive.”

We select several functions to explain how the relationship between functions happened in the FRAM model in a particular time activation for simplification. We picked up seven functions from the departure situation, marked with a green, consisting of three foreground functions and three background functions, as shown in Figure 1. “To follow the rules,” “to pay attention to the VHF radio,” and “to watch the electronic devices” are background functions. “To monitor (by Captain),” “to communicate with engine department,” “to prepare the engine,” and “to instruct Helmsman” are foreground functions. Their time activation is denoted with numbers 1 to 4.

After the “to monitor (by Captain)” function is activated, the other three background functions are also activated and consumed by the “to monitor (by Captain)” function while it is being carried out (code 1). Here, the role of background and foreground functions can be seen clearly. “To follow the rules,” “to pay attention to the VHF radio,” and “to watch the electronic devices” are assumed not to be variable while the activity is being performed. On the other hand, the “to monitor (by Captain)” function is where performance has variability that can affect the system output.

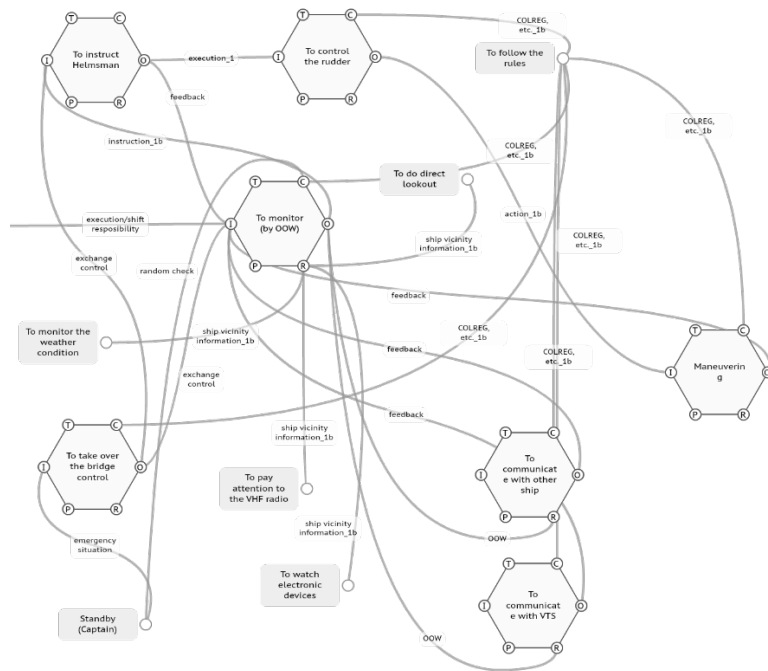


Figure 2. Key functions and their couplings for sailing situation.

While foreground and background functions explain the general role of function in the system, the upstream and downstream functions explain the temporal relationship between two or more functions. As shown in Figure 4, the output from the “to monitor (by Captain)” function (code 1) is consumed by “to communicate with engine department” as an input. In this case, “to monitor (by Captain)” is an upstream function, and “to communicate with engine department” is a downstream function. The upstream and downstream function label can change over time depending on the time activation when those functions are being carried out. This category explains where the potential coupling can emerging functional resonance, which function has high potency to become vary because of its couplings.

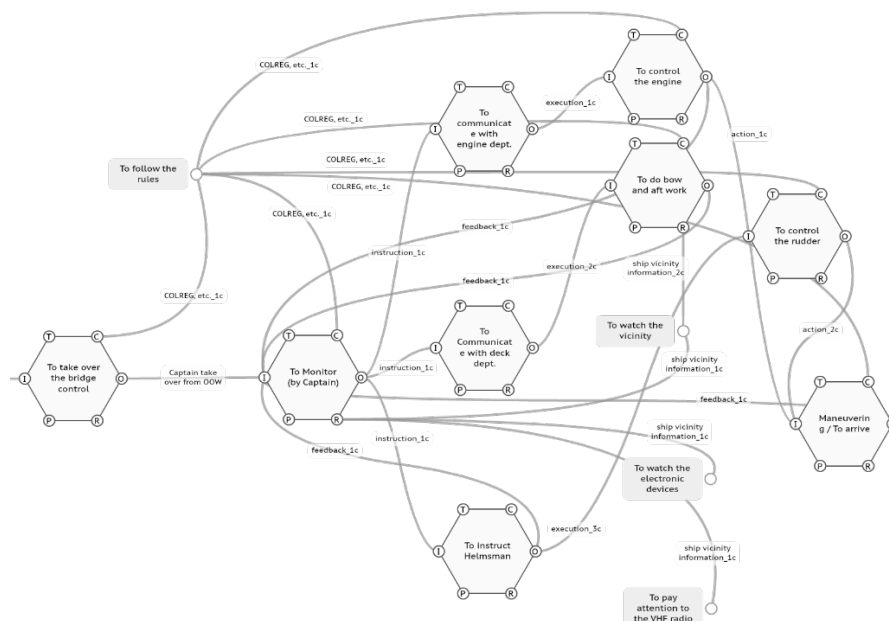


Figure 3. Key functions and their couplings for arrival situations.

4. Analysis Result

The grounded theory has been performed to reveal key functions and their dependency for safe and efficient ship operation. Besides, FRAM analysis is presented through generated key functions to provide systematic relation between functions using the FRAM model. This model includes visualization of how sailing activities go right and demonstrates a more in-depth understanding of how safety is established in everyday ship operations based on the idea of Safety-II.

4.1. *Everyday Performance of Ship Officer*

Recorded video and semi-structured interviews have been analyzed to capture patterns of ship officer performance in everyday ship operations. As a result, the grounded analysis revealed how relations among functions create valuable foresight and monitoring for safe and efficient ship operation. Ship movement is slow—the bigger a ship, the slower it be. When the Helmsman turns the wheel to change the ship's direction, it cannot change instantly after the action is made. Moreover, dynamic changes in traffic flow and environmental conditions are also the other challenging conditions the officer should face. Therefore, creating foresight and monitoring are essential for an officer to operate the ship.

Departure and arrival procedures are considered critical because of the complexities involved with them. In order to ensure the safety of the ship and all crews, Captain should be ready on the bridge and take all commando. Therefore, extra watch at the bow and aft of the ship is needed to manage ship movement because the port area is usually narrow and shallow. Creating foresight during departure and arrival activities is strongly affected by lookout, communication, and teamwork. On the other hand, monitoring takes the other essential part to maintain the work onboard is under acceptable performance.

For sailing situations, the most concerning part is OOW-Helmsman-navigation devices interaction. Electronic navigation devices, manual compass, binoculars, and human eyes are essential to gain information about ship vicinity. OOW, in this case, is the core to process this information to make any decision. The communication between OOW and Helmsman has its own value for this situation. Intimate relation is needed since the instruction and response are continuous in a certain amount of time and repeated along the voyage. Hence, both creating foresight and monitoring are intended to produce a flawless transfer of information. Once the information flows smoothly between officers, the complexity of work on board will be easier to manage.

4.2. *FRAM Model for Officer Activities Onboard*

FRAM model for ship operation is divided into three situations, as explained in the previous chapter. While the grounded analysis provides insight into the essential work of officers on board, FRAM, on the other hand, provides a Safety-II-based systemic model and concept of how to determine safety in the complex socio-technical system. Thus, function and its potential couplings for each situation are obtained. Two variability phenotypes, time and precision, were used to characterize the variability performance in each function.

The variability performance for each foreground function in the departure situation is shown in Table 1. Function variability performance for departure situations, in general, is relatively high. The actual work is complex and sensitive in terms of time and precision. Slightly change in time and precision can change system outcomes significantly. In general, the port area is narrow and shallow. The obstacles and number of other ships that move at the port area are also a lot. This condition causes ship operation in this situation composed of many functions that work simultaneously. Then, this coupling causes the variability performance to spread easily.

Moreover, the flow of information and function activation is also changing rapidly, for example, in the “to instruct Helmsman” function. The way Captain or OOW instructs his team is, indeed, by verbal communication and extra gesture. However, in the specific situation, the instruction's quality may vary depending on when Captain starts to give the instruction and how precise he delivers his thought through speak. In the departure/arrival situation, a narrow area becomes an additional limitation in the

ship's movement. But, this condition does not happen when a ship sails in the open sea. In this case, the ship needs extra movement, which requires extra interaction between Captain and his team. Therefore, the variability performance of the "to instruct Helmsman" function at this state to become increasing. The same situation also happened on the other functions in departure and arrival situations. Hence, the variability performance of functions at this state is relatively high, and the amplifying effect becomes likely. System propagation has also become more extensive and harder to manage.

The number of foreground functions in a sailing situation is low, as shown in Table 2. In practice, the active foreground functions are only "to monitor (by OOW)," "to instruct Helmsman," "to control the rudder," and "to maneuver" functions. The other three functions are not likely to be active, except in emergency or special conditions. The flow of information and function activation is also slower compared to departure or arrival situations. For example, when the ship encounters the other ship, it is easier to maneuver when the encounter occurs at the open sea compare with the port area—the number of the ship that exists in the port area and port regulation causes extra consideration to make a movement. If Captain wants to avoid a target ship at the open sea, he only needs to do two or three instructions to move his ship. Meanwhile at the port area, he needs more than five instructions to do the same maneuver. Therefore, a function such as "to instruct Helmsman" in a sailing situation has lower variability performance compare with the same function in departure/arrival situation. Low variability performance means the kind of potential work of this function is few. In general, variability performance for sailing activities is moderate, where the To Monitor (by OOW) function has the highest variability performance.

Table 1. The variability performance of foreground function for departure activities.

No.	Foreground Function	Variability Performance
1	To board the ship	Variability performance is high. It is sensitive in terms of precision. This function variability performance is not likely to be amplified from its coupling.
2	To monitor (by Captain)	Variability performance is high. It is sensitive in terms of time and precision. This function variability performance is likely to be amplified from its coupling.
3	To communicate with engine dept.	Variability performance is low. This function variability performance is not likely to be amplified from its coupling.
4	To instruct Helmsman	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.
5	To communicate with deck dept.	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.
6	To prepare the engine	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.
7	To do bow and aft work	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.
8	To control the rudder	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.
9	Maneuvering / To depart	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.

As mentioned in the previous chapter, this training ship is departing and arriving at the same port. Therefore, the officer's work for departure and arrival is generally similar. The work situation for arrival looks like reverse work from departure. The situation is also considered critical, so the Captain should be available on the bridge to conn the ship. Function variability performance in this situation is also relatively high. The summary of variability for arrival situations is shown in Table 3.

Table 2. The variability performance of foreground function for sailing activities.

No.	Foreground Function	Variability Performance
1	To monitor (by OOW)	Variability performance is high. It is sensitive in terms of time and precision. This function variability performance is likely to be amplified from its coupling.
2	To instruct Helmsman	Variability performance is low. This function variability performance is not likely to be amplified from its coupling.
3	To control the rudder	Variability performance is low. This function variability performance is not likely to be amplified from its coupling.
4	Maneuvering	Variability performance is low. This function variability performance is not likely to be amplified from its coupling.
5	To communicate with other ship	Variability performance is moderate. However, this function is not likely to be active in the system.
6	To communicate with VTS	Variability performance is moderate. However, this function is not likely to be active in the system.
7	To take over the bridge	Variability performance is moderate. However, this function is not likely to be active in the system.

Monitoring is essential for safe and efficient ship operation. It can be seen from how complex the work of “to monitor (by Captain/OOW)” function is in the FRAM model. To monitor (by Captain/OOW) function has many background functions that work while this function is carried out. Furthermore, the input information not only comes from the background function but also from the foreground function. Therefore, the work of this function becomes crucial because this function not only produces information to activate the other function. At the same time, this function should also process the information that comes to it. To monitor (by Captain/OOW) function performance also can easily resonate with its couplings and emerging the amplifying or damping effect and affect the system outcomes.

Table 3. The variability performance of foreground function for arrival activities.

No.	Foreground Function	Variability Performance
1	To take over the bridge	Variability performance is low. This function variability performance is not likely to be amplified from its coupling.
2	To monitor (by Captain)	Variability performance is high. It is sensitive in terms of time and precision. This function variability performance is likely to be amplified from its coupling.
3	To communicate with engine dept.	Variability performance is low. This function variability performance is not likely to be amplified from its coupling.
4	To instruct Helmsman	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.
5	To communicate with deck dept.	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.
6	To control the engine	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.
7	To do bow and aft work	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.
8	To control the rudder	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.
9	Maneuvering / To depart	Variability performance is moderate. This function variability performance is not likely to be amplified from its coupling.

Highlighted part to view the difference of complexity in departure/arrival and sailing situation is in the number of active functions. There are seven foreground functions in a sailing situation, as shown in Table 2. However, in normal conditions, there are only three functions that are usually active. Besides, in the departure and arrival situations, eight out of nine functions are active, along with the situations. One function on departure and arrival situations, respectively, “to board the ship” function and “to take over the bridge” function is only activated once and will stop after the information processed in this function is delivered to its coupling. The more the connection available in function, the higher the function to resonate and amplify its variability performance.

5. Discussion

This research proposed FRAM analysis to elucidate the complexity in ship operation. The Safety-II idea is highly used to produce the model and performed analysis. The FRAM model could show the complexity of officers’ everyday work to operate the ship and how the adaptation was established to create safe and efficient ship operations. Based on the three main situations explained in Chapter 4, the departure and arrival situation has the highest complexity than the sailing situation. In a regular voyage of a merchant ship, some destination port areas are requiring a Pilot to conn the ship to enhance safety. However, in this study, we are not considering the Pilot role because Fukae-maru is a small ship that not required pilot. In addition, this training ship is also departs and arrives at the same port. Nevertheless, each situation also has its own specific complexity.

Preparation is the first important part of ship operation. As shown in Figure 1, there are two background functions related to preparation: “Briefing” function and “To perform checklist” function. These functions are essential to begin the other activities before the ship is ready to depart. Even though these three functions are considered stable, the processing information in the “to board the ship” function may vary and affect the performance of to monitor (by Captain) function. Consequently, all officers should do the work at this stage carefully under the Captain’s responsibility. Especially for a merchant ship and passenger ship, checking ship stability is critical. The variability performance in that situation can be very high and very sensitive in terms of precision.

In addition, creating foresight and monitoring in departure/arrival situations is complex. The vast number of background and foreground functions that are active together to process and transfer the information alternately makes these situations critical. Surprisingly, this complex relationship provides enough information to produce useful foresight for ship safety. In contrast, unwanted variability performance from one function also becomes easily spread, and emerging amplification effect to the other function performance through couplings.

The complexity in sailing situations is lower than the departure or arrival situations. Foresight is generated only through background functions that are connected with to monitor (by OOW) function. The temporal relationship between functions other than background function only occurs between “to monitor (by OOW)” and “to instruct helmsman”. The open sea gives valuable advantages for ship operation in this situation. In a normal situation, ship maneuvering can be done more straightforward because it has enough area for its movement. The OOW, on the other hand, has enough time to process information in order to create useful foresight. Consequently, each function has enough sources to produce a useful performance for itself and its couplings.

FRAM analysis in this study has presented how successful everyday ship operation is established by creating foresight and monitoring. The FRAM model has also raised a better understanding of how the system creates valuable foresight and monitoring. To monitor (by Captain/by OOW) function is a function that represents the Captain/OOW role during sailing. This function has the highest connections in all situations. The increased amount of information that this function should deliver and receive through its couplings makes this function is essential for the system. Together with its couplings, advantageous variation of monitoring performance can create useful foresight and produce wanted outcomes for ship operation.

This research still has lots of opportunities for further development. For instance, the cyclic process between the monitoring (by Captain/by OOW) function and its couplings arguably is the most

complex part of the model. The continuous change of upstream and downstream roles in function time activation can emerge several system propagations. This relationship can be one exciting topic for further research. Furthermore, the FRAM analysis of everyday ship operation has the potency to use to develop the training strategy of new officers.

6. Conclusion

This study has presented a more-in-deep understanding of success factors in everyday ship operation. FRAM model of officers' everyday performance was not generated in a specific scenario. Instead, direct observation and expert input were used to determine key functions and couplings. As a result, the FRAM model offers a unique explanation of how the officer does the activities onboard through function. In total, 41 key functions have been obtained to describe everyday ship operations systematically. In addition, foreground functions have also been observed to elaborate how successful ship operations happened.

Besides, function dependency explained how the potential coupling could produce signals to detect where the functional resonance emerges. This current study provides how officer variability performance emerges wanted outcomes for everyday ship operation by creating useful anticipation and monitoring. Recommendations for system improvements are possible, but further exploration is needed. For example, a possible precondition or other aspects that act as a background function for some foreground function may need deeper investigation to improve everyday ship operation.

7. Acknowledgment

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References

- [1] Transport D of 1988 The Mv Herald of Free Enterprise: Report of Court No. 8074 (Merchant Shipping Act 1894 formal investigations Department of Transport) *Station. Off.* 75
- [2] Anthony F. Molland 2008 Marine safety *The Maritime Engineering Reference Book* (Elsevier) pp 784–875
- [3] Hollnagel E, Wears R L and 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
- [4] Patriarca R, Di Gravio G, Woltjer R, Costantino F, Praetorius G, Ferreira P and Hollnagel E 2020 Framing the FRAM: A literature review on the functional resonance analysis method *Saf. Sci.* **129** 104827
- [5] MacKinnon R J, Pukk-Härenstam K, Kennedy C, Hollnagel E and Slater D 2021 A novel approach to explore Safety-I and Safety-II perspectives in in situ simulations—the structured what if functional resonance analysis methodology *Adv. Simul.* **6** 1–13
- [6] Raben D C, Viskum B, Mikkelsen K L, Hounsgaard J, Bogh S B and Hollnagel E 2018 Application of a non-linear model to understand healthcare processes: using the functional resonance analysis method on a case study of the early detection of sepsis *Reliab. Eng. Syst. Saf.* **177** 1–11
- [7] Patriarca R, Bergström J and Di Gravio G 2017 Defining the functional resonance analysis space: Combining Abstraction Hierarchy and FRAM *Reliab. Eng. Syst. Saf.* **165** 34–46
- [8] De Carvalho P V R 2011 The use of Functional Resonance Analysis Method (FRAM) in a mid-air collision to understand some characteristics of the air traffic management system resilience *Reliab. Eng. Syst. Saf.* **96** 1482–98
- [9] Praetorius G, Lundh M and Lützhöft M 2016 Learning From The Past For Pro-activity – A Re-

analysis Of The Accident Of The MV Herald Of Free Enterprise *Proc. fourth Resil. Eng. Symp.* 217–26

- [10] Lee J, Yoon W C and Chung H 2020 Formal or informal human collaboration approach to maritime safety using FRAM *Cogn. Technol. Work* **22** 861–75
- [11] Salihoglu E and Bal Beşikçi E 2021 The use of Functional Resonance Analysis Method (FRAM) in a maritime accident: A case study of Prestige *Ocean Eng.* **219**
- [12] Adhita I G M S and Furusho M 2021 Ship-to-Ship Collision Analyses Based on Functional Resonance Analysis Method *J. ETA Marit. Sci.* **9** 102–9
- [13] Praetorius G, Hollnagel E and Dahlman J 2015 Modelling Vessel Traffic Service to understand resilience in everyday operations *Reliab. Eng. Syst. Saf.* **141** 10–21
- [14] Hollnagel E and Goteman Ö 2004 The Functional Resonance Accident Model *Proc. Cogn. Syst. Eng. Process plant* 155–61
- [15] Hollnagel E 2012 *FRAM: the Functional Resonance Analysis Method* (England: Ashgate)